WIREMAN

3rd Semester

TRADE THEORY

SECTOR: Power Generation, Transmission, Distribution, Wiring & Electrical Equipment

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

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FOREWORD

The National Instructional Media Institute (NIMI), Chennai, an autonomous body under the Directorate General of Training (DGT), Ministry of Skill Development & Entrepreneurship has been developing, producing and disseminating Instructional Media Packages (IMPs) for various trades under the Craftsman Training Scheme, Apprenticeship Training Scheme, Center of Excellence (CoE) Scheme and Modular Employable skills (MES) under Skill Development Initiative (SDI) Scheme. These IMPs are extensively used in the Government and Private Industrial Training Institutes and other Vocational Training Institutes to impart both Theory and Practical training and develop work- skills for the trainees and trainers.

Providing the current industry relevant skill training to students requires regularly updated syllabus and trainers who are trained in the latest syllabus. Mentor Councils were constituted in January 2014 to revamp courses to be run in 25 sectors. The Mentor Councils have representatives from thought leaders among various stakeholders viz. one of the top ten industries in the sector, innovative entrepreneur who have proved to be game-changers, academic/ professional institutions, champion ITIs for each of the sectors and experts in delivering education and training through modern methods like through use of IT, distance education etc..

11 sectors were identified as priority sectors and internal core groups were created to tap the expertise of officers in the various institutions of Directorate General of Training (DGT). A review of curriculum, admission criteria, course duration etc. was done and a revised curriculum was recommended.

The Institute has now come up with instructional material to suit the revised curriculum under Semester pattern for **Wireman Trade Theory 3rd Semester in Power Generation, Transmission, Distribution, Wiring and Electrical Equipments Sector** to enhance employability of ITI trainees across the country and also to meet the industry requirement.

I have no doubt that the trainers and trainees of ITIs, other vocational training institutes and industries will derive maximum benefits from this book and that NIMI's effort will go a long way in improving the quality of vocational training in the country by publishing the instructional materials for various courses and also assist in enhancing the employment opportunities of the trainees and other beneficiaries.

The Director and the staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

RAJESH AGRAWAL, I.A.S.,
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PREFACE

This National Instructional Media Institute (NIMI) an autonomous body under the Directorate General of Training (DGT), Ministry of Skill Development & Entrepreneurship, Government of India was set up at Chennai in 1986 with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and disseminate uniform instructional materials for various trades as per the prescribed syllabi under the Craftsmen and Apprenticeship Training Schemes approved by NCVT.

The instructional materials are developed and produced in the form of Instructional Media Packages (IMPs). An IMP consists of Trade Practical book,Related Trade Theory book, Test and Assignment book, Workshop calculation & Science,Engineering Drawing, Instructor guide, Wall Charts and Transparencies.

Hon'ble **Prime Minister** of India during his speech on 15th August 2014 mentioned about developing **Skill India** and made the following announcement

"Skilling is building a better India. If we have to move India toward development then Skill Development should be our mission."

Providing the current industry relevant skill training to students requires regularly updated syllabus and trainers who are trained in the latest syllabus. Mentor Councils were constituted in January 2014 to revamp courses to be run in 25 sectors. The ultimate approach of NIMI is to prepare the validated IMPs based on the exercises to be done during the course of study. As the skill development is progressive the theoretical content on a particular topic is limited to the requirement in every stage. Hence, the reader will find a topic spread over a number of units. The test and assignment will enable the instructor to give assignments and evaluate the performance of a trainee. If a trainee possesses the same it helps the trainee to do assignment on his own and also to evaluate himself. The wall charts (NIMI Wall Chart are displayed in Premier Institutes like IIT-Madras etc.) and transparencies are unique, as they not only help the instructor to effectively present a topic but also helps the trainees to grasp the technical topic quickly. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirement ,

To fulfill the Prime Minister Vision of making **Digital India** NIMI has also taken the steps to diversify the Instructional Material in the form of **E- Book (Digitalized Content - www.nimilearningonline.in), E-Learning and Videos** for the IMP's developed. Thus the availability of a complete Instructional Media Package in an institute helps the trainer and management to impart an effective training. Hence, it is strongly recommended that the Training Institutes/Establishments should provide at least **one IMP** per unit. This will be small, one time investment but the benefits will be long lasting along with strengthening library facilities.

The **Wireman 3rd Semester - Trade Theory** under **Power Generation Transmission Distribution Wiring and Electrical Equipments Sector** is one of the book developed by the core group members of the Mentor Councils (MCs) This 3rd Semester book includes **Module 1 - Electronic Devices, Module 2 - Domestic Appliances, Module - 3 DC Machines** and **Module 4 - AC Machines**.

The **Wireman 3rd Semester - Trade Theory** is the outcome of the collective efforts of Team India Members of Mentor Council which includes academic/professional institutions (IITs etc.), experts from relevant industries, field institutes of DGT, champion ITIs for each of the sectors, and also Media Development Committee (MDC) members and staff of NIMI.

NIMI wishes that the above material will fulfil to satisfy the long needs of the Trainees and Instructor and helps the trainees for their employability in vocational training for all Engineering and Non-Engineering disciplines.

NIMI would like to take this opportunity to convey sincere thanks to all the Mentor Council Core Group members and Media Development Committee (MDC) members.

A. MAHENDIRAN
Director, NIMI.

Chennai - 600 032

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledge with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisation to bring out this IMP **(Trade Theory)** for the trade of **Wireman** under the **Power Generation, Transmission, Distrubution, Wiring and Electrical Equipment** Sector for Craftsman Training Scheme. This Book is prepared as per Revised Syllabus.

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NIMI records its appreciation of the Data Entry, CAD, DTP operators for their excellent and devoted services in the process of development of this instructional material.

NIMI also acknowledges with thanks, the invaluable efforts rendered by all other staff who have contributed for the development of this Instructional material.

NIMI is also grateful to all others who have directly or indirectly helped in developing this IMP.

INTRODUCTION

This manual of trade practical is intended to be used in the workshop. It consists of a series of practical exercises to be completed by the trainees during the **third semester** course of the ***Wireman*** trade, supplemented and supported by instructions/information to assist the trainees in performing the exercise. These exercises are designed to ensure that all the skills in the prescribed syllabus are covered including the allied trade skills. The syllabus for the **3rd Semseter** Power Sector is divided into **four modules**. The distribution of time for the various modules are given below.

Module 1 - Electronic Devices		11 Exercises	050 Hrs.
Module 2 - Domestic Appliances		12 Exercises	050 Hrs.
Module 3 - DC Machines		16 Exercises	175 Hrs.
Module 4 - AC Machines		25 Exercises	250 Hrs.
	Total	64 Exercises	525 Hrs.

A careful study of the syllabus and the content matter in the modules reveal that these modules are interlinked with each other. Further to this, the number of workstations available in the electrical section is limited by the machinery and equipment. Because of these constraints, it is necessary to interpolate exercises in various modules to form a proper teaching and learning sequence. The sequence of instruction suggested for various modules is given in schedule of instruction which is incorporated Instructor's Guide. There are 25 practical hours in a week of 5 working days and thus, 100 hours of practical in a month.

Contents of Trade Practical

The procedure for carrying out exercises during the **3id semester** and the specific objectives to be achieved at the end of each exercise is arranged in the sequence indicated below.

Objectives

The skill objectives to be achieved at the end of each exercise are listed in the beginning of each exercise.

Requirements

The tools/instruments, equipment/machines and materials required to perform the exercise is given in the first page of each exercise.

Exercise drawing and Procedure

The skill training in the shop floor is planned through a series of practical exercise/experiments to support the theory information so as to make the trainees to achieve practical skills in the **Wireman** trade with the relevant cognitive skills. A minimum number of projects have been included to make the training more effective and at the same time to improve the attitude of group work among the trainees. Pictorial, schematic, wiring and circuit diagrams have been included in the exercises wherever necessary to assist the trainees to broaden their views. The symbols used in these diagrams are in accordance with the Bureau of Indian Standards specifications.

More number of illustrations are available to make this manual, to the extent possible, less language oriented.

The procedure to be followed for completing the exercises are also given. To enhance the interaction between the trainee and instructor as well as between trainees various forms of intermediate test questions are included in the exercises wherever required.

Skill Information

Only the skill areas which are repetitive in nature are given as separate skill information sheets. On the other hand the skills which are to be developed in specific areas are included in the exercise itself. Titles of skill information sheets are given in italics in the content, with the page numbers indicated against each.

This manual on trade practical forms a part of the Written Instructional Material (WIM). WIM also includes manuals on trade theory and assignment/test. The answers to the assignment/test are to be written on the response sheets only.

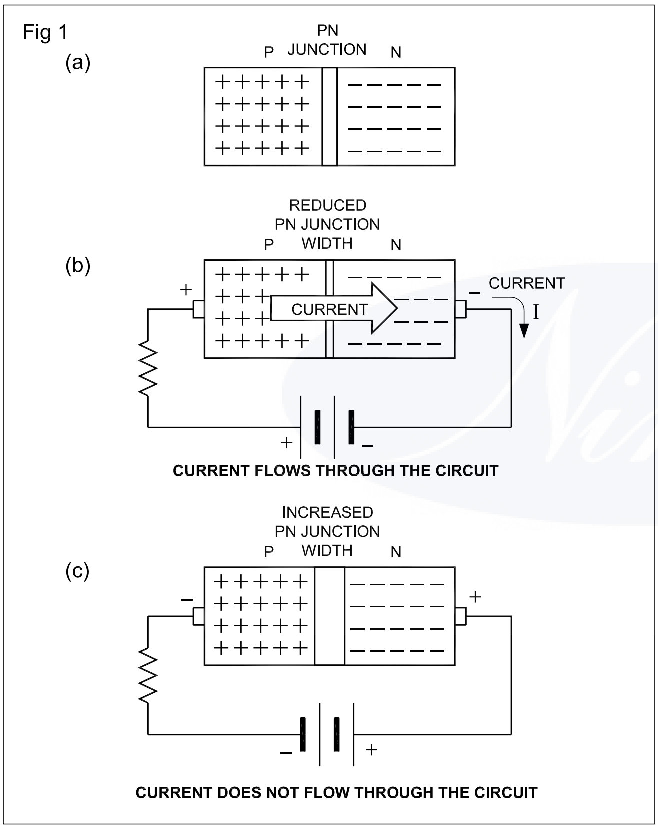
CONTENTS

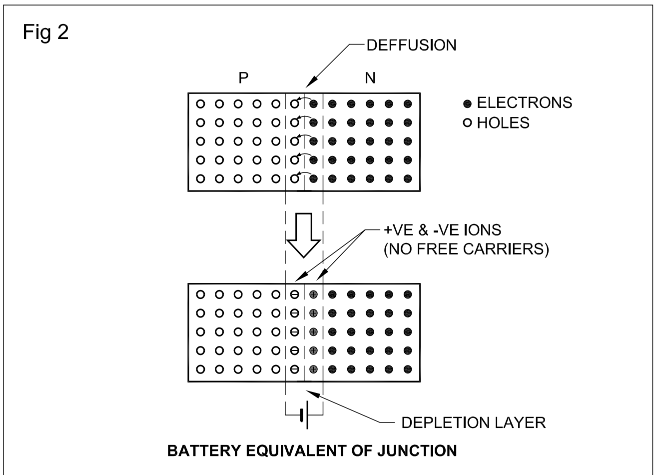
PN junction diodes

Objectives: At the end of this lesson you shall be able to
- **explain how a semiconductor diode lets the current flow in one direction**
- **describe the forward and reverse biasing of PN junction diode**
- **explain the VI characteristic of the diode**
- **state the applications of a diode.**

P-N junction

When a P-type and a N-type semiconductors are joined, a contact surface between the two materials called PN-junction. This junction, has the ability to pass current in one direction and stop current flow in the other direction as shown in Fig 1.





Such a PN junction with terminals attached is called a **Diode.** The typical symbol of a PN-junction diode is shown in Fig 5a.

When a P and N material is put together, at the junction of P and N materials, as shown in Fig 2, some electrons from the N-material jump across the boundary and re-combine with the hole near the boundary of the P-material. This process is called **diffusion.**

This recombination makes atoms near the junction of the P-material gaining electrons and become negative ions, and the atoms near the junction of the N-material, after losing electrons, become positive ions. The layers of negative and positive ions so formed behave like a small battery. This layer is called the **depletion layer** because there are neither free electrons nor holes present in the depletion layer. This depletion region prevents further the movement of electrons from the N-material to the P material.

The internal voltage set up due to +ve and -ve ions at the junction is called **barrier potential**. If any more electrons have to go over from the N side to the P side, they have to overcome this barrier potential. This means, only when the electrons on the N side are supplied with energy to overcome the barrier potential, they can go over to the P side.

In terms of voltage applied across the terminals of the PN junction diode, a potential difference of 0.7V is required across the terminals in the case of silicon diode and 0.3V in the case of Germanium diode for the electrons, in order to cancel off the barrier potential and cross over the barrier as shown in Fig 3. Fig 4 shows the reverse biased PN junction

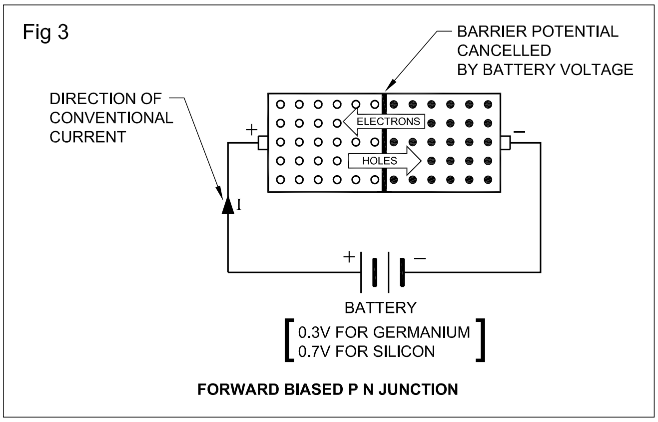
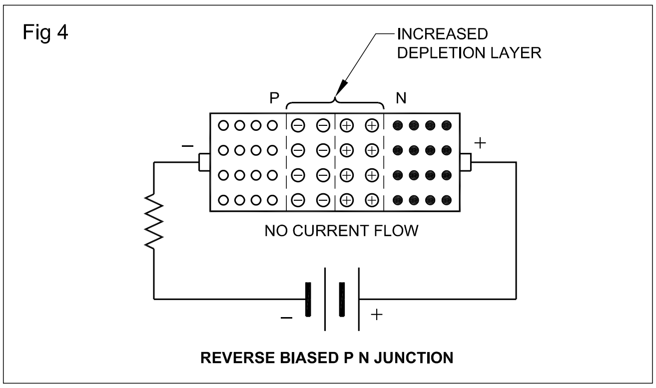


Fig 5a shows the symbolic representation of a Diode. The two leads connected to the P and N terminals are known as Cathode and Anode.

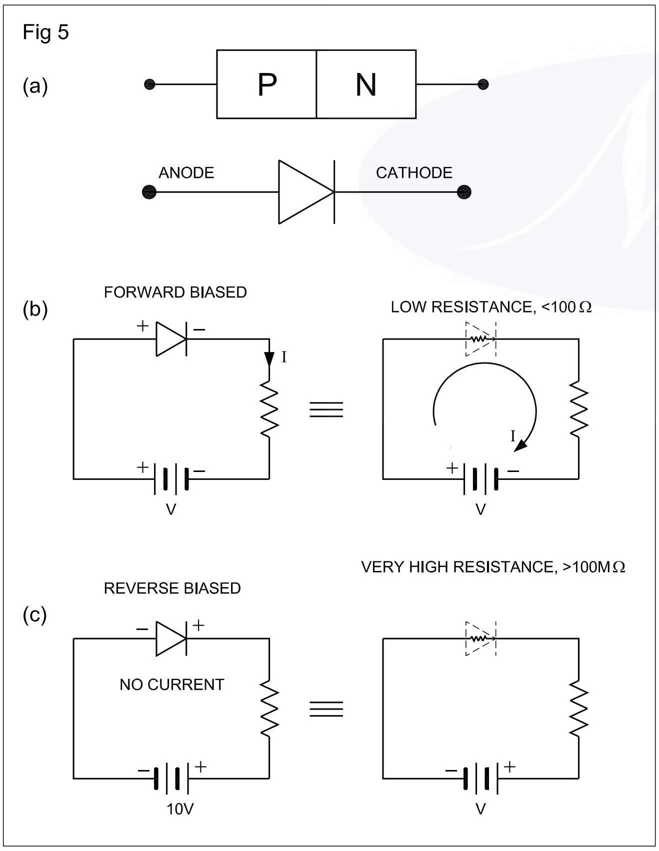
Fig 4



To forward-bias a diode, the Anode should be connected to the +ve terminal of the battery and the Cathode to the -ve terminal of the battery, as shown in Fig 5b. When a diode is in the forward biased condition, the resistance between the terminals will be of the order of a few ohms to a few tens of ohms. Hence, current flows freely when a diode is forward biased.

On the other hand, when a diode is reverse biased as shown in Fig 5c, the resistance between the terminals will be very high, of the order of several tens of megohms. Hence, current does not flow when a diode is reverse biased. As a rule, the ratio of resistance in forward to reverse bias should be of at the minimum order of 1:1000.

Fig 5



a) V-I Characteristics of PN Junction when Forward biased

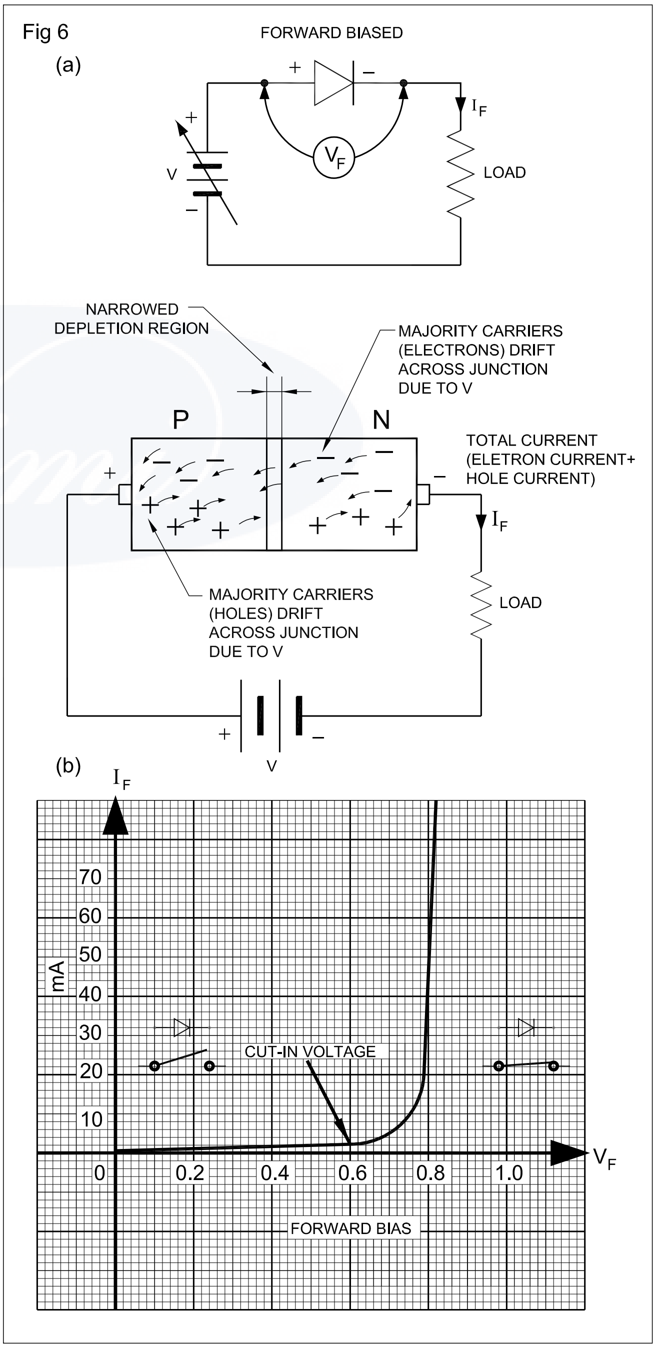
Fig 6a shows a forward biased silicon PN junction diode using a variable DC supply. When the applied voltage is slowly increased starting from 0 volts as long as the voltage across the diode V_F is less than that of the depletion barrier potential (0.7 volts for Si diodes), no current or a negligible current flows through the diode. This is shown in the graph at Fig 6b.

But once the voltage V_F across the diode becomes equal to or greater than the barrier potential 0.6 to 0.7V, there will be a canceling effect of the barrier potential. Hence, the free electrons from the N region get pushed away by the -ve battery terminal(remember like charges repel) and cross over the junction, pass through the P region and get attracted by the + terminal of the battery. This results in the *electron current* passing through the diode, and, hence, through the Load.

In a similar way, the holes in the P region are pushed away by the +ve battery terminal, cross over the junction, pass through the N region and get attracted by the -ve terminal of the battery. This results in *hole current* through the diode, and, hence, through the Load.

Thus current flows through the diode when the forward bias potential is higher than the barrier potential. This current flow through the diode is because of both elec-

Fig 6



trons and holes. Hence, diodes are called **bipolar devices** in which both hole current and electron current flows.

From the graph at Fig 6b, it can be seen that, once the forward voltage goes above 0.6V the diode starts conducting, resulting in considerable current through the circuit. This voltage level across the diode is referred to as **cut-in** or **knee or threshold voltage.**

If the applied forward voltage is further increased beyond the cut-in voltage, the depletion layer further narrows down allowing more and more current to flow through the diode. It can be seen from the graph at Fig 6b, that beyond the cut-in voltage, the current increases sharply for very small voltage increase across the diode.

In this region, above the cut-in voltage, the forward biased diode behaves almost like a closed switch. The only limiting factor for the current at this stage is the maximum current the diode can handle without getting burnt or the junction getting punctured permanently. This current limit is given in diode data books as **maximum forward current, $I_{f\,max.}$**

b) When reverse biased

When an external DC voltage is connected across the diode with the polarity as shown in Fig 7, the diode is said to be reverse biased.

In this condition, when the battery voltage is increased from 0 to several tens of volts, the polarity of the applied voltage instead of cancelling narrowing the depletion layer, widens the depletion layer. In other words, the polarity of the applied voltage is such that the holes and electrons are pulled away from the junction resulting in a widened depletion region.

Referring to the graph shown in Fig 7b, it can be seen that there is no current even when the voltage V_R across the diode is several tens of volts. Because of widening of the depletion layer.

It the applied reverse voltage is kept on increased, say to hundred volts (this depends from diode to diode), at one stage the applied voltage V_R across the junction is so large that it punctures the junction damaging the diode. This results in shorting or breaking down of the diode. This short results in uncontrolled heavy current flow through the diode as shown in graph at Fig 7b. This voltage at which the diode breaks down is referred to as *reverse break-down or avalanche breakdown.*

The maximum reverse voltage that a diode can withstand by a diode is referred to as the **Peak-Inverse-voltage** or **PIV** of the diode. This value for diodes is given in the diode data manual. The PIV of diodes varies from a minimum of 50 volts in small signal diodes to several thousands of volts in high power diodes as shown in Fig 8

Fig 7

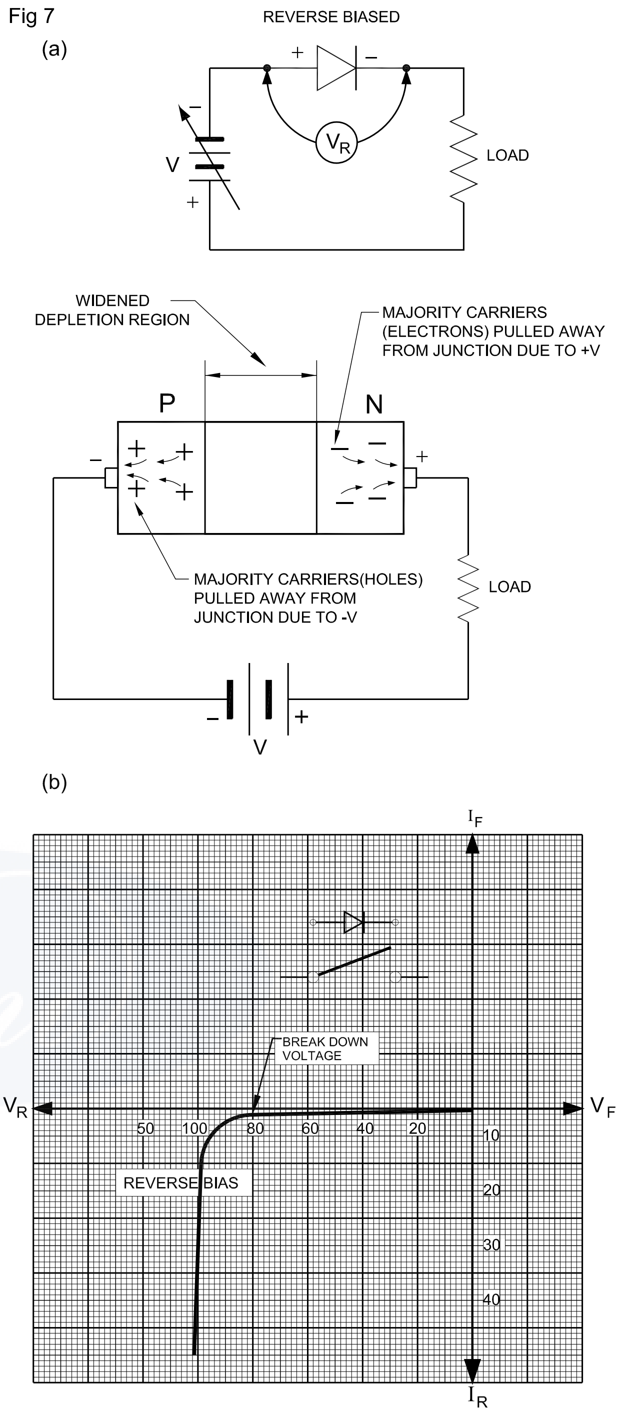
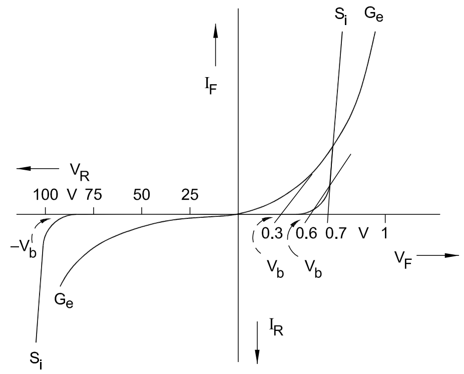


Fig 8



CHARACTERISTICS OF DIODES

Zener diode

Objectives : At the end of this lesson you shall be able to
- **explain how the operation of a zener diode differs from that of a conventional diode**
- **explain the characteristics of a zener diode**
- **explain the terms zener break-down and avalanche break-down**
- **state the specification of a zener diode**
- **state and explain the applications of zener diode.**

Introduction: Generally the small signal diodes and rectifier diodes are not operated in the reverse breakdown regions, because they may be damaged due to excessive power dissipation.

A **zener diode** is a specially doped silicon semiconductor diode which is specifically manufactured to operate in the reverse break-down region. It can be repeatedly operated in the breakdown region without any damage. It is often called a breakdown diode.

The difference between a rectifier diode and a zener diode are listed below;

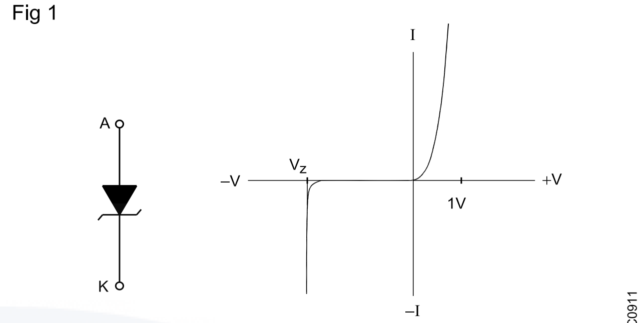
- Compared to normal rectifier diodes, zener diodes are heavily doped.
- Unlike ordinary diodes which do not work in the break-down region, zener diodes work only in the breakdown region.
- General rectifier diodes are used in forward-biased condition, whereas zeners are always used in reverse-biased condition.
- The reverse breakdown voltage of zener diodes is very much less (3 to 18V) compared to rectifier diodes (minimum 50V).

The similarities of a zener diode with those of general purpose rectifier diodes are listed below;

- Zener diodes are also PN junction diodes, which are also generally made of silicon.
- Zener diodes also have two terminals (anode and cathode).
- In physical appearance, the zener diodes and ordinary diodes look alike.
- Like rectifier diodes, zener diodes are also available with glass, plastic and metal casing.
- The anode and cathode marking technique on the body is same for both zener and rectifier diodes.
- The zener can be tested with an ohmmeter in the same way as in rectifier diodes.
- Zener requires approximately the same voltage for it to be forward-biased into conduction as that of an ordinary diode.

VI Characteristics of a zener diode : A zener diode is represented by mean of a schematic symbol as shown in Fig 1a. The voltage-current characteristics is shown in Fig 1b.

Fig 1



a) SYMBOL b) I–V CHARACTERISTICS

The zener diode acts as a rectifier diode when forward biased as its forward characteristics is similar to that of a conversational diode. In the forward biased region it starts conducting around 0.6 V. In the reverse biased region a very small reverse current (leakage current) flows despite the increase in the reverse-biased voltage till the break down voltage (also called zener voltage) is reached. Once the zener break down voltage is reached the diode current begins to increase rapidly and the zener suddenly begins to conduct. The following points are observed in the reverse biased characteristics of the zener diode.

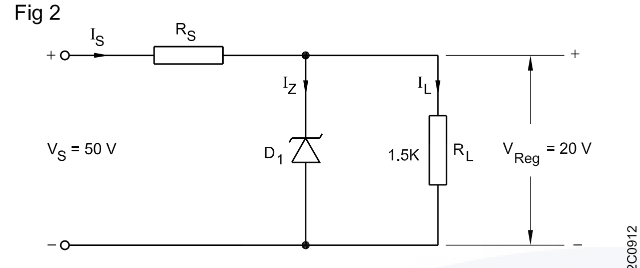
- The breakdown has a very sharp knee followed by an increase in the reverse current.
- The voltage is approximately constant and equal to V_Z.

Avalanche break down : When the diode is reverse biased, minority carriers produce a very small reverse current below the breakdown voltage. When the reverse voltage is increased beyond breakdown, the minority carriers gain enough energy to dislodge valence electrons from their orbit and they in turn knock other electron. This process is continued and a large number of free electrons are produced. This causes a large reverse current. This is called avalanche break down, which takes place.

When the reverse voltage is increased much more higher than the zener break down voltage. Once the avalanche break down occurs, the zener diode may get damaged permanently.

Zener break down : In heavily doped diodes, reverse bias produces a strong electric field across the junction. The strong electrified is sufficient to cause electrons to break away from their orbits. Hence the current in the reverse direction suddenly increase and the zener diode begins to conduct in reverse bias. This is known as field emission. This effect is known as zener effect and the breakdown is called **zener breakdown**. The zener breakdown takes place in zener diodes. The zener (break down) voltage will be much less than the avalanche break down voltage. When the reverse voltage reaches the nominal zener voltage (V_Z). Fig 2 shows the Zener voltage regulator

Fig 2



ZENER VOLTAGE REGULATOR

Specification of zener diodes : The important zener diode specifications are listed below.

1 **Nominal zener voltage V_z:** This is the reverse biased voltage at which the diode begins to conduct in reverse bias.

2 **Zener voltage tolerant:** This indicates the percentage above or below V_z for example 6.3 v ± 5%.

3 **Maximum zener current** (I_z max.): This is the maximum current that the zener can safely withstand while in its reverse biased conduction mode.

4 **Maximum power dissipation (P_z):** Maximum power dissipation (P_z) is the maximum power the zener can dissipate without getting damaged.

5 **Impedance (Z_z):** The impedance of the zener while conducting in Zener Mode.

6 **Maximum operating temperature**: The highest temperature at which the device will operate reliably.

These specifications of zener diodes are given in diode data books.

Example : The type code on a Zener is B Z C 9V1

B Z C 9 V 1

Silicon Zener 5% tolerance 9.1 V

Applications of zener diode: Zener diodes are normally used in voltage regulating circuits. Here it will hold the load voltage constant however large the changes in line voltage and load resistance are.

Zener diodes - designing for voltage regulator

Objectives: At the end of this lesson you shall be able to
- **state the need for minimum current through the zener**
- **state the worst case conditions to be considered while designing a zener regulator**
- **calculate the value and wattage of a series resistor**
- **calculate the required wattage of a zener for a given application.**

Designing a simple zener regulator

If the voltage across a zener tends to increase or decrease, the voltage across the series resistor has to be R_S increased or decreased, thus keeping the voltage across the zener, and, hence, the voltage across the output/load constant.

From this it is clear that, to make a voltage regulator circuit using zener, a series resistor (Rs) and a zener diode are required. The value of the resistor should be chosen so as to meet the following conditions ;

- Under full load condition (i.e., I_L=max), at least the minimum reverse current (I_Z)should flow through the zener such that the zener remains to be in the zener breakdown condition and conducts the current.

  The minimum IZ = I_T - I_L

Where, I_T is the total current and I_L is the load current.

For the zener to hold the output voltage constant, the zener must remain in the breakdown region under all conditions.

- Under no load condition, the series resistor R_S must restrict the current through the zener, such that, the power dissipation and voltage across the zener is within the specified limit of the device.

The voltage drop across R_S should be such that,

$V_{RS} = V_{IN} - V_Z$

The design steps for a simple zener regulator circuit is given below through an example:

Example: A zener regulator circuit is needed to supply a constant output voltage of 12V DC ± 0.1V. The load current may vary (depending on load resistance) from 0 to 100mA. The unregulated input to the regulator is 34V DC (maximum).

Design steps:

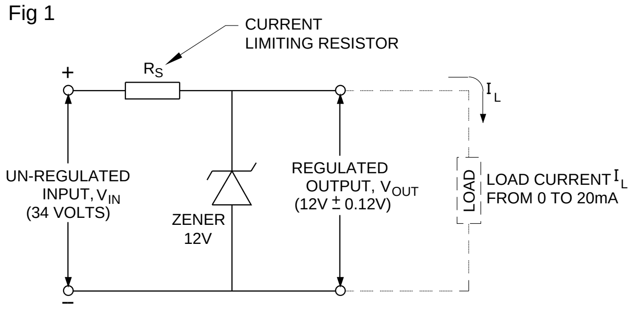
1 Draw a schematic of a regulator as shown in Fig 1.

2 Choose a zener of V_Z = 12 volts as the output voltage required is 12 Volts. Choose the zener with a tolerance of >10%, so that the output will be 12 V DC ± 0.12 V.

3 From the specifications of the zener, find I_Z. Say the minimum I_Z of the chosen zener is = 20mA.

4 Calculate the current through the zener in the worst conditions as explained below;

Fig 1



One of the worst conditions is, when the input voltage V_{IN} is minimum and, the load current is maximum. For this condition, choose the minimum I_Z that should flow through the zener to keep it in reverse-ON condition.

In the example considered, minimum I_Z = 20mA.

Since, $I_T = I_Z + I_{L(max)}$

For the given example,

I_T = 20mA + 100 mA = 120 mA.

The other worst condition is, when maximum current flows through the zener as the load current is zero and the source voltage is maximum. In the example considered.

When I_L = 0 mA, current through the zener will be maximum and I_Z max is,

120 mA – 0 mA = 120 mA.

5 Calculate the zener wattage.

The zener wattage is determined from the maximum I_Z

$$W_Z = V_Z \times I_Z = 12 \times 0.12 = 1.44 \text{ Watts}$$

where, V_Z is the zener voltage and I_Z is the maximum current through zener.

6 Calculate the required value of R_S

$V_{IN} - V_{OUT} = I_T\ R_S$

or, $I_T R_S = V_{IN} - V_{OUT}$

= 34V – 12V = 22V

Since, I_T = 120mA

R_S = $(22/(120 \times 10^{-3})$ = 183Ω

Therefore, $R_S = 183\Omega$

Since 183 is not a standard resistance value, choose the nearest lower value of RS which is 180Ω upon choosing 180W in place of 183Ω, the changed value of I_T will be,

$$I_T = (22/R_S) = (22V/180\ \Omega) = 122mA$$

The increased I_T of 122mA instead of 120 results in an excess of 2mA through the zener. Therefore add an extra wattage of 12V x 0.002 = 24mw to the already calculated zener wattage of 1.44 watts. Therefore the new wattage of zener should be 1.4 watts + 0.024 W = 1.464 ≈ 1.5Ω

7 Calculating the wattage of R_S

Maximum current through R_S in the worst condition will be 122mA.

Therefore, $W = I_T^2 R_S = (0.122)^2 . 180$

$= 2.69 \approx 2.7$ watts

From the above calculations, On No-load,

$I_Z + I_L = I_T = 122mA$

Since $I_L = 0$, $I_Z = I_T = 122mA$

On Full-load (100mA)

$I_T = I_Z + I_L$

$I_T = 122mA$

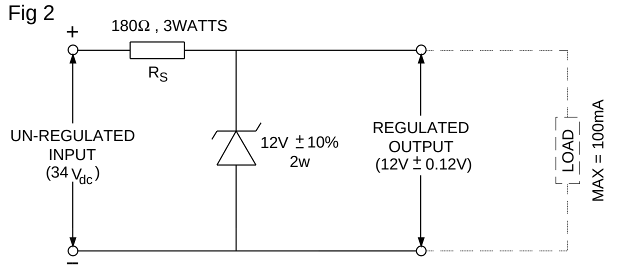
Therefore, $I_Z = I_T - I_L$

$= 122mA - 100mA = 22mA$

I_Z of 22mA is sufficient to keep the zener in reverse ON condition even during full load.

In steps 6 and 7, a good design practice is to overrate the wattage of the resistor and zener, so that the components do not get overheated and fail prematurely. Hence, the resistor should be rated at 3 watts or more and the zener at 2Ω. The designed simple zener regulator with component values and ratings is shown in Fig 2.

Fig 2

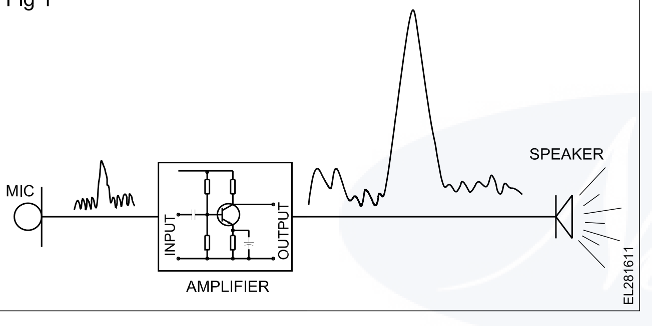


Transistors

Objectives: At the end of this lesson you shall be able to
- **explain about the transistor**
- **explain the working of PNP & NPN transistor**
- **explain the important packages and type number systems**
- **explain testing of a transistor**
- **explain the advantages of transistors over vacuum tubes**
- **use a transistor data book**
- **explain the terminals of a transistor**

Introduction : Transistor is a three layer, two junction and three terminal semi conductor active device which is the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as shown in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), there was vaccum tubes or valves which were used in amplifiers.

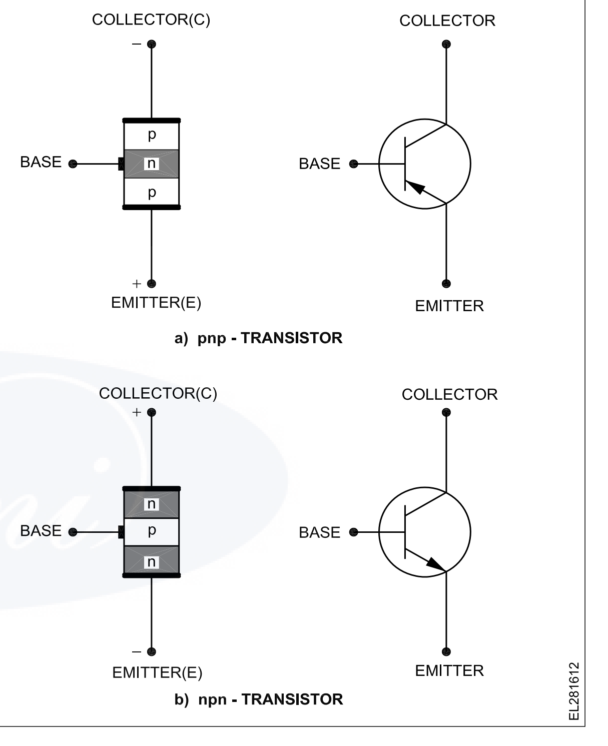
Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum or no power loss in the form of heat
- Low operating voltage
- Rugged in construction.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used.

- Germanium transistors
- Silicon transistors

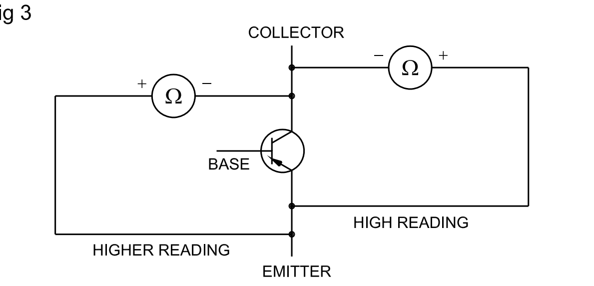
Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor shown in Fig 3, first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Fig 3



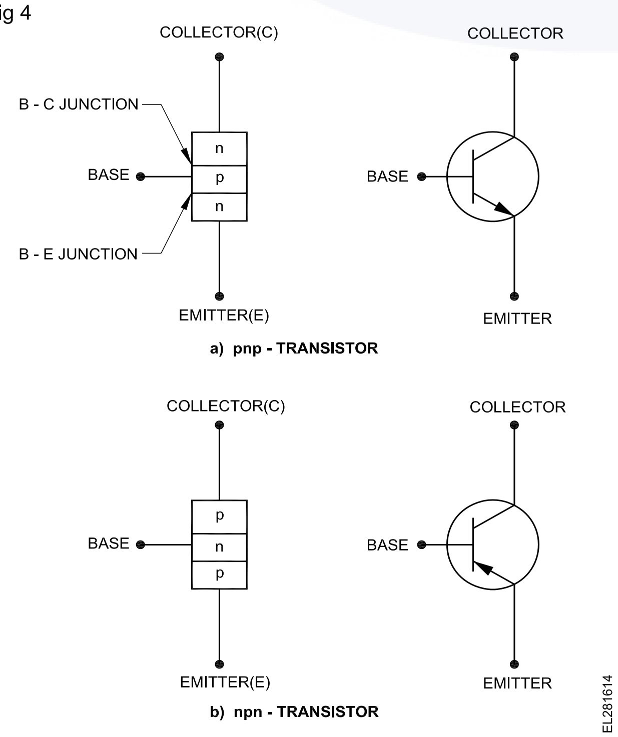
OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as shown in Fig 4

- NPN transistor
- PNP transistor

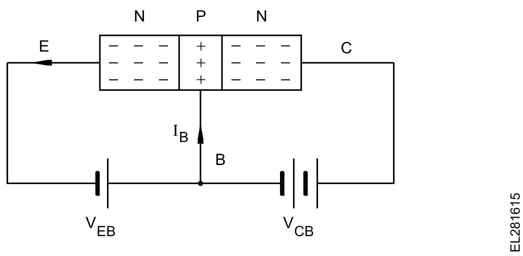
Fig 4



Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Operation of NPN transistor : During the normal operation of the transistor, the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as shown in Fig 5.

Fig 5

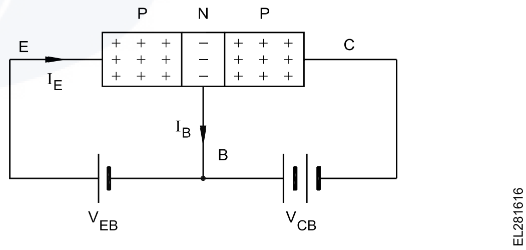


If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high position potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

$I_E = I_B + I_c$

Working of PNP transistor : For proper operation of a PNP transistors, the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as shown in Fig 6.

Fig 6



Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

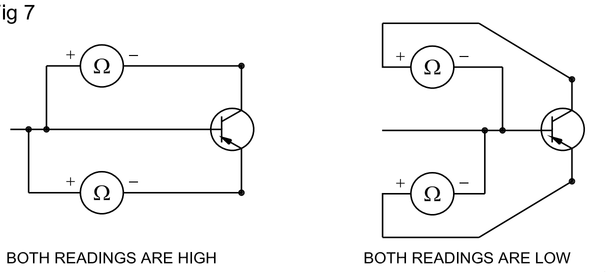
In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7
2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.
3 If both readings showing high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)
4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.
5 If both readings show low resistance, then it is a PNP transistor.

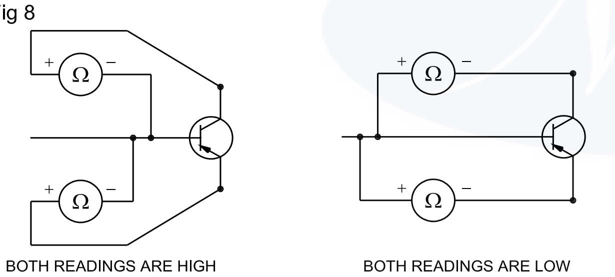
Fig 7



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE PNP TYPE

NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE NPN TYPE

Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.
2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.
3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts
2 Medium power transistors is 2 to 10 watts
3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low freq. transistor (Audio Frequency of A/F transistors)
- High freq. transistor (Radio frequency of R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

5 Based on the manufacturing method

- Grown junction
- Alloy junction
- Planar contact
- Epitoxial
- Mesa

The aim of each manufacturing process is to yield transistors most suitable for a particular type of application.

Transistor data books generally do into give information about the adopted manufacturing process of transistor. However, the relevant details can be obtained from the transistor manufacturer.

6 Based on the type of final packaging

- Metal
- Plastic
- Ceramic

Metal packaged transistors are generally used in medium and high power amplifications. Plastic packaging is generally used for low power amplification. Some plastic packages come with a metal heat sink. Such transistors are used for medium power amplification. Ceramic packaging is used for special purpose very high frequency applications, for higher temperature stability etc.,

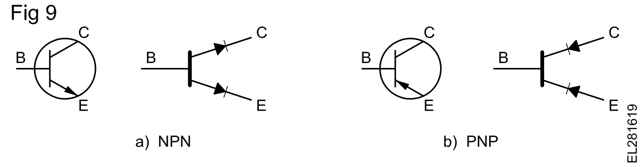
Some examples of packaging type codes used with transistors are, TO-3, TO-92- SOT-25 and so on.

Transistor data books give information about the type of packaging and its case outline.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

Fig 9



An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings. Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohmmeter/multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.

2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3 When both the forward and reverse R are very high, close to infinity, the junction is open.

4 When both junctions are good transistor is good.

5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

> **Normally for any power transistor, collector is connected to the metalic part/case to dissipate excess heat generated.**

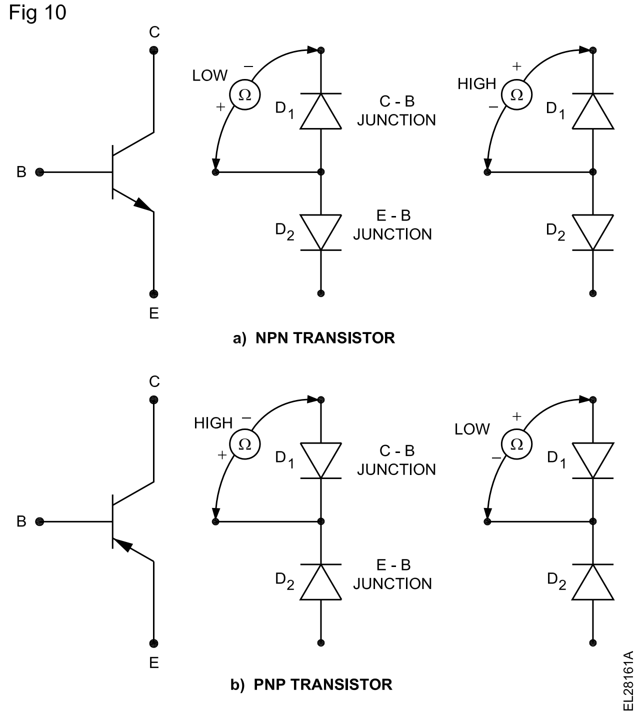
6 With a high voltage multimeter (motwane multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one diretion and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

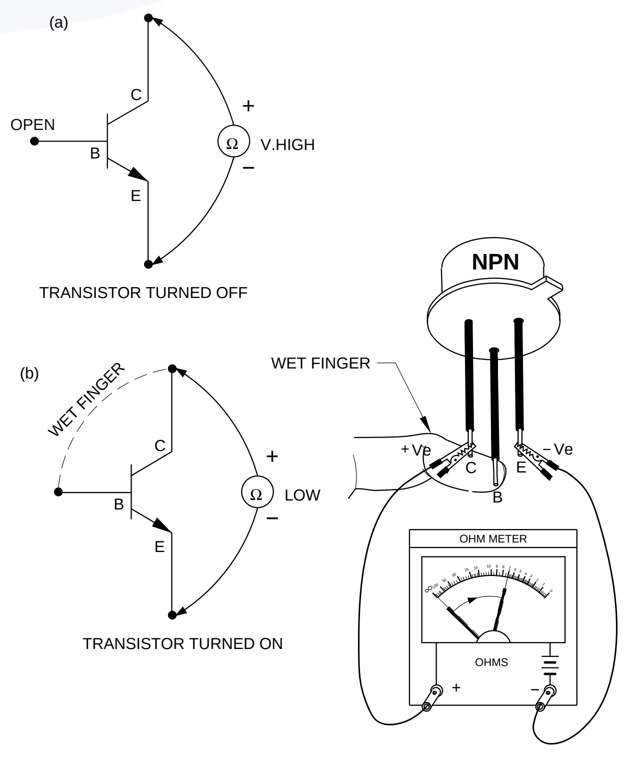
Fig 10



Quick TURN-ON test

Recall that the base lead of the transistor controls the flow of current carriers from emitter to collector. So, if the base is open, then there can be no current flow through emitter-

Fig 9



NOTE: +VE AND -VE INDICATED ACROSS OHMMETER IS THE INTERNAL BATERY PLORITIES OF THE METER AND NOT THE MARKINGS AT THE METER PROD SOCKETS collector. This means, the resistance between emitter and collector will be high when the base is open. This can be checked using an ohmmeter with the base lead open.

When the collector and base leads of a transistor is touched with a wet finger as the base of the transistor turns ON the transistor and makes current to flow through emitter-collector. Because of the current flow, the resistance across emitter-collector will be low. From this test it is possible to make a quick test of the transistors basic operation. This test is most suitable for low power and medium power transistors.

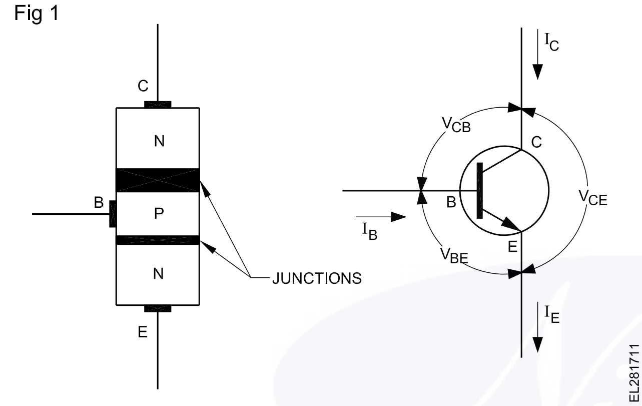
The above two tests on a given transistor, using a simple ohmmeter revels the condition of the transistor. These tests are essential before using a transistor in a circuit.

Characteristics of transistors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of characteristic curves for transistors**
- **list the two important characteristic curves of transistors**
- **state the meaning of early effect**
- **state the meaning of knee voltage and break down voltage in the output characteristic curve**
- **state the importance of DC load line curves**
- **state the meaning of Q-point**
- **state the method of fixing Q-point for a given transistor using the transistor data.**

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E as shown in Fig 1.

Fig 1



Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

- Input characteristics
- Output characteristics

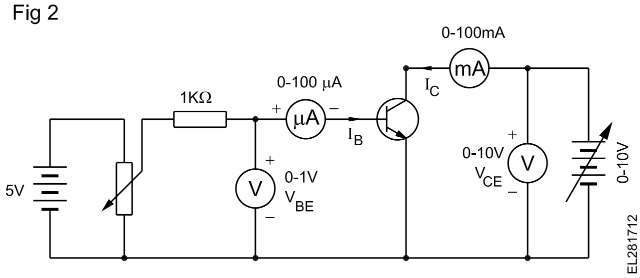
For simplicity in understanding, consider a common-emitter amplifier. The two characteristics graphs are shown in Fig 3 and Fig 4

Input characteristics or Base characteristics of a common emitter amplifier

The graph at Fig 3 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

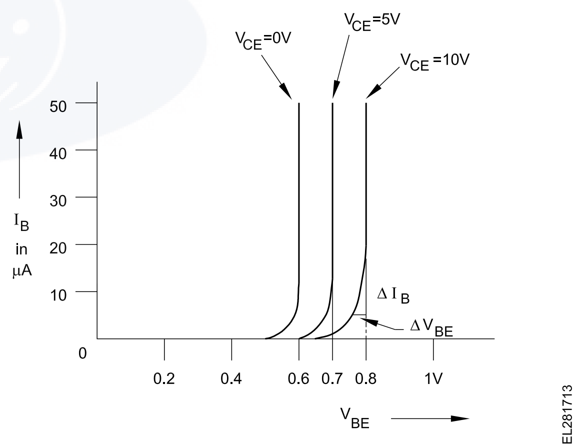
To find the input characteristics from the circuit as shown in Fig 2 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Fig 2



Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is shown in Fig 3.

Fig 3



The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu\,A - 10\mu\,A} = \frac{0.02}{10\mu\,A} = 2k\Omega$$
$(\mu = \text{micro})$

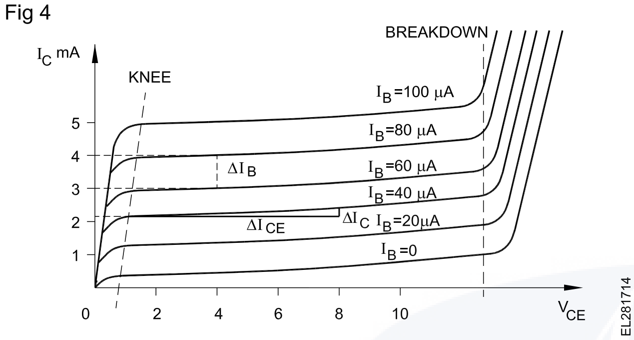
The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu\,A - 0.65\mu\,A} = \frac{5\,V}{0.1\mu\,A} = 50$$

Output CE characteristics : To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 4.

Fig 4



It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B= 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\,m\,A - 2m\,A} = \frac{6}{0.15m\,A} = 40\text{ k ohms.}$$

Current gain can be calculated by the formula

$$\text{Beta } \beta = \frac{I_C}{I_B} = \frac{4mA - 3\,mA}{80\,\mu\,A - 60\,\mu\,A} = \frac{1mA}{20\,\mu\,A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha } \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Analysis of ce output characteristics

Active region : In the active region the collector junction is reverse-biased and the emitter junction is forward-biased. In the active region, the collector current is Beta times greater than the base current. Thus, a small input current I_B produces a large output current I_c.

Saturation regions : In the saturated region, the emitter and collector junctions are forward-biased. When the transistor is operated in the saturated region, it acts as a closed switch having V_{CE} = 0 and I_c maximum.

Behaviour of Ic for different values of V_{CE} is explained below:

- When V_{CE} is 0, the collector-base diode is not reverse-biased. Therefore, the collector current is negligibly small and this continues upto knee point.
- For V_{CE} between 0.7V and 1V, say up to knee point voltage the collector diode gets reverse-biased. Once reverse biased, the collector gather all the electrons that reach its depletion layer. Hence the collector current rises sharply and then becomes almost constant.
- Above the knee voltage and below the break down voltage, the collector current does not rise steeply or the current is almost constant even if the value of V_{CE} is increased. Thus the transistor works like a controlled constant current source in this region.
- Assuming that the transistor has a $ß_{dc}$ of approximately 50, the collector current is approximately 100 times the base current as shown in Fig 4 (1mA is 50 times 20 μA).
- If V_{CE} is further increased, beyond the break down level, $V_{CE(max)}$, the collector-base diode breaks down and normal transistor action is lost. The transistor no longer acts like a current source. As the collector-base gets ruptured, the junction is shorted and hence current increases rapidly above the breakdown point as shown in Fig 4.

Cut off region : In the cut off region, the emitter and collector junctions are reverse-biased. When the transistor is operated in the cut off region, it acts as an open switch, having $V_{CE} = V_{cc}$ and $I_c = 0$

Break down region : When the collector voltage is too large, the collector diode breaks down, which is indicated by a rapid increase of collector current as shown in Fig 5. Usually, a designer should avoid operation in the breakdown region because the excessive power dissipation may destroy the transistor.

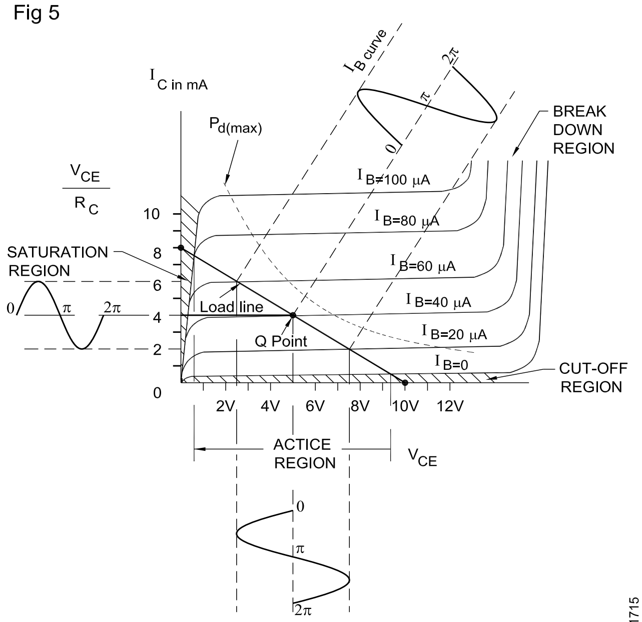
For instance, a 2N3904 has a collector break down voltage of 40V. For normal operation, therefore, V_{CE} should be less than 40V.

Maximum power dissipation region : The maximum power dissipation ($P_{o\ max}$), defined as the product of maximum collector current $I_{c\ max}$ and maximum collector emitter voltage $V_{CE\ max}$, restricts the operation to an area on the output characteristic bounded by a hyperbola.

To understand the function of the transistor at active, cut off, saturation regions and breakdown regions, refer to Fig 5.

The collector curves are very important because, from these curves the following important information required while designing an amplifier circuit using a particular type of transistor can be obtained;

Fig 5



OUTPUT CHARACTERISTIC WITH LOAD LINE SUPERIMPOSED

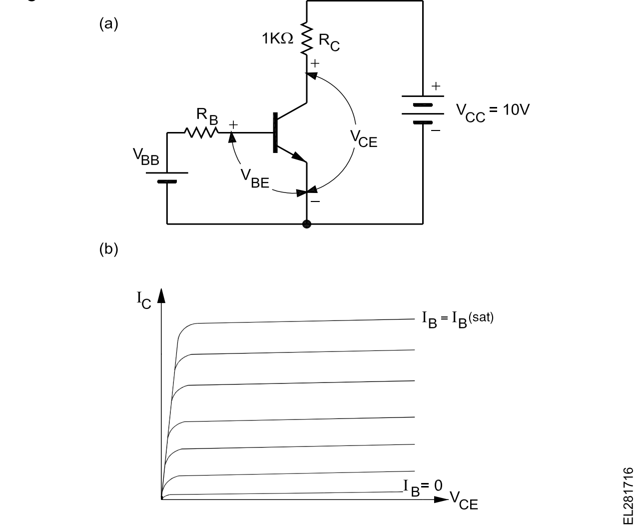
- DC current gain ß of the transistor at different set DC values of I_B and V_{CE}
- Maximum value of V_{CE} that can be applied for a set value of I_B and I_c.
- Maximum value of I_c that can be made to flow for a set value of I_B

Operation point : The position of the operating point on the D.C. load line determines the maximum signal that we can get from the circuit before clipping occurs. The operating point or quiescent point is a point on the D.C. load line which represents the values of Ic and V_{CE} that exist in a transistor circuit when no input signal is applied. The best position for this point is midway between cut-off and saturation point where V_{CE} = 1/2 V_{cc}.

DC load lines of transistors : To have a further insight into how a transistor works and in what region of the collector characteristics does it work better can be found using DC load lines.

Consider a forward biased transistor as shown in Fig 6a. Fig 6b shows the collector characteristics of the transistor used.

Fig 6



In the circuit at fig 6a, consider the following two situations,

– Maximum collector current, $I_{c(max)}$

– Minimum collector current, I_c

For situation (1) assume that V_{CE} is zero or collector is at short. In that case, the collector current is limited only by the collector resistor R_c.

Therefore

$$I_C = \frac{V_{CC}}{R_C} \text{ at } I_{CE} = 0$$

Under such a condition for the circuit at Fig 6 a I_c will be equal to 10V/kΩ = 10mA

Mark this I_c=10mA point along V_{CE}=0 on the collector characteristics of the transistor as shown in Fig 7 at point A.

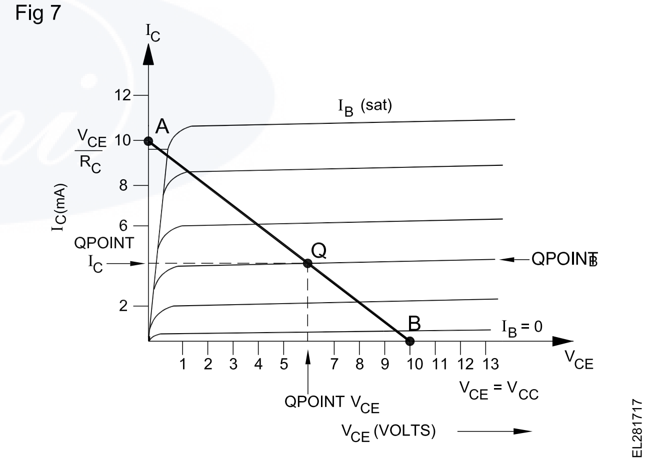
For situation (2), assume that V_{CE} is maximum or collector emitter is open. In that case, the collector current is zero.

Therefore,

$V_{CE} = V_{cc}$ In the circuit at 6a, $V_{CE} = V_{CC}$ = 10V

Mark this point of I_C = 0 and V_{CE} = 10 V on the collector characteristics of the transistor as shown in Fig 7 at point B.

Fig 7



Connect the two marked points A and B through a straight line as shown in Fig 7. This line is called the load line.

The point at which the load line intersects the I_B = 0 is known as the cut off point. At cut off, I_B = 0; hence emitter diode is out of forward bias and the transistor action is lost.

The point at which the load line intersects $I_B = I_B$(sat) is called the saturation point. At this point the base current is maximum and the collector current is also maximum. At saturation, the collector diode comes out of the reverse bias, and hence, the normal transistor action is lost.

For a transistor to work in a normal way, i.e. as a controlled current source, it must not be made to work either in the cut off or in saturation. Therefore the ideal point would be somewhere in the middle of these extreme points on the load line. This middle point is known as Quiescent point or Q-point as shown in Fig 7.

Knowing the Q point, you can fix-up the value of resistors R_c and R_B of the circuit.

The DC load line shows at a glance the active V_{CE} voltage range of the transistor. In other words, it indicates that the transistor acts like a current source anywhere along the DC load line, excluding the saturation or cut off, where the current-source action of the transistor is lost.

Fixing Q point from the data available in data sheets: The Q point can be fairly and accurately be fixed from the data of a transistor given in transistor data books. This reduces the time consuming work of plotting the collector characteristics and the load line. To do so, the following points are very important to remember;

1 The chosen V_{cc} must be less than $V_{CE(max)}$ given in the data book.

Preferably restrict the value of V_{cc} to 34 of $V_{CE(max)}$

2 Fix the Q point Ic at 1/2 of $I_{C(max)}$ given in the data book.

3 At the Q point I_c at 1/2 of RV$_{cc}$ will be across V_{CE}.

4 From points (2) & (3) calculate the value of R_c.

5 From the H_{FE} value given in data book, fix the approximate value of the base current at the Q point as given below.

$$I_B \text{ at Q point} = \frac{\text{Chosen value of } I_C \text{ at the Q - point}}{\text{Typical value of } H_{FE} \text{ from data book}}$$

6 From the value of I_B at the Q point and allowing a 0.7 volts drop across the base-emitter, calculate the value of R_B.

AC load line : The A.C. load line is a line joining point V_{CE} (cut off) (=V_{CEQ} + I_{CQ} R_{AC}) on the voltage axis and point I_c(sat) (=I_{CQ} + V_{CEQ}/R_{AC}, where R_{AC} is the A.C. load resistance).

Voltage regulator

Objectives: At the end of this lesson you shall be able to
- **state the disadvantages of a zener regulator**
- **explain the principle and working of a series voltage regulator**
- **explain how the series regulator maintains a constant output voltage when the input AC voltage varies or load resistance varies**
- **explain method of determining zener voltage, value of series resistance, zener wattage and power rating of the series regulator transistor**
- **explain the term load regulation and line regulation**
- **state the necessity of heat sinks and their types.**

Voltage regulated power supply using zener diode is the simplest form in voltage regulator. But, zener voltage regulators have two main disadvantages:

– When the load current requirement is higher, say of the order of a few ampere, the zener regulator requires a very high wattage zener diode capable of handling high current.

– In a zener regulator, the load resistor reflects the output impedance of approximately the zener impedance, (Rz), which ranges from a few ohm to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohm.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 1.

The advantages of this circuit are listed below;

i) less load on the zener diode

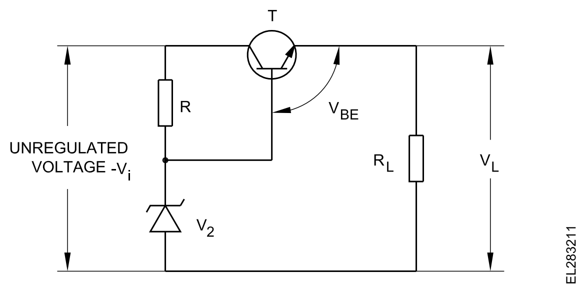
ii) the circuit has lower output impedance which is an additional feature for any power supply.

Series voltage regulator

Series voltage regulator is an electronic circuit consists of zener diode and transistor and gives the constant output voltage and lower output Impedance

The principle and working of a series regulator: Fig 1 shows the basic circuit where the transistor (control element) acts as a variable resistance connected in series with the load resistor. The transistor resistance is determined by the base current.

Fig 1



The unregulated voltage from the rectifier and filter is applied to the input of the series regulator circuit. The input voltage V_1 is divided between the emitter-follower transistor T and the load R_L.

The operation is as follows.

If the input voltage V_1 is increased, the output voltage V_L tends to increase and the base voltage V_{BE} decreases,

$$\text{since, } V_L + V_{BE} - V_Z = 0$$

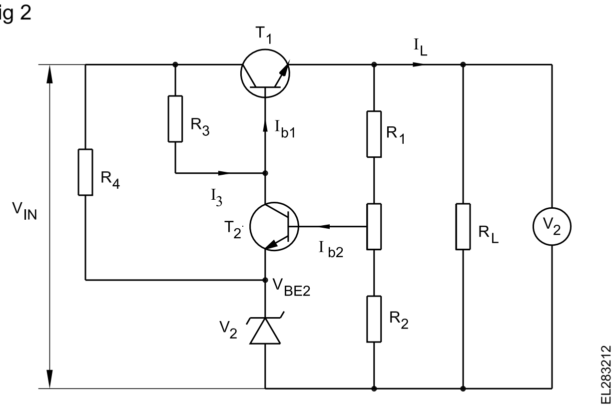
$$V_{BE} = V_{z(fixed)} - V_L$$

This will decrease the forward-bias of the transistor, thereby its level of conduction, will lead to an increase in the collector/emitter resistance of the transistor which will slightly increase the voltage drop on the transistor so that the output voltage V_L will remain at a constant value.

The output voltage remains constant even in the case of a decrease in the input voltage but the above actions will be vice-versa.

Feedback series regulator: Fig 2 shows a feedback series regulator circuit. The D.C. input voltage V_{IN} comes

Fig 2



from an unregulated power supply, such as a bridge rectifier and a capacitor input fitter. Typically, V_{IN} has a peak-to-peak ripple of about 10 percent of the D.C. voltage. The output voltage V_{out} is almost perfectly constant, eventhough there is any change in the input voltage and load current. This is possible as any change in output voltage is fedback through the voltage divider to the base of T_2. This produces an error voltage that automatically compensates for the attempted change. For instance, if V_{out} tends to increase due to increase of input voltage V_{in}, more V_F is fed back to the base of T_2, producing a larger T_2 collector current through R_3 and less base voltage at T_1. This reduced base voltage to the emitter-follower results in less output voltage. similarly, if the output voltage tends to decrease, due to decrease of the input voltage, there is less base voltage at T_2, more base voltage at T_1, and more output voltage.

Suppose R_L is decreased, then, I_L increases but V_2 decreases. Decrease in V_L decreases I_{B2} and also I_{C2}. Assuming I_3 to be relatively constant (or decreasing only slightly), I_{B1} is increased, thereby decreasing the collector-emitter resistance of T_1. This leads to decrease in V_{CE1}, thereby offsetting the decrease in V_2 which is, therefore, returned to its original value.

In either case, the output voltage V_{out} is almost constant, even though the input voltage and load current may change.

Design guidelines for a simple series regulator

Example

For the series regulator shown in Fig 1, find the values of the components for an output voltage of 12volt. The input unregulated DC voltage V_{in} to the regulation may vary 30V to 40V. The load resistor R_L is 390Ω.

Step 1: Finding zener voltage rating

Required output voltage

$$V_{out} = 12V$$
$$V_{out} = V_z - V_{BE}$$
$$\text{or, } V_z = V_{out} + V_{BE}$$
$$= 12V + 0.7V = 12.7V$$

Since the nearest value is 12V, choose a zener of voltage 12V.

A zener of 12V, ±5% rating will have output of 12V +0.6V = 12.6V. Hence practically the output voltage of the regulator will be 12.6 – 0.7V = 11.9V. Hence for further calculations V_{out} is taken as approximately 12V.

Step 2: Finding the value of R and the wattage of the zener diode.

a) At the given, the worst case (minimum) V_{in} of 30V, the minimum current through the zener to be in breakdown condition = 10mA.

$$R = \frac{30V - 12V}{10mA} = \frac{18V}{10mA}$$
$$= 1800\Omega = 1.8k\Omega$$

b) When V_{in} = 40V(given)

$$I_R = \frac{40V - 12V}{1800\Omega} = 15.6mA.$$

Therefore the wattage of zener should be,

$$P_z = V_z \times I_R$$
$$= 12V \times 15.6mA = 187mW$$

Hence, a 1/4watt, 12V zener is sufficient.

Step 3: Finding wattage rating of pass transistor.

a) For the given load of 390Ω, the load current will be,

$$I_L = \frac{V_{out}}{R_L} = \frac{12V}{390\Omega}$$
$$= 30.76mA = 31mA$$

b) Maximum power is dissipated in the transistor, when

i V_{in} is maximum, i.e. V_{in} = 40V and

ii Load current is maximum, i.e. I_L = 31mA.

Therefore, power rating of pass transistor P_Q should be,

$$P_Q = V_{CE} \times I_L = (V_{in} - V_{out}) \times I_L$$
$$= (40V\text{-}12V) \times 31mA$$
$$= 28V \times 31mA = 868 \text{ mwatts}$$

Choose any transistor with a power rating of 20% more than P_Q i.e. 868 + 174 = 1042mW = 1W (approx.)

For further calculations SL100 is chosen as the pass transistor although its wattage rating is less than 1watt. The damage to the transistor can be avoided if load current is restricted to <28mA.

c The base current for the chosen pass transistor

SL100/HL100 has β_{dc} between 50 to 200. Assuming an average β_{dc} of 80,

$$I_B = \frac{I_E}{\beta_{dc}} = \frac{31mA}{80} = 0.39mA$$

Total maximum zener current I_z will be, $I_z = I_R - I_B$

$$I_z = 15.6mA = 0.39mA$$
$$= 15.2mA$$

Step 4: Finding the output impedance of the regulator. Assuming the zener resistance, R_z= 7Ω

$$Z_{out} = r'e + \frac{R_Z}{\beta_{dc}}$$

$$\text{where, } r'_e = \frac{25mV}{I_E} = \frac{25mV}{31mA} = 0.8\Omega$$

$$\text{and, } \frac{R_Z}{\beta_{dc}} = \frac{7\Omega}{80} = 0.0875$$

$$\text{Therefore, } Z_{out} = r'e + \frac{R_Z}{\beta_{dc}}$$
$$= 0.8 + 0.0875 = 0.89\Omega$$

Note: r'_e is high because I_L is low. If I_L is high then r'_e becomes very small.

Step 5: Finding V_{out} variations for higher loads. If the load resistance is decreased from 390Ω to 330Ω, the load current increases from 31mA to 36mA. This change in 5.3mA of load, decreases the load voltage by,

$$V_L = (\text{Change in } I_L)(Z_{out})$$

$$\text{Therefore, } V_L = (5.3\text{mA})(0.89\Omega) = 4.7\text{mV}$$

This change is negligible compared to 12V and hence, for all practical purposes, the output voltage can be taken as well regulated.

Power supply characteristics: A power supply is said to be good, if its output voltage changes by as small a value as possible when the load current changes or when the input voltage changes. These are specified in terms referred as,

– Load regulations
– Source regulation (also called line regulation).

Load regulation: Load regulation is defined as the change in the regulated output voltage when the load current changes from the minimum to the maximum when the input A.C voltage remains constant.

$$\text{Load regulation} = V_{NL} - V_{FL}$$

where, V_{NL} = output voltage at no-load

V_{FL} = output voltage at full-load

For instance, in the regulated power supply designed above, it has 12V across its output when the load is not connected, and, 11.8V when the rated full load is connected. The load regulation of this power supply is given by,

$$\text{Load regulation} = V_{NL} - V_{FL} = 12\text{V} - 11.8\text{V} = 0.2\text{V}$$

Load regulation is generally expressed as a percentage. Percentage regulation is calculated as follows; if

– Regulation (down)
– Regulation (up)

i % Load regulation (Regulation down)

$$= \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

ii Load regulation (Regulation up)

$$= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Tip: The lower the percentage load regulation value, the better is the quality of the power supply.

Line regulation: Line regulation is the change in the regulated load voltage for the specified range of input voltage or line voltage at a constant load resistance.

Line voltage generally means the mains AC supply voltage.

For example, if the output voltage (also referred to as load voltage) changes from 12V to 11.6V when the line voltage changes from 240 to 216V, then the line regulation of the power supply is,

$$\text{Line regulation} = 12\text{V} - 11.6\text{V} = 0.4\text{V}.$$

Line regulation is also generally in percentage as,

$$\%\text{ Line regulation} = \frac{\text{Line regulation}}{\text{Nominal load voltage}} \times 100$$

For the above example,

$$\%\text{ Line regulation} = \frac{0.4\text{V}}{12\text{V}} \times 100 = 3.33\%$$

When AC input voltage changes from 240V to 216V which is 10% down of rated voltage.

Tip: The lower the percentage line regulation the better is the quality of the regulated power supply.

Ripple rejection: Voltage regulators not only regulate or stabilize the output voltage against changes in the load current and input voltage but also reduce or attenuate the ripple that comes with the input voltage.

This is because of the fact that the ripple in the input is equivalent to a change in the input voltage, the voltage regulator reduces the effect of these changes at the output.

Ripple rejection (RR) is expressed as a ratio of the amount of ripple at the output and that at the input. RR is expressed usually in decibels. For example, if RR is specified as 80db, it means that the ripple at the output is 80db or 10,000 times less than the ripple at the input.

With an intention to further reduce the ripple in the regulated output some series regulator circuits use a small value electrolytic capacitor at the output.

Summarising, the advantages of simple series regulators over zener regulator:-

– reduced wattage requirement of zener diode
– reduced output impedance
– increased load and line regulation
– reduced ripple at the output

The necessity for heat sinks and types of heat sinks: The main advantages of a series regulator is the power dissipation in the series transistor:

$$P_D = V_{CE} \times I_C$$

where V_{CE} is collector-emitter voltage

$= (V_{in}) - (V_{out})$ and

I_C is the load current plus divider current.

As long as the load current is not too large, the pass transistor does not get too hot. But where the load current is heavy, the pass-transistor has to dissipate a lot of power.

A heat sink is a metallic heat conducting device (aluminium alloy) placed in close contact with the transistor to increase the dissipation capability of the transistor. Fig 3 shows one type of heat sink, when this is pushed on to the transistor case, heat radiates more quickly because of the increased surface area of the fins.

Fig 3

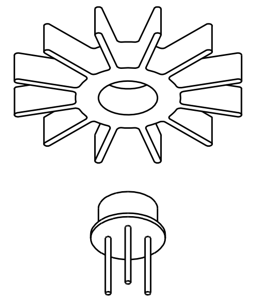


Fig 4 shows a power transistor in which the metal top provides a path out of the transistor for the heat. This metal top can be fastened to the chassis of the electronic equipment. Because the chassis is a massive heat sink, heat can easily escape from the transistor to the chassis. Large power transistors, like the one shown in Fig 4 have the collector connected directly to the case to let the heat escape as easily as possible.

The transistor case is then fastened to the chassis. To prevent the collector from shorting the chassis to the ground, a thin mica washer is used between the transistor case and the chassis alongwith asbestos ferrules.

Fig 4

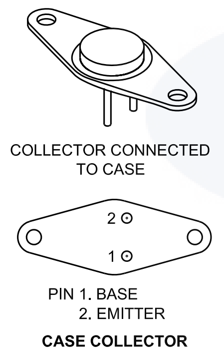
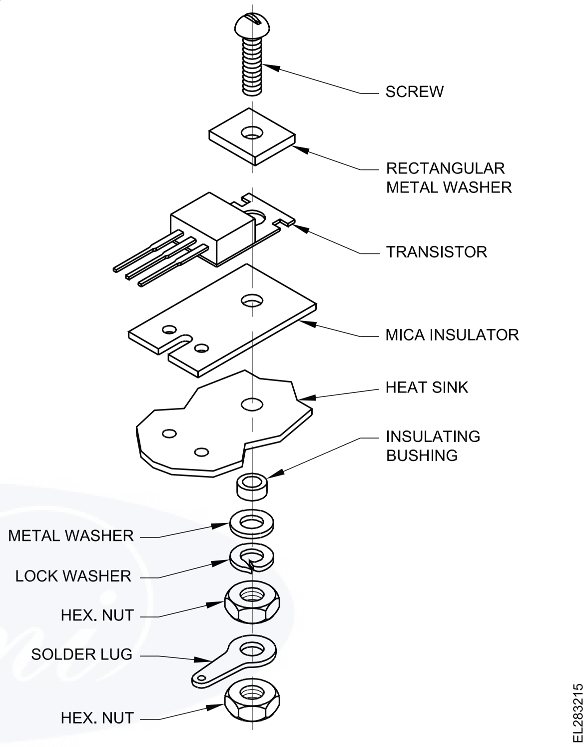


Fig 5 shows that the popular mounting packages for power transistors are the diamond shaped TO-3 and TO-66 types which may have dissipation in the order of 100W.

When the transistor body is to be insulated from the heat sink, the mica insulators are used in between the transistor and the heat sink. The air gap in between the heat sink, mica and the transistor acts as a heat insulator. To provide better conduction and better cooling, heat-sink pastes (silicon grease) are used in between the contact surfaces of the heat sink and the transistor.

Fig 5



Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
- **state the meaning of integrated circuits**
- **state the classification of integrated circuit**
- **state the two main types of IC voltage regulators with examples**
- **design voltage regulators for the required output**
- **modify a fixed voltage regulator to a variable output regulator.**

Introduction

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator.

If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components.

Miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as **Integrated circuits** or **ICs**. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry
   - i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.
   - ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC
   - i Small scale integration (SSI) - consists of 1 to 10 transistors.
   - ii Medium scale integration (MSI) - consists of 10 to 100 transistors.
   - iii Large scale integration (LSI) - 100 to 1000 transistors.
   - iv Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used
   - i Bipolar - carries both electron and hole current.
   - ii Metal oxide semiconductor (MOS) - electron or hole current.
   - iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.

ICs are available in different packages and shapes. The usual packages are:

- dual in the packages DIP
- single in line package SIP and
- metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

TABLE 1

Integrated circuits	Discrete circuits
Advantages	
1 All in a single chip are necessary	All discrete components
2 Required less space due to smaller size	Required more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
Disadvantages	
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

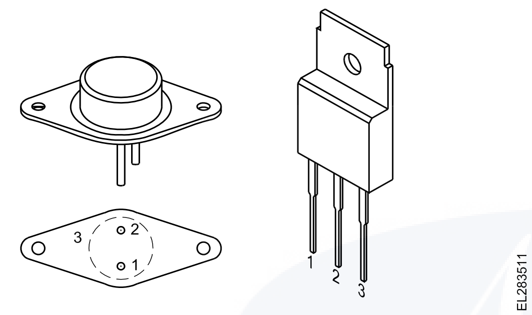
Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

There are two types of voltage regulator ICs. They are,

- Fixed output voltage regulator ICs
- Adjustable output voltage regulator ICs.

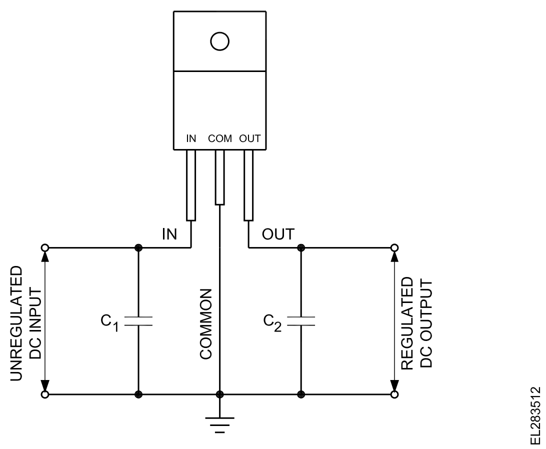
Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as shown in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

Fig 1



These ICs consists of all those components and even more in the small packages shown in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as shown in Fig 2.

Fig 2



The reason behind using capacitor C_1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC.

Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220μF to 1μF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1μF to 10μF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

The most popular three terminal IC regulators are,

1 LMXXX-X series
Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series
Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC μA7812. The table 2 given below lists the specifications of μA7812.

TABLE 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Output voltage: This specification indicates the regulated DC output voltage that can be obtained from the IC. As can be seen from the sample specification table given above, the manufacturer specifies minimum, typical and maximum output voltage. While using this IC take the typical value as this value corresponds to the output voltage at IC under normal input and load conditions.

Output regulation: This indicates the amount by which the output voltage may vary at rated maximum load condition. For example, in μA7812 IC, the output voltage may vary by 4mV from its rated 12V DC when the rated typical load current is 2.2A.

Short circuit output current: This indicates the shorted current I_{SC}, if the output gets shorted. In μA 7812 the output current is limited to 350mA when the output terminals are shorted.

These regulators also use fold back current limiting.

Drop out voltage: For instance, in μA7812 in which the output voltage is +12V, the input unregulated DC voltage to the regulator must be higher than the output voltage. The specification drop out voltage indicates, the minimum positive different between the input and output voltages for the IC to operate as a regulator.

For example, in, µA7812 the unregulated input voltage should be atleast 2 volts more than the regulated DC output of 12V. This means for µA7812 the input must be atleast 14V.

The difference between the voltage across the input and output of the IC should also not to be very high as this causes unwanted dissipation. As a thumb rule, the input voltage to the regulator shall be restricted to a maximum of twice the output voltage of the regulator. For example, for µA7812, the unregulated input voltage should be more than 14V, but less than 24V.

- Ripple rejection

  This indicates the ratio of ripple rejection between the output to input, expressed in decibels,

- Peak output current

This indicates the highest output or load current that can be drawn. Above this rated maximum current the safety of the IC is not guaranteed.

Identification of output voltage and rated maximum load current from IC type number

- 78XX and 79XX series are 3 Terminal voltage regulators.

  All 78XX series are positive output voltage regulators

- All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

Example

Indicates positive output regulator	**7805**	Indicates output voltage is +5V
Indicates negative output regulator	**7912**	Indicates output voltage is –12V

It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX - L indicates rated maximum load current as 100mA.

78MXX - M indicates rated a maximum load current as 500mA

78XX - Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.

78SXX - S indicates rated maximum load current is 2amp.

Example

µPC 78 M 15H

µPC — Indicates positive Fair Child (Manufacturer's code)

78 — Positive regulator

M — Rated maximum load current is 500mA

15H — Indicates Regulated output voltage is 15V

LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX → Fixed –ve voltage regulators.

LM340-X or LM340-XX → Fixed +ve voltage regulators.

Examples

LM 320 - 5

LM — RCA (Manufacturer)

320 — Fixed negative voltage regulator

5 — Output voltage -5V

LM 340 - 15

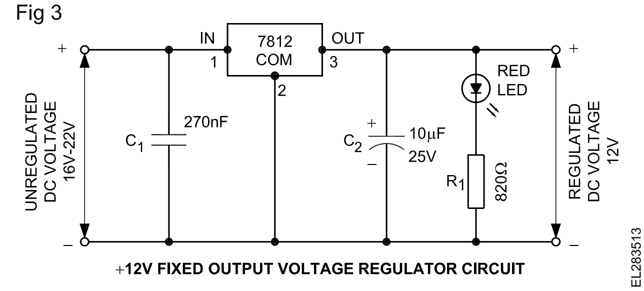
LM — RCA

340 — Fixed positive voltage regulator

15 — Output

Practical 78XX and 79XX voltage regulator: Fig 3 shows the circuit connections of a 12V, 1A regulated power supply using 7812.

Fig 3

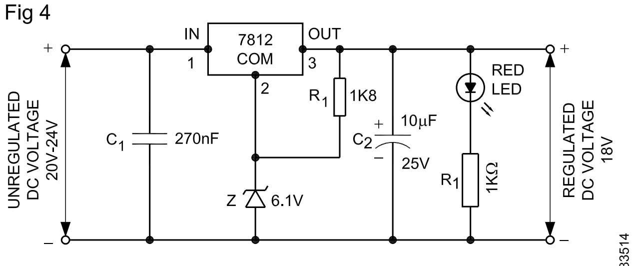


+12V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

The output voltage of a 3-terminal regulator IC is with reference to the IC's common terminal (COM). When the COM terminal is grounded, the output voltage of the regulator will be the specified output voltage of the IC as shown in Fig 3. But the output voltage of the IC can be increased above the specified value by rising the voltage at the COM terminal as shown in Fig 4.

Because of 6.1V zener, the output voltage of the IC can be increased above the specified value by raising the voltage at the COM terminals as shown in Fig 4. Because of 6.1V zener, the output voltage will be 6.1V + 12V = 18.1V or approximately 18V as shown in Fig 4.

Fig 4

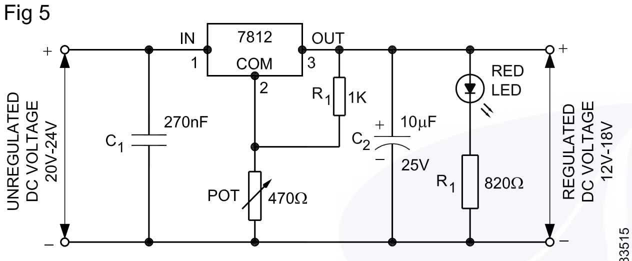


+18V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

When the COM terminal of the IC is grounded as shown in Fig 3, the quiescent current flowing from the COM terminal to ground in 78 series is around 8μA. This current decreases as the load current increases. When a zener is connected at COM terminal as shown in Fig 4, to ensure that the zener is always in the reverse ON condition, resistor R_1 is used. If R_1 = 1.8K, I_z will be 7mA which is sufficient to keep the zener ON always.

Fig 5 shows a variable output voltage regulator. The variable reference voltage at COM terminal is obtained using a POT.

Fig 5



VARIABLE OUTPUT VOLTAGE REGULATOR CIRCUIT

Four-terminal regulators: These are adjustable output voltage regulators and are also available as +ve and -ve regulators. These ICs have internal reference voltages and are protected internally for thermal overload, short circuit etc. Table 1 provides important specifications for most common ICs.

Fig 6

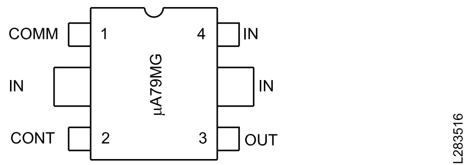


Fig 7

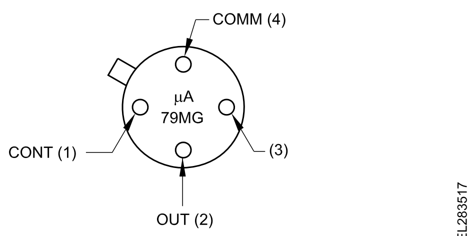


Fig 6 to 8 shows the common ICs used as voltage regulators with their terminal marking and Figs 9 to 11 shows the circuit configuration.

Fig 8

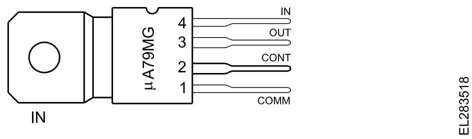


Fig 9

BASIC POSITIVE REGULATOR

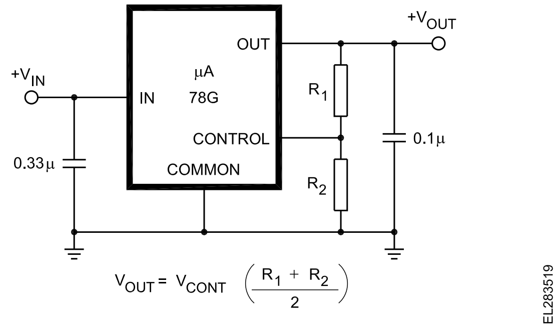


Fig 10

POSITIVE 5 TO 30V
ADJUSTABLE REGULATOR

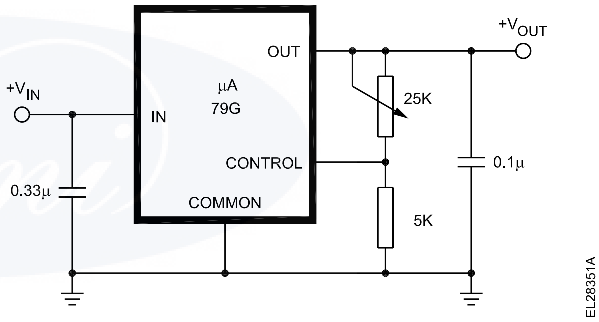


Fig 11

–30V To –2.2V
ADJUSTABLE REGULATOR

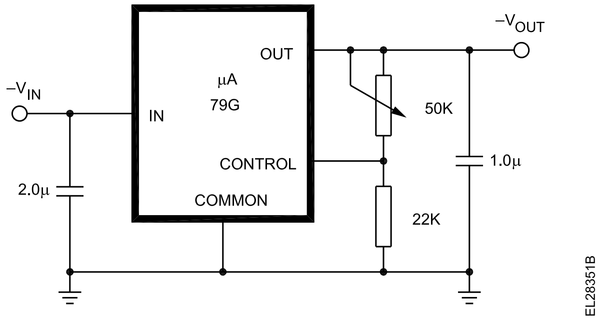


Table 1

Specifications of a 4-terminal voltage regulator

Sl. No.	IC	MA 78G	MA78MG	MA79G	MA79MG
1	Input voltage range	7.5V to 40V	7.5V to 40V	–7V to –40V	–7V to –40V
2	Output voltage range	5V to 30V	5V to 30V	–2.23V to –30V	–2.23V to –30V
3	Line regulation				
4	Load regulation				
5	Drop out voltage	3V	3V	2.5V	2.5V
6	Peak output current	2.2A	800mA	2.2A	–800mA
7	Control pin current	5µA	5µA	2 µA	2µA
8	Short circuit current	750mA	300mA	250mA	100mA
9	Internal reference voltage	5V	5V	2.23V	2.23V
10	Ripple reflection {When the [(V_{IN}) - (V_{OUT})] > 10 V}				

The defects in power supply

Objectives: At the end of this lesson you shall be able to
- **list the activities involved in troubleshooting**
- **list the three general steps involved in troubleshooting**
- **list and explain the two popular methods of troubleshooting**
- **list the possible defects in a simple power supply with filter**
- **state the meaning and use of problem trees (PT)**
- **state the meaning and use of service-flow-diagrams (SFD).**

Introduction

Troubleshooting any equipment or a circuit involves the following activities:

- To identify the exact nature of the problem.
- To identify the section causing the problem.
- To isolate and arrive at the exact cause(s).
- To confirm the causes by necessary tests.
- To replace the problem-causing parts.
- To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting:

1 Physical and sensory tests

a) Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt components.
b) Smell for hot or burning components.
c) Feel with the fingers for unduly hot components.

2 Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

3 Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fail in most cases.

(a) Active high power components

For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.

(b) Active low power components

These are the same as in (a) but are physically small and can handle smaller amounts of power.

(c) High voltage/power passive components

Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/power. They are found in power supplies and output circuits.

(d) Low power passive components

These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohms, microfarads, microhenries, etc.)

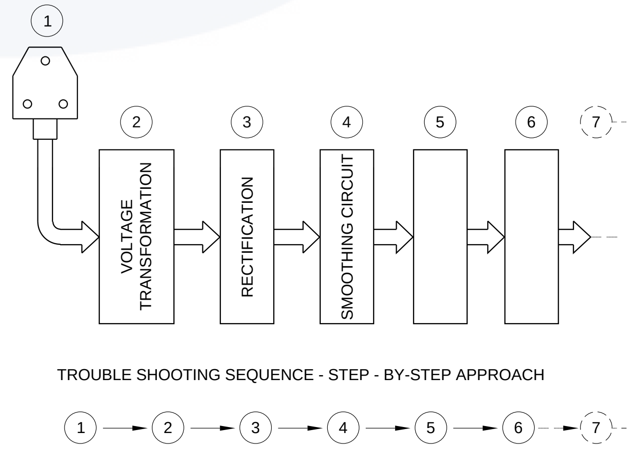
This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting

This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

Fig 1



Although this approach may take more time, this is the most suited approach for the beginners.

Short cut or logical approach method of troubleshooting

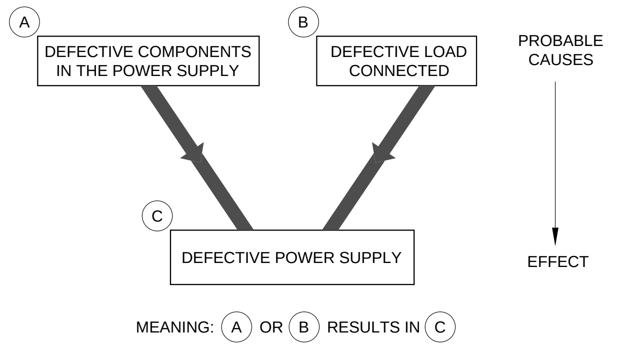
This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. *Divide and conquer* procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting Power supplies

All electronic systems can be broken down into blocks, generally based on their function. Fig 1a shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the problem tree (PT) in Fig 2.

Fig 2



Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

STEP-BY-STEP approach to troubleshoot power supply

In the step-by-step approach of troubleshooting, the various blocks of the power supply shown in Fig 1a and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

LOGICAL approach to troubleshoot power supply

In this approach steps 1 to 4 of the step-by-step approach are the same. The next step is to refer to the *Logical Service Flow Diagram(SFD)* for the identified problem and proceed with the troubleshooting as directed in the SFD.

SFDs are very good tools in troubleshooting as they take into account, the *divide and conquer technique*, thus reducing the overall time taken to troubleshoot the defect in the power supply.

The possible types of defects that can occur in a simple power supply consisting of a bridge rectifier and capacitance input filter are listed below along with their SFD numbers.

Possible defects in a power supply using Bridge rectifier and filter capacitor

[1] No output voltage

This defect in the power supply may be due to one or more component of the circuit. Problem Tree-1(PT-1) given at the end of this lesson for the causes of the problem *No output voltage.*

This PT shows the cause-effect relationship of the defective components with the problem. The cause is given at the top and the effect at the bottom for the only reason that it is a normal tendency to read a page from the top to the bottom.

PT-1 shows two problem trees. The first tree in Chart 1, indicated as Level-1 is a simple tree which gives the level-1 causes of the problem. Level-2 is an extension of the same problem tree, which gives one more level of the causes for the causes given in the simple tree at level-1.

[H.I: Instructor to discuss PT-1 and ensure that trainees clearly understand the need and meaning of PTs.]

Chart 2 at the end of this lesson, shows the sequence to be adopted while servicing a defective power supply. The *Service Flow Sequence -1(SFS-1)* at Chart 2 is self-explanatory. However the following tips make it easy to go trough the SFS.

1] The flow is from Top to Bottom.
2] Rectangular blocks indicate work to be done or action to be taken.
3] Follow the path of the arrow.
4] Diamond blocks indicate a decision to be taken after conducting a test or making a measurement. If the answer to the question in the diamond block is YES, follow the path of YES and continue. If the answer is NO, follow the path of NO and continue.
5] Rounded rectangular block indicates the end of the job.

[2] Low output voltage/ Increased ripple in output

Here, note that two defects are combined. The reason being, that these two defects generally occur simultaneously. If the output voltage is low, the cause(s) for this also results in increased ripple and vice versa.

Ofcourse with one exception that, if the mains level itself is low or if the secondary voltage of the transformer itself is low due to shorted windings, a low output voltage is not associated with increased ripple.

The causes for this defect are given in problem tree PT-2 in Chart 3. Chart 4 shows, the service flow diagram(SFS-2) for servicing the defect.

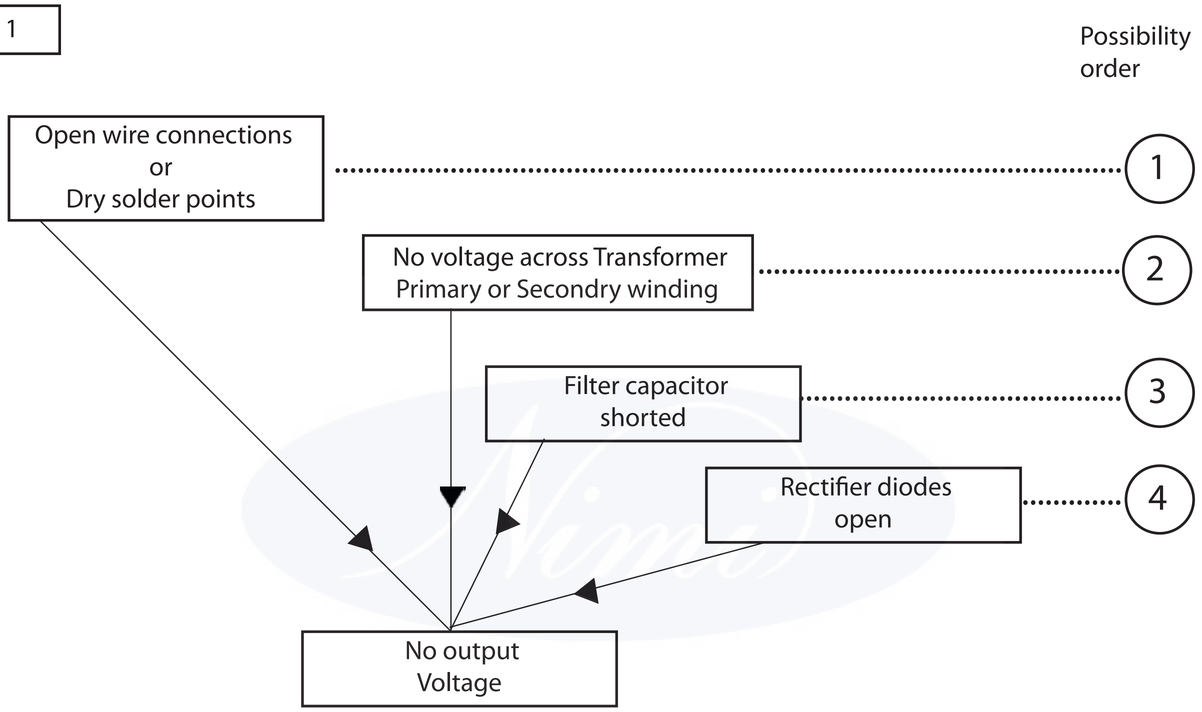
The SFSs and PTs for a fullwave rectifier with a capacitance filter is almost similar to that of a bridge rectifier. However, it is suggested that the trainees shall make SFSs and PTs for a fullwave rectifier power supply on their own for practice and better understanding of the method.

Problem Tree - PT1

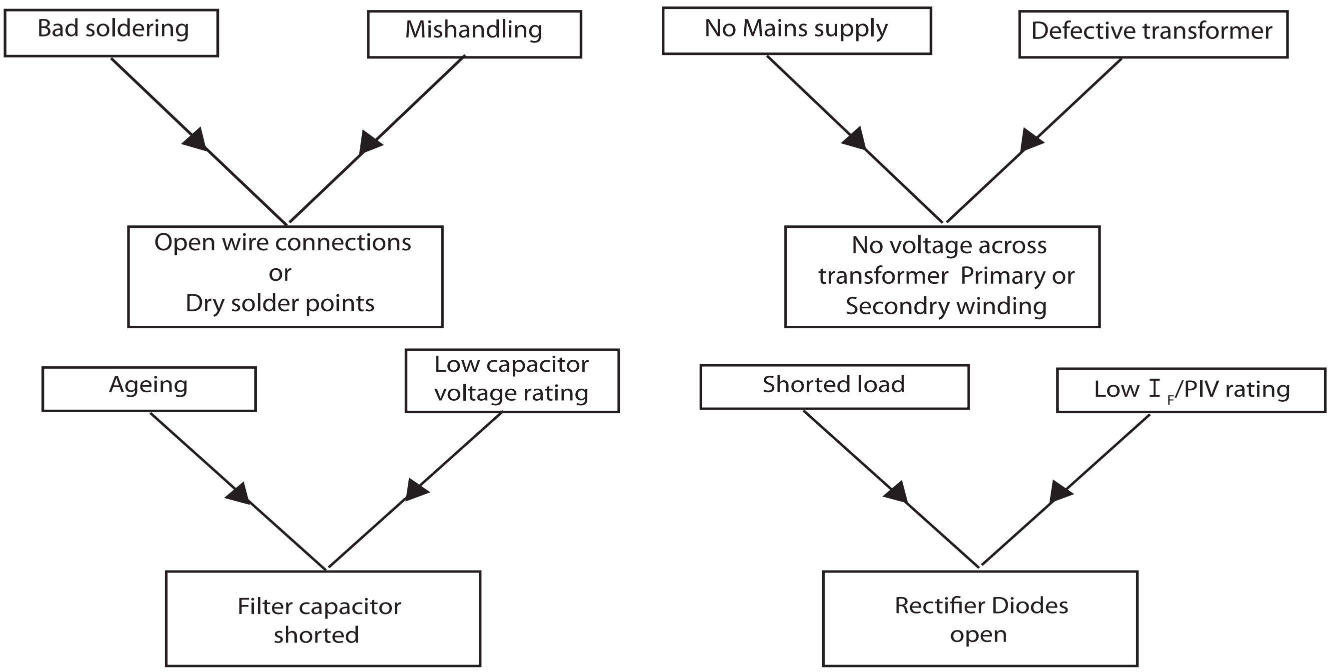
NATURE OF DEFECT : **No Output voltage**

TYPE OF SYSTEM : **Bridge rectifier with capacitor filter**

LEVEL 1

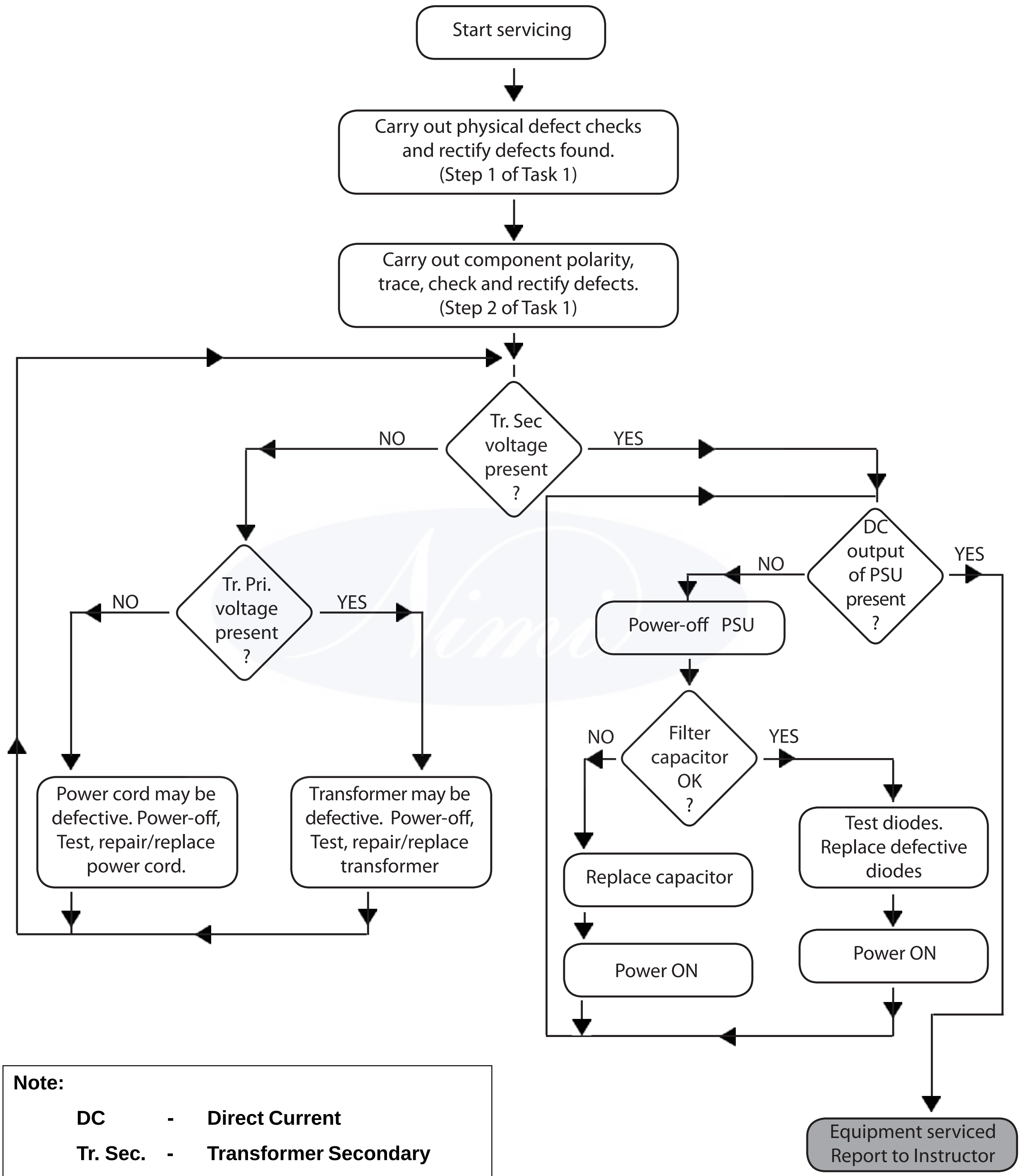


LEVEL 2



Service flow sequence (SFS-1)

NATURE OF DEFECT : **Defective power supply with NO OUTPUT VOLTAGE**



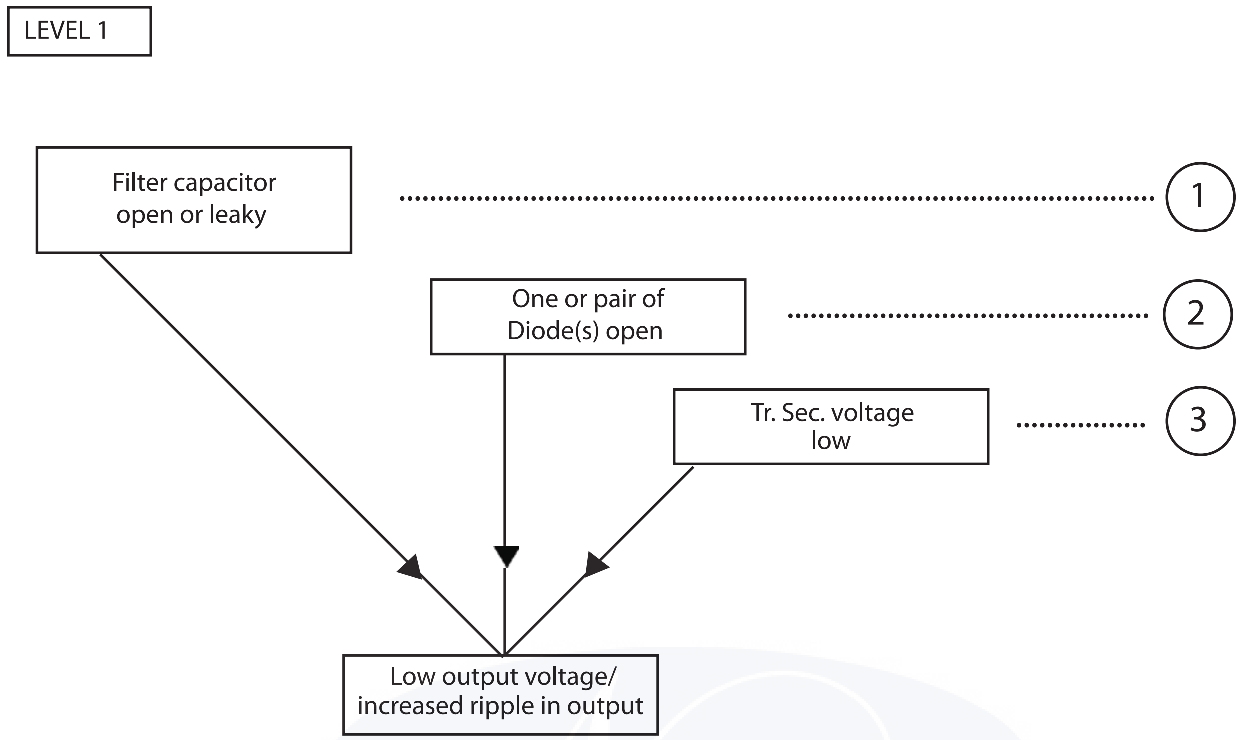
Note:

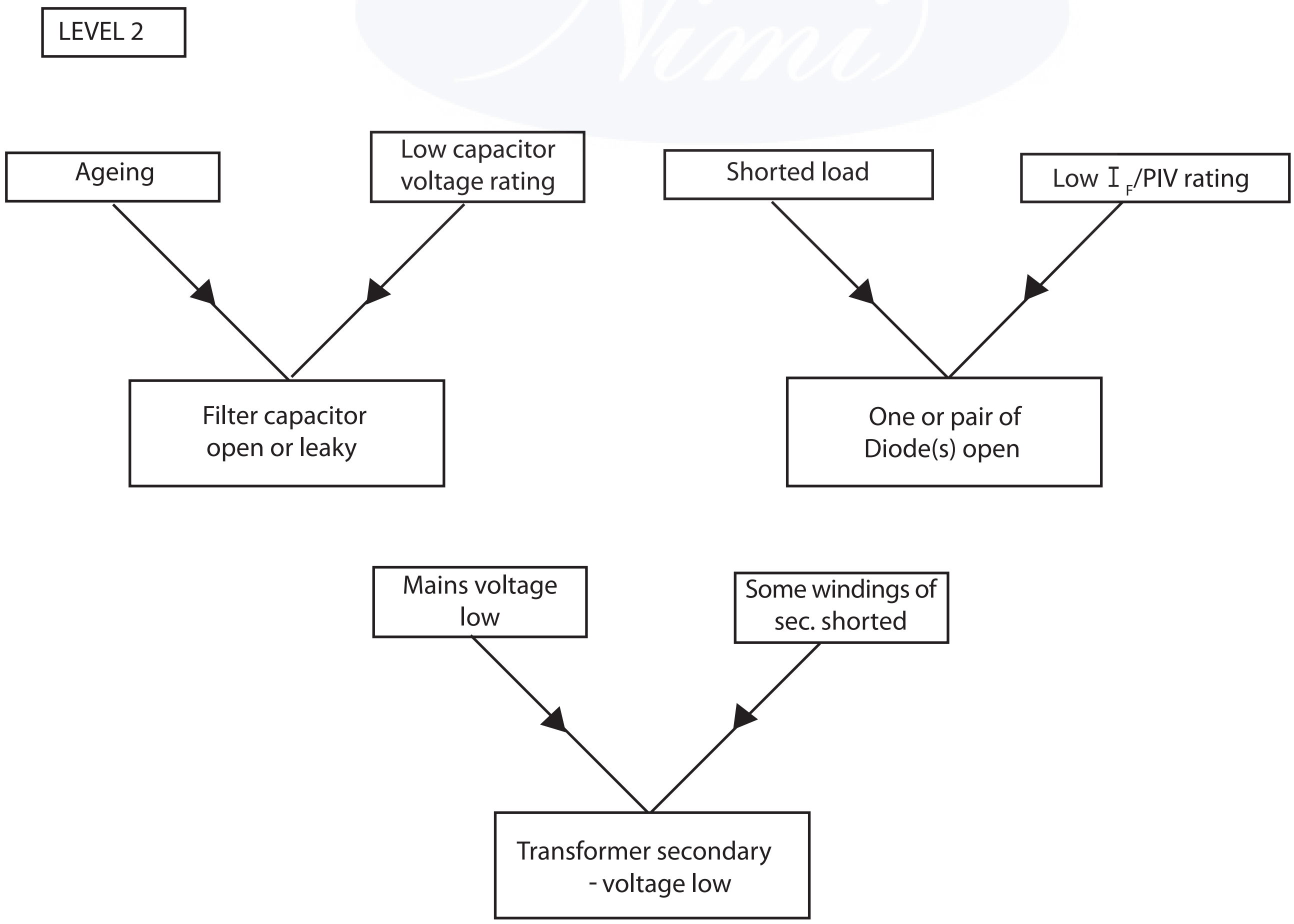
DC	**-**	**Direct Current**
Tr. Sec.	**-**	**Transformer Secondary**
Tr.	**-**	**Transformer**
Pri.	**-**	**Primary**
Sec.	**-**	**Secodary**
PSU	**-**	**Power Supply Unit**

Problem Tree - PT2

NATURE OF DEFECT : **Low Output DC/Increased ripple**

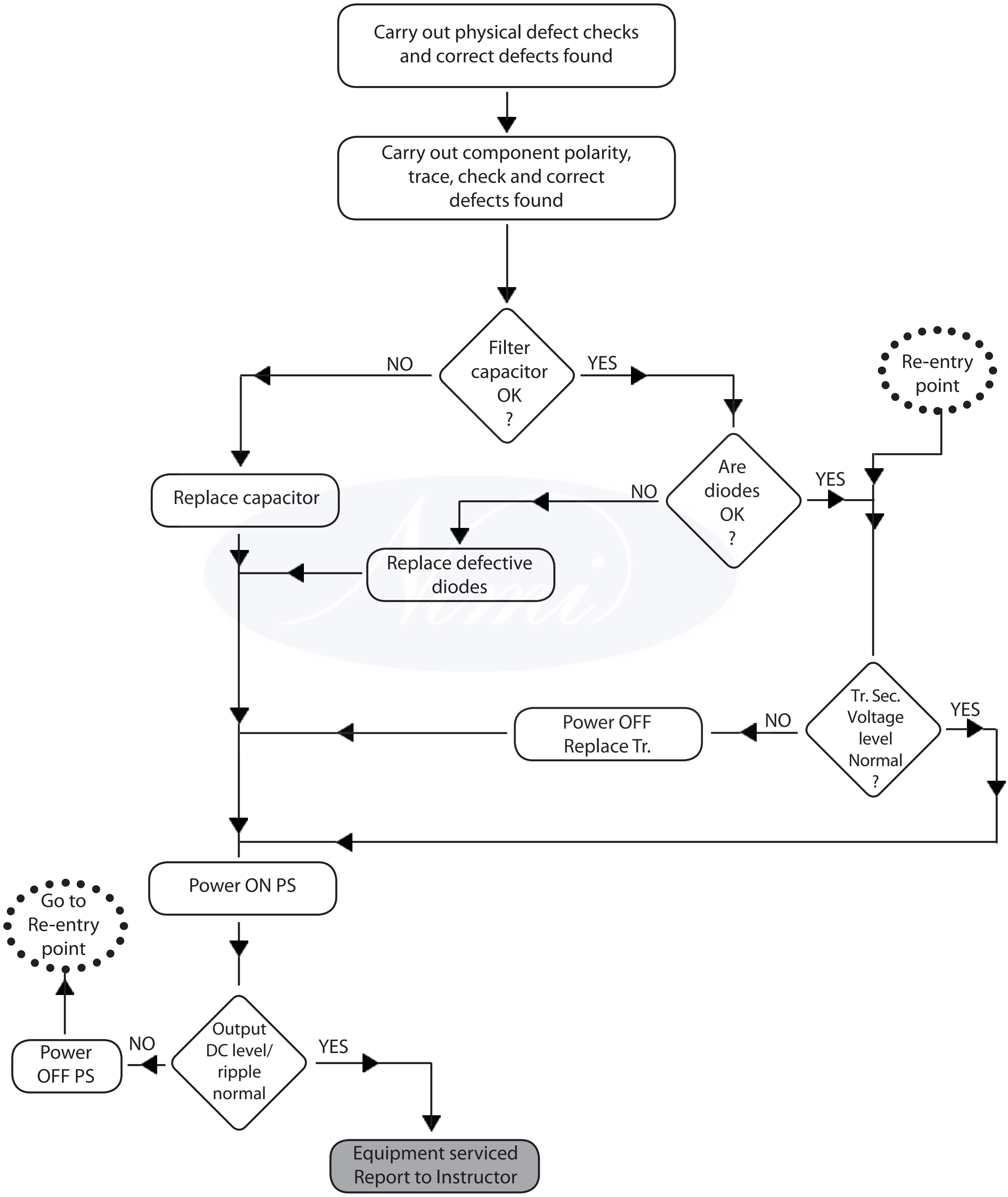
TYPE OF SYSTEM : **Bridge rectifier with capacitor filter**





Service flow Sequence (SFS-2)

NATURE OF DEFECT : **Low output DC/ Increased ripple**



The characteristics of SCR

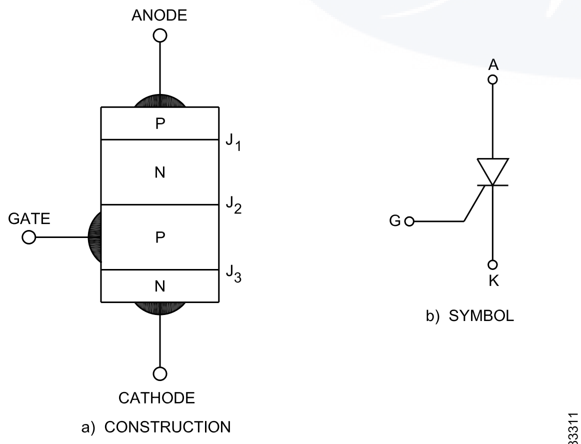
Objectives: At the end of this lesson you shall be able to
- **state the purpose of using SCR**
- **explain its construction**
- **state the working of SCR**
- **state the characteristics of SCR**
- **state the application of SCR**
- **state the triggering of SCR**
- **state the method of testing SCR with a multimeter.**
- **state the disadvantages in mechanical switches**
- **explain how the SCR can be used as a electronic ON/OFF switch**

Introduction

Thyristors is four layer, three junction and three terminal semi conductor active device which can be switched 'on' or 'off' electronically to control relatively large amounts of current for motors and other electrical equipments. The Silicon Controlled Rectifier (SCR) and the triac are examples of thyristor. Almost all electronic controls used in modern industries consists of electronic circuits with thyristors.

Construction of SCR: The cross-sectional view of a typical SCR and the symbol are shown in Fig 1. Basically, the SCR consists of a four-layer pellet of P and N type semiconductor materials. Silicon is used as the intrinsic semiconductor to which the proper impurities are added.

Fig 1



SILICON CONTROLLED RECTIFIER

The SCR is a four-layer device with three terminals, namely, the anode, the cathode, and the gate.

Working of SCR:

Holding and latching currents: The holding current (I_h) is the minimum forward current necessary in the anode circuit to maintain the SCR in conduction state while it is ON. The latching current (I_Z) is the minimum forward current required to switch the SCR ON from the OFF condition. This I_L is typically about three times more than the holding current.

When the anode is made positive with respect to the cathode (Fig 1), junction J_2 is reverse-biased and only the leakage current will flow through the device. The SCR is then said to be in the **forward blocking state** or **off-state**. When the anode-to-cathode voltage is increased, the reverse-biased junction J_2 will break down due to the large voltage gradient across the depletion layers. This is the avalanche breakdown. Since the other junctions J_1 and J_3 are forward-biased, there will be free carrier movement across all the three junctions, resulting in a large anode to-cathode forward current I_F. The voltage drop V_F across the device will be the ohmic drop in the four layers, and the device is then said to be in the **conduction state** or on-state.

In the on-state, the current is limited by the external impedance. If the anode-to cathode voltage is now reduced, since the original depletion layer and the reverse-biased junction J_2 no longer exist due to the free movement of the carriers, the device will continue to stay on. When the forward current falls below the level of the holding current I_h, the depletion region will begin to develop around J_2 due to the reduced number of carriers, and the device will go to the blocking state. Similarly, when the SCR is switched on, the resulting forward current has to be more than the latching current I_L.

This is necessary for maintaining the required amount of carrier flow across the junctions; otherwise, the device will return to the blocking state as soon as the anode-to-cathode voltage is reduced. The holding current is usually lower than, but very close to the latching current; its magnitude is in the order of a few milliampere(mA). When the cathode is made positive with respect to the anode, junctions J_1 and J_3 are reverse-biased, and a small reverse leakage current will flow through the SCR. This is the **reverse blocking state** of the device.

When the SCR is reverse-biased the device will behave in the same manner as two diodes connected in series with the reverse voltage applied across them. The inner two regions of the SCR will be lightly doped as compared to the outer layers.

Hence, the thickness of the J_2 depletion layer during the forward-bias condition will be greater than the total thickness of the two depletion layers at J_1 and J_3 when the device is reverse-biased. Therefore, the forward break-over voltage V_{BO} will be generally higher than the reverse break-over voltage V_{BR}.

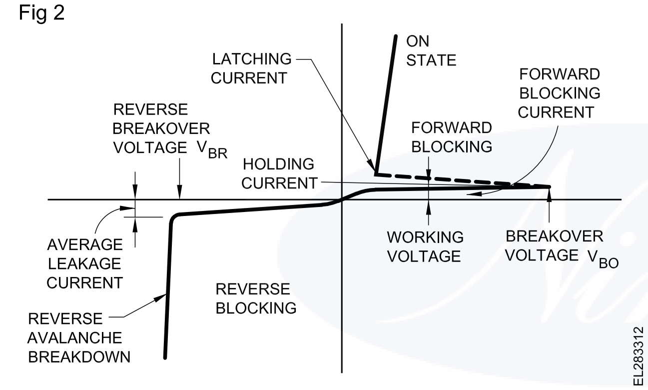
SCR has two stable and reversible operating states. The change over from off-state to on-state, called turn-on, is achieved by increasing the forward voltage beyond V_{BO}. There reverse transition, termed turn-off, is made by reducing the forward current below I_h. A more convenient and useful method of turning on the device employs the gate drive.

Characteristics of SCR

SCR voltage current characteristic: Fig 2 shows the voltage current characteristic of an SCR whose gate is not connected(open). When the anode-cathode circuit is reverse biased a very small current in micro ampere called reverse blocking current flows through the SCR. When the reverse break over voltage reaches a value equivalent to peak reverse voltage V_{BR}, the SCR conducts due to reverse avalanche breakdown and the current increases sharply into ampere.

In most of the cases the SCR gets damaged in this mode. The behaviour of the SCR at reverse bias mode is shown by VI characteristic of Fig 2.

Fig 2



When the SCR is forward biased, there is small forward leakage current (as shown in Fig 2) called forward blocking current which remains small, until the forward breakdown voltage V_{BO} is reached. This is the forward avalanche region.

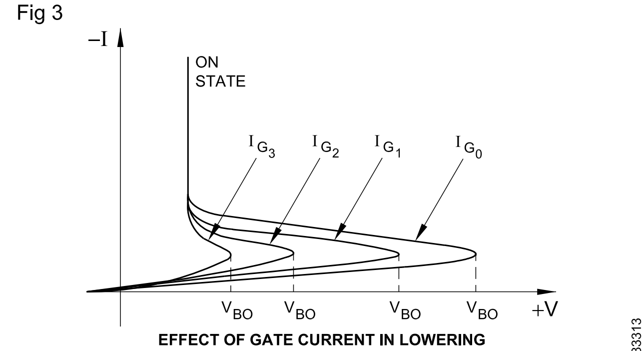
At that point current increases suddenly to higher conduction level. At this point the anode to cathode resistance of the SCR becomes very small and the SCR acts like a closed switch. The voltage across the SCR drops to about 1.4V.

Hence we can say that in forward bias mode when the applied voltage is less than B_{FO} the SCR behaves as open switch and when the applied voltage exceeds B_{FO} the SCR behaves as closed switch. The current through SCR is limited by the external load resistance.

Triggering of SCR: SCR can be switched into conduction either by increasing the forward voltage beyond V_{BO} or by applying a positive gate signal when the device is forward-biased. Of these two methods, called the gate-control method, is used as it is more efficient and easy to implement for power control.

Gate-current control: Injecting gate current into the SCR lower the breakover voltage, as shown in Fig 3. Here I_{GO} is for zero gate current. This situation is the same as that shown in Fig 2, but the other examples in Fig 3 are for increasing gate current. Note that, as gate current is increased, the breakover voltage is reduced.

Fig 3



EFFECT OF GATE CURRENT IN LOWERING THE BREAKOVER VOLTAGE OF AN SCR

When there is enough gate current, the break over voltage becomes lower than the operating voltage or the forward blocking voltage of the SCR. That is how the SCR is used. The injection of gate current lower the break over voltage to a value below that of the applied voltage, thereby turning the SCR on.

Note that the 'ON' state is the same for all different values of gate current in Fig 3. The gate current triggers the SCR'on'; but when the SCR conducts the amount of forward current is determined by the anode circuit impedance.

Applications: The following are the major applications of SCR

- Power control
- Over voltage protection
- Time delay circuit
- Soft start circuit
- Logic and digital circuits
- Pulse circuits references
- Phase control in AC power control
- full-wave control circuit
- Speed control of motors
- Regulated DC power supplies
- DC motor control

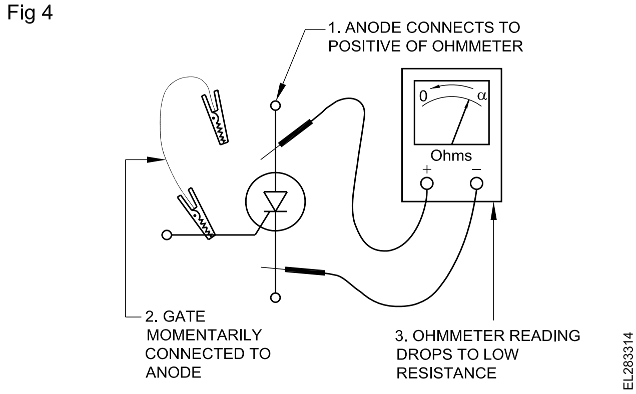
Testing of SCR by multimeter

SCR can be tested in the multimeter in the following sequence.

Set the multimeter to a low range. Adjust to zero and infinity with the adjustment knob. Connect the SCR as shown in Fig 4. The meter will not indicate any reading. Even the test prods are interchanged because of the junctions. The multimeter shows infinite resistance. Connect the SCR as shown in Fig 4.

When the gate is touched momentarily with the anode prods, the meter reads low resistance between 30 and 40ohm. When the gate is removed, the meter still continues to read the same value of 30 and 40 Ohms.

Fig 4



This means that the SCR is in good working condition. If the meter does not show any reading, the SCR is faulty. When the gate is given a small forward bias, the gate switching the SCR and the internal resistance of the junction is low, so the current can flow easily from the cathode to the anode.

Once the SCR is conducted, even if the gate's forward bias is removed, the SCR anode-to-cathode current will flow through the meter, and the multimeter will continue to read a low resistance, ie 30 to 40ohm.

SCR as a ON/OFF switch

Mechanical ON/OFF switches have the following main disadvantages;

- Heavy arcing between mechanical contacts due to load current
- Low reliability
- higher cost of operation
- limited life

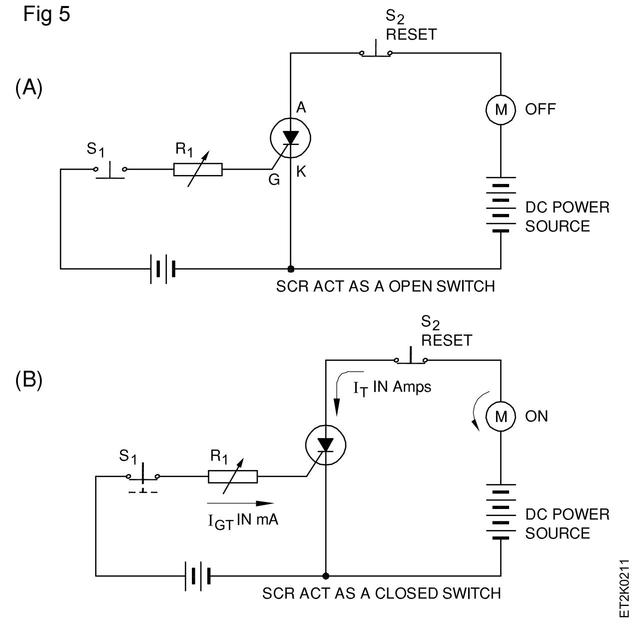
SCR can be used as an electronic switch and it overcomes all the disadvantages of mechanical on/off switches. The major advantage of using SCR as a switch is that a small current(gate current) can be used to control a large load current. This is illustrated in Fig 5 below;

As seen in Fig 5a, as long as the gate trigger is not applied (S1-off), SCR is in OFF state(as if SCR is a switch put in OFF position).With SCR off, there is no current in the load and hence the motor is off.

When the motor is to be switched-on, a small current of the order of a few milliampers is applied to the gate of the SCR by momentarily pressing the switch S_1 as shown in Fig 5b. This small gate current in mA turns-on the SCR and SCR fires into conduction allowing several amps of current to flow through it and the motor.

In this condition SCR behaves almost as a short circuit with a drop across the SCR as low as 0.2(as if SCR is a switch put to ON position). Once the SCR is turned-on by

Fig 5



the gate current, gate loses its control and therefore gate current may be switched-off.

When the motor is no more required to be ON, the reset switch S_2 is pressed which cuts off the load current and hence the SCR returns to OFF state.

Two important points to remember in the above circuit are;

- the gate trigger current should not be less than the required gate trigger current(I_{GT}) as specified for the SCR used.

Example: For MCR 218-5 SCR, I_{GT} is between 10 to 25mA.

Also the gate trigger current should not be more than the forward gate peak current(I_{GM}) specified for the SCR used.

Example: For MCR 218-5 SCR, I_{GM} is 2 Ampers.

- The load connected in series with the SCR should draw a minimum load current at least slightly greater than the SCR holding current (I_H). Otherwise the SCR will not remain in conduction even if it is turned on by the gate current.

Example: For MCR 218-5 SCR, I_H is 30mA. Therefore the load connected should draw at least 30mA from the supply.

Also, the load should not draw current more than the specified maximum forward current or on-state current(I_T) of 8 Amperes.

The Uni-Junction Transistor (UJT)

Objectives: At the end of this lesson you shall be able to
- **explain the construction, equivalent circuit and symbol of an UJT**
- **explain the working of UJT and its characteristic**
- **explain the term intrinsic stand off ratio**
- **explain the function of UJT as relaxation oscillator.**

UJT is an unijunction three terminal semi conductor active device.

The uni-junction transistor (UJT)**:** The uni-junction transistor consists of a bar of lightly doped n-type silicon with a small piece of heavily doped P-type material joined to one side at 60% of height from the base as shown in Fig 1a.

The end terminals are named as base 1 (B_1) or Cathode (K) and base 2 (B_2) or anode (A) and the P-type material as emitter (E). The highly doped n-type material has a high resistance and can be represented by two resistors r_{B1} and r_{B2}. The sum of r_{B1} and r_{B2} is designated as R_{BB} (Refer Fig 1b).

The emitter (P-type) form a PN junction with the n-type silicon bar and this junction is represented by a diode in the equivalent circuit (Fig 1b). The circuit symbol is shown in Fig 1c.

When the voltage V_{B1B2} is applied as shown in Fig 1b, the voltage at the junction r_{B1} and r_{B2} is

$$V_1 = V_{B1} \text{ x } V_{B2} \text{ x } \frac{V_{B1}}{r_{B1} + r_{B2}}$$

$$= V_{B1B2} \text{ x } \frac{r_{B1}}{r_{CB}}$$

Where $r_{B1} + r_{B2} = R_{BB}$

V_1 is also the voltage at the cathode of the diode representing the PN junction while the emitter terminal is open circuited the only current flowing is

$$I_{B2} = \frac{V_{B1B2}}{R_{BB}}$$

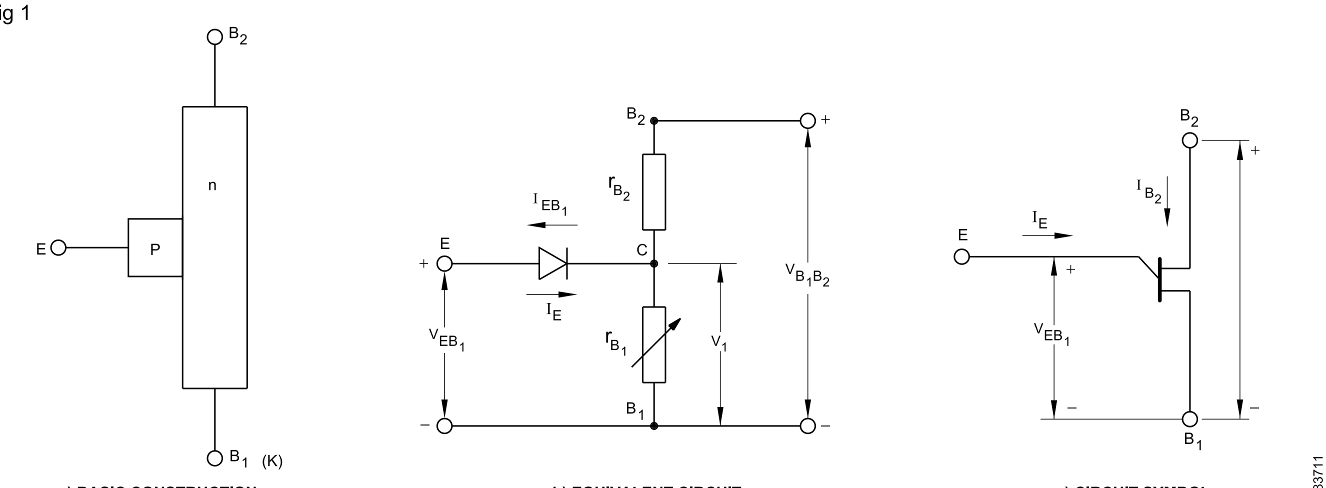
If the emitter terminal is grounded, the PN junction is reverse biased and a small reverse current I_{EO} flows. This is shown as point 1 in the characteristic curve. (Fig 2)

Let us consider the effect of applying an input voltage V_{EB1} across the B_1 and E. Assume V_{EBC} is increased from zero. As V_{EBS} becomes equal to V_1, I_{EO} will be reduced to zero. This happens due to equal voltage at junction. This occurs at point (2) of the characteristic curve shown in Fig 2. With further increase of V_{EB1}, the PN junction is forward biased, and a forward emitter current I_E begins to flow from the emitter terminal into the silicon bar.

When this occurs the charge carrier are injected into the r_{B1} region of the silicon bar. Since the resistance of a semiconductor depends upon the doping level, the introduction of charge carrier curve cause the resistance of r_{B1} to rapidly decrease.

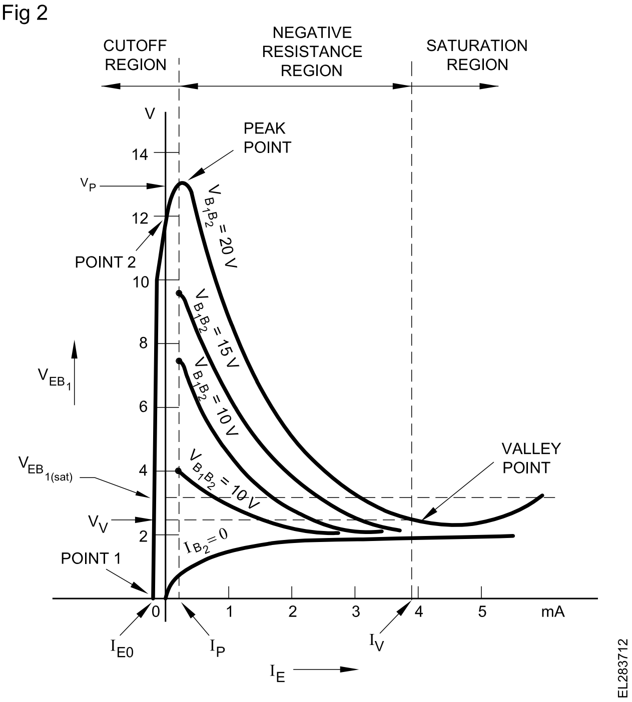
Consequently the voltage drop across the r_{B1} also decreases, causing the p-n junction to be more heavily forward biased. The drop in voltage across r_{B1} is indicated in the characteristic curve shown in Fig 2.

Fig 1



a) BASIC CONSTRUCTION b) EQUIVALENT CIRCUIT c) CIRCUIT SYMBOL

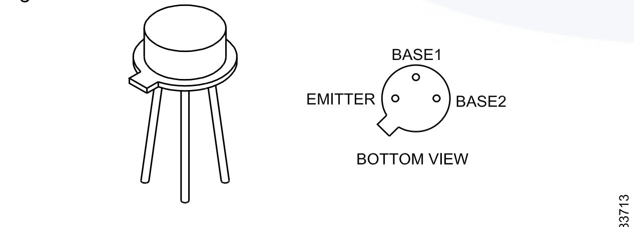
Fig 2



The decrease of voltage V_{EB1} to a point called 'Valley Point' and the input current I_E is increased to a limit determined by the source resistance. The device remains in this 'ON' condition until the input is open circuited or until I_E is reduced to a very low level.

UJT characteristic curve (Fig 2) shows the relation between emitter current and emitter voltage at different levels of supply voltage whereas Fig 3 shows the UJT encapsulation.

Fig 3



UNIJUNCTION TRANSISTOR METAL CAN-TYPE ENCLOSURES AND TERMINALS

Intrinsic stand-off ratio η: The intrinsic stand-off ratio, which is represented by the symbol η (Greek letter η), simply defines the ratio of r_{B1} to R_{BB}. Together with V_{B1B2} and the emitter junction voltage drop V_D, η also determines the peak voltage V_P for the UJT.

$$V_1 = V_{B1B2} \times \frac{r_{B1}}{r_{B1} + r_{B2}} = \eta V_{B1B2}$$

and the peak voltage V_P is $V_D + V_1$. That is,

$$V_P = V_D + \eta V_{B1B2}$$

V_D is the forward voltage drop of a silicon diode, typically 0.7V.

Example

Determine the minimum and maximum emitter voltages at which a 2N4948 UJT will trigger on (or fire) when V_{B1B2} = 30V.

Solution

From data book η = 0.55 minimum and 0.82 maximum

From Eq. 1 $V_P = V_D + \eta V_{B1B2}$

$V_{P(min)}$ = 0.7V + (0.55 x 30) = 17.2V

$V_{P(max)}$ = 0.7 + (0.82 x 30) = 25.3V and

Therefore, the device will fire at some emitter voltage between 17.2V and 25.3V.

Application of UJT: The UJT could be used as a relaxation oscillator to generate saw tooth wave forms as shown in Fig 4. The circuit comprises of an UJT, a capacitor and resistor of suitable values. As shown in Fig 4, the capacitor C_1 charges via resistor R_E.

When the capacitor voltage reaches V_P, the UJT is (on) fires and rapidly discharges C_1 to $V_{EB(sat)}$. The UJT then cuts off and the capacitor starts to charge again. The cycle is repeated continuous by generating a saw tooth wave form across C_1.

The time 't' for the capacitor to charge from $V_{EB(sat)}$ to V_P can be calculated, and the frequency of the saw tooth determined approximately as 1/t.

The discharge time td is difficult to calculate because the UJT is in its negative resistance region and its resistance is changing. However the time td is very much less than t and can be neglected for approximation.

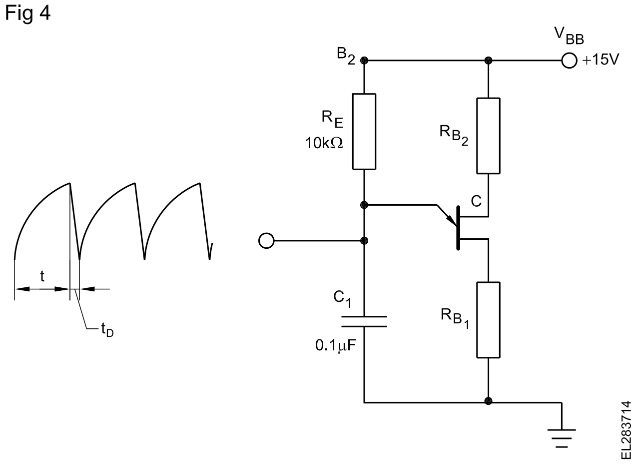
Fig 4 In the UJT relaxation oscillator, capacitor C_1 charges up to the device triggering voltage. The UJT then switches on and discharges the capacitor.

The general equation for the charging time of a capacitor charged via a series resistor is

$$\text{where } t = CR_{in} \frac{E - E_o}{E - e_c}$$

C = capacitance in farads
R = resistance in ohms
E = supply voltage
e_c = capacitor voltage at time t
E_o = initial voltage on capacitor

Fig 4



Example

The relaxation oscillator in Fig 4 uses a 2N4948 UJT. Calculate the typical frequency of oscillation.

Solution: When the UJT fires, the capacitor voltage is

$$e_c = V_P$$

$$\text{From Eq.1 } e_c = V_D + \eta V_{B1B2}$$

From the data book, a typical value of the intrinsic stand-off ratio might be $\eta = 0.7$. Also, $V_D = 0.7$ V. Accordingly,

$$e_c = 0.7V + (0.7 \times 15V) = 11.2V$$

Once the UJT fires, the capacitor is discharged to $V_{EB(sat)}$, which is the capacitor voltage E_o at the start of each charging cycle. For the 2N4948, $V_{EB(sat)} = 2.5V$ typically.

$$\text{So, } E_o = 2.5V$$

$$\text{From Eq.(2) } t = CR_{in} \frac{E - E_o}{E - e_c}$$

$$t = 0.1\mu F \times 10\,k\Omega \times \ln \frac{15V - 2.5V}{15V - 11.2V}$$

$$= 3.2ms$$

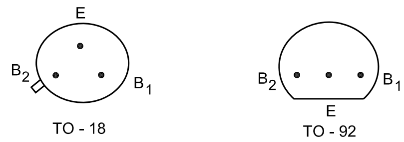
The frequency is

$$f = \frac{1}{t} = \frac{1}{3.2ms} = 312.5Hz$$

Testing UJT: The details as available from data book for two numbers of UJT is given in Table 1 below for your reference and Fig 5 shows the bottom view.

While testing UJT with the help of a multimeter first be sure about the +ve and -ve polarities of the multimeter. Once you are sure about the +ve and -ve polarity.

Fig 5



U.J.T BOTTOM VIEW

EL283715

Test leads of the multimeter, proceed to test the UJT as suggested in the Table 2 and the expected results are also given in Table 2.

Table 1

Unijunction Transistor (UJT)

Transistor No.	P.D W	I_e mA	V_{B2} E V	V_{B2} b_1 V	R_{B1B2} kΩ	Package
2N2646	0.3	50	30	35	47 - 9.1	TO-18/92
2N2647	0.3	50	40	45	4.7 - 9.1	TO-18/92

Table 2

B_1	B_2	E	Reading of ohmmeter for a good UJT
+ve	–ve	Open	4.7 - 9.1kΩ
-ve	+ve	Open	4.7 - 9.1k
+ve	Open	–ve	Very high
-ve	Open	+ve	2 - 4 kΩ
Open	+ve	–ve	Very high

Application of UJT as time delay circuit using SCR

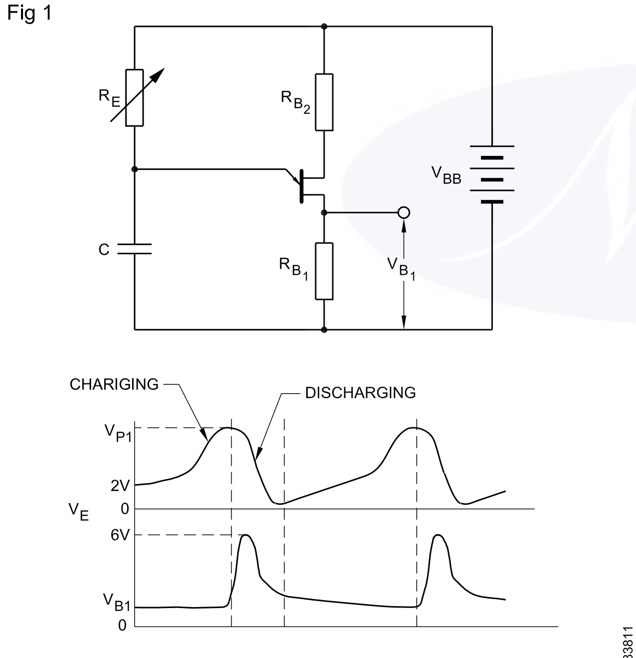
Objectives: At the end of this lesson you shall be able to
- **list the use of UJT in electric circuit**
- **state the method of varying oscillator frequency**
- **explain the method of triggering SCR through UJT band relaxation oscillator.**

Application of UJTs: UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

- triggers for thyristors
- as oscillators
- as pulse and sawtooth generators
- timing circuits
- regulated power supplies
- bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R_1 with respect to the relaxation oscillator shown in Fig 1.

Fig 1



UJT AS RELAXATION OSCILLATOR

The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 1 to develop a relaxation oscillator.

The wave form developed across the capacitor is shown in Fig 1 as V_E, whereas the waveform produced across the resistor R_{B1} is shown as a pulse V_{B1}.

The frequency of oscillation

$$f = \frac{1}{R_E C}$$

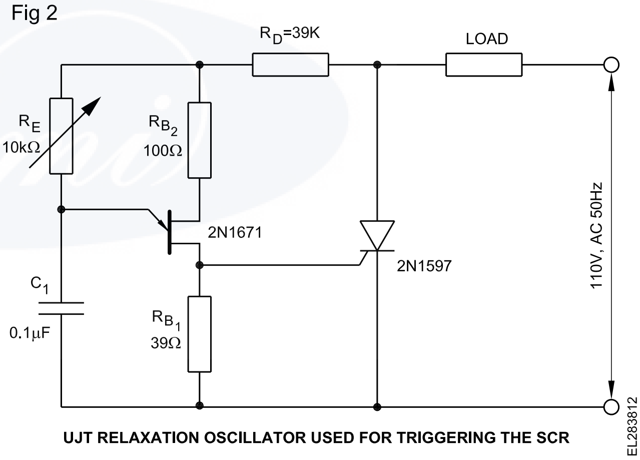
Where R_E is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of R_E, the frequency of the oscillator can be varied. Although such an oscillator using a DC supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current.

Time Delay (Triggering) Circuit

Fig 2 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

Fig 2



UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR

The low output impedance of the UJT (39ohms) is ideal for driving the SCR, which has a relatively low input impedance from gate to cathode.

Resistor R_D is used as a dropping resistor to restrict the peak voltage across the UJT to within its specifications.

By varying the variable resistor R_E the oscillator frequency can be varied thereby the frequency of trigger pulses which are used to trigger the SCR. Time used for delay in switching the SCR could be measured through a slip watch from the time of switching on.

Heating appliances

Objectives: At the end of this lesson you shall be able to
- **list the names of some common appliances working on the heating effect of electric current**
- **name the common materials, used in heating elements**
- **state the factors on which heating in such appliances depend**
- **state the normal temperature range of the heating appliances**
- **state the rules to be followed while installing and testing domestic heating appliances.**

Application of heating effect

Heat is produced by electricity when current flows through the resistance. This heat producing effect of electricity is utilized in heating appliances such as heater, iron, hot plate, kettle, toaster etc.

In heat producing appliances, instead of using a good conductor for the heating element, we use resistance wires such as Nichrome or Eureka. The current which flows through the high-resistance heating element of the appliance, produces the heat that is desired.

These materials must be able to withstand high temperatures without melting. The resistance must be constant (low temperature resistance coefficient) over a wide temperature range, and expansion due to heat must be held to a minimum (low coefficient of expansion) to prevent sagging and consequent short circuiting.

Alloys are used generally in heating elements. For heating elements that are surrounded by air and where temperatures in excess of 1035°C are not required, a composition of chromium and nickel has been found to be the most durable resistor.

Nickel-chromium alloys, called **Nichrome wire**, when operated within their designed temperature limits, will last for years without any noticeable deterioration. In industries where constant temperature is required alloys like Eureka and Kanthal are used.

Factors on which heating in the appliance depends

1 Current flow in the heating element.
2 Resistance of the element.
3 Time duration of heating.
4 Ventilation i.e. cooling rate due to draught.
5 Proximity of element turns with each other.
6 Shape of the element (Circular wire or ribbon).

All heating appliances are not working at the same condition or temperature. If an electric kettle is operated without water, the life of the heating element reduces considerably, whereas an open type heater element can withstand the heat. The normal temperature of the heating element of appliances lies between 550 ^{0}C to 900^0 C.

Heating elements are of two types.

– Bare element
– Closed insulated type

An electric stove has a bare type element. (Fig 1a) Closed insulated types are used in immersion heaters, kettles, hotplates etc. (Fig 1b)

Fig 1a

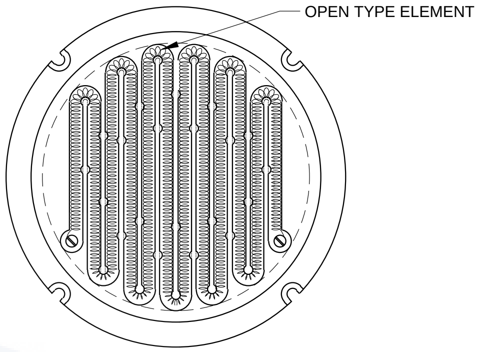
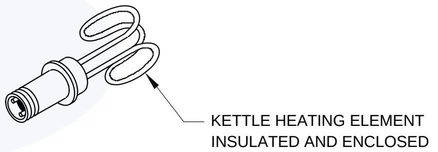


Fig 1b



If the domestic appliances are purchased after ascertaining BIS mark, properly installed, effectively tested and regularly maintained, they give a long trouble-free service. If the I E rules given below are followed, the shocks and the electrocution deaths, that occur in many houses, could be totally avoided.

Rules to be followed in installing, domestic heating appliances. (Reference: National Electric Code)

1 Bare element heaters are not recommended to be used as there is a potential danger of getting a shock. When used the elements should be protected by a metal guard which should have effective earth connection.

2 All the plugs and sockets shall be of 3-pin type, one of the pins being connected to earth.

3 Means shall be provided for proper double earthing of all apparatus and appliances in accordance with BIS 732 and 3043-1987.

4 Metal bodies of hotplates, kettles, toasters, heaters, ovens and water boilers shall be earthed by the use of three-pin plugs. However, if fixed wiring has been used for earthing these appliances , the green coloured cable of the three-core cable is to be connected to the earth pin.

5 The body of automatic electric water heaters shall be earthed by the use of a three-pin plug or by a separate earth wire, if fixed wiring has not been done. All non-electrical metal work including the bath tub, metal pipes, sinks and tanks shall be bonded together and earthed.

6 Refrigerators, air-conditioners and coolers, electric radiators, electric irons etc. shall be earthed by the use of three-pin plugs.

7 The electrical appliances which need more than 800 watts should be supplied with power through separate power circuits.

8 The switches, cables should have sufficient rating to withstand the current taken by the appliances.

9 Fuses used in the appliance circuits should be of correct rating and should be in phase lines only.

10 The electric cables used in the appliances should be well protected against mechanical damage as well as damage due to heat produced in the proximity of heating appliances.

11 No defective switch, plug, socket cable or appliance should be used in the circuit.

12 All the single pole switches shall be on phase/live conductor only.

13 The electrical outlets for appliances in the bathrooms shall be away from the shower or sink.

14 Wiring for power outlets in the kitchen shall be preferably done in metallic conduit wiring.

15 The electrical outlets shall not be located above the gas stove.

16 It is preferable to provide earth leakage circuit-breaker at the intake of power supply at the consumer's premises to safeguard the human beings.

The following tests should be carried out before commissioning the appliances.

1 Continuity of the heating element and power cord to be checked separately.

2 Insulation resistance between the body of the appliance and the terminals with and without power cord.

3 Insulation resistance between conductors of the power cord.

More than one megohm will be the insulation resistance of a good heating appliance.

The following points need to be checked before commissioning the appliances.

1 Correctness of earthing.

2 Correctness of fuse rating.

3 Leakage of electric current to the body not to exceed more than 0.2 milliamperes or insulation resistances not less than 1 megohm.

4 Control of phase / live line through switch.

5 Sound condition of switches, plugs and sockets and of proper capacity.

6 Cable capacity to withstand the load current, the voltage drop within limits taking into consideration the capacity, load and length of the circuit. As well as soundness of insulation and protection against mechanical damage.

Electric kettle

Objectives: At the end of this lesson you shall be able to
- **identify the parts of an electric kettle**
- **state the precautions to be observed while replacing the heating element in the appliance**
- **describe the method of fitting a new element**
- **state the general care and maintenance.**

An electrical kettle is used to boil water or to make tea/ coffee by using electricity

There are two types of electric kettles:

- Saucepan type
- Immersion heating type.

Saucepan type

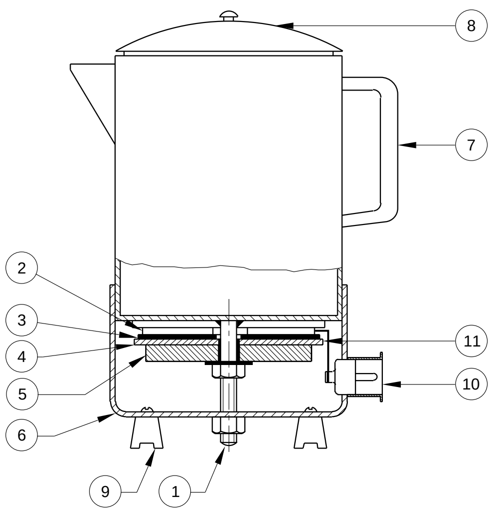
The construction of the sauce pan type kettle is shown in Fig 1. The parts are as follows.

1 Bolt, nut and washer holding bottom cover
2 Heating element
3 Asbestos sheet
4 Sole-plate
5 Pressure plate
6 Bottom cover
7 Handle
8 Top lid
9 Ebonite leg
10 Outlet socket
11 Brass strips

Bottom cover

The bottom cover is fitted to the central bolt of the body by a nut and washer. On removal of the bottom cover, ready access is made to the terminal and heating element assembly. (Fig 1)

Fig 1



Heating element

In its general construction, the heating element is made of Nichrome ribbon. The Nichrome ribbon is wound over mica. This is placed between two circular mica pieces, so that the Nichrome wire may not come in contact with any metallic part of the kettle. The two ends of the elements are connected to the outlet socket terminals of the kettle through two brass strips.

Asbestos sheet

This is placed below the element and mica insulation to serve as a heat insulator. It reduces the heat loss in the kettle in addition to giving increased insulation.

Sole-plate

The sole plate is a cast iron plate having a flat surface and its main function is to keep the element in close contact with the container and to avoid deformation of the element when heated.

Pressure plate

This is made of cast iron and fitted by a nut on the middle bolt. The pressure plate holds the sole plate in position. If this pressure plate is loosely fitted, the sole plate and the element become loose. This leads to expansion and contraction of the element during working and the element will get damaged.

Method of fitting new element

Dismantle the kettle by the following steps.

1 Invert the kettle and loosen the bottom cover holding nut. Take out the nut and remove the bottom cover.
2 Remove the brass strip connections of the elements at the socket terminal sides.
3 Remove the terminal socket by loosening the fitting screws.
4 Open the nut of the pressure plate.
5 Take out the pressure plate, sole-plate, asbestos sheet and then the heating element.
6 Replace with a new heating element having the correct size and rating.
7 Reassemble the kettle.
8 Test the insulation resistance for any earth fault and insulation failure.

Immersion type

The heating element in this type is of tubular immersion heating design. In some kettles an ejector type safety device is incorporated in the socket terminal side. In case the kettle is switched ON without water the safety pin (Fig 2) which is soldered against a spring tension comes out and pushes the plug out. This safety pin can be placed in position by soldering. The heating element is concealed inside a hollow tube and mineral insulated.(Fig 3)

Fig 2

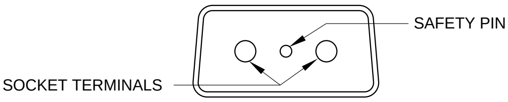
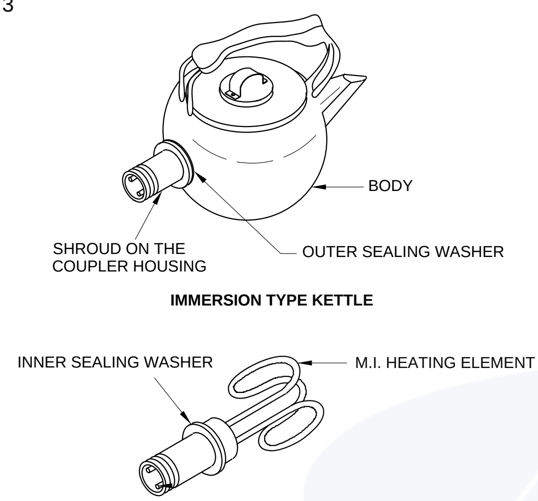


Fig 3



IMMERSION TYPE KETTLE

KETTLE HEATING ELEMENT

New elements can be fitted to most types of kettles without difficulty.

Fitting a new element

A new element should be fitted in the following manner.

1 Hold the element in one hand and unscrew the shroud on the coupler housing.

2 Slide out the outer fibre sealing washer.

3 Twist the element assembly inside the kettle and pull it out gently through the top.

4 Take the old element to an electric shop to make sure that the replacement is of the exact design and wattage.

5 Remove stubborn scales inside the kettle with a blunt knife without knicking the metal surface.

6 Put an inner sealing washer, usually made of fibre, on the new element.

7 Take care to fit new washers at the coupler housing in the correct order. Reassemble.

Care and maintenance

- Never empty a kettle while it is still switched 'ON'.
- Remove the plug from the socket before carrying out maintenance or repairs.
- Never pour water into a kettle which has just boiled dry, which apart from danger to the users, may damage the element.
- The metal portion of the kettle should be earthed using a 3-pin plug and a 3-pin appliance socket.
- Replace cracked or damaged sealing washer.
- Check for the good condition of asbestos sheet. Replace with a new one, if damaged during removal.
- Immediately replace the defective plug, socket or cable, if once noticed.
- Earth clips of the appliance power cord plug should snugly fit into the inner side of the appliance socket to have perfect earth connection. Check for proper fitting and cleanliness.

Electric heater

Objectives: At the end of this lesson you shall be able to
- **describe the various parts of an exposed element type electric heater**
- **select the suitable size (diameter) of the 'heating element' wire for a given wattage and voltage rating by referring to the table**
- **calculate the length of the selected wire of the heating element to produce a given wattage at the specified supply voltage**
- **state the safety precautions to be followed while installing a heater**
- **state the safety methods to be followed by the user**
- **describe the conditions to be checked in the heater while repairing**
- **calculate the efficiency of the heater.**

Introduction

One of the methods of obtaining heat for cooking is to use the heating effect of electricity. An electric heater is the simplest form of an electric cooking device.

Electric heater

There are two types of electric heaters.

i Exposed element type heater.

ii Enclosed element type heater.

Element

In the exposed element type of heater the element is made of Nichrome wire which is an alloy of Nickel (80%) and Chromium (20%). It possesses high resistivity and withstands a working temperature of 900°C. Nichrome will not readily oxidise even at such temperature. Increase in the length of wire at higher temperature is very small.

Different wattage heaters are made for working at the rated supply voltage of 240 V. The wattage is given by

$W = V \times I = I^2 R$ watts.

From the above formula it is clear that increased wattage heaters carry more current. The element wire of 2000 W should have increased diameter compared to that of a lower wattage, say, 1000 W heater.

An increased diameter wire decreases its resistance per metre length. The resistance per metre length of Nichrome wire of some readily available Nichrome wires with relevant particulars are given in Table 1.

Selection of Nichrome wire size (Diameter)

The current to be carried is calculated for a given wattage and rated voltage. Referring to the Table 1, the nearest size (diameter) Nichrome wire is selected.

The resistance of the heater element is determined from the formula $R = V/I$ ohms.

Alternatively, As $I = V / R$ and $I^2R = W$.

We have $V^2 / R = W$.

As such Resistance $R = V^2 / W$.

Length

The length of the Nichrome wire that can produce the above calculated resistance is found by using the data of resistance per metre length in Table 1.

TABLE 1
Nichrome wire table

	SWG	*Dia. in mm	**Resistance in ohm per metre at 500°C**	**Current flow in amperes to produce 500°C**
1	18	1.18	0.9744	12.6
2	20	0.90	1.7355	8.6
3	22	0.7	2.8707	6.3
4	24	0.56	4.6587	4.45
5	26	0.45	6.9553	3.5
6	28	0.375	10.2690	2.8
7	30	0.315	14.665	2.3
8	32	0.28	19.291	1.99

* Size equivalent to SWG is as per IS No. SP:2 - 1982, Table 1.

$$\frac{\text{Calculated resistance}}{\text{Resistance per metre of selected diameter}}$$

Detemination of the length of the heating element for a given wattage and voltage

Example

Select the size of Nichrome wire and calculate its length for a heater of 1000 watts for 250 V.

The wattage of the heater = 1000 W.

$$\text{Current drawn} = \frac{P}{V} = \frac{1000}{250} = 4A$$

The Nichrome wire suitable to carry this current could be selected from Table 1.

Accordingly, 24 SWG is suitable for this heater as it can carry 4.45 amps.

It is necessary to select a wire which can carry the maximum specified current.

The 24 SWG Nichrome wire has a resistance of 4.6587 ohms/ metre.

Total resistance of the heating element

$$= \frac{V}{I} = \frac{250}{4} = 62.5 \text{ ohms}$$

$$\text{Length required} = \frac{\text{Total resistance}}{\text{Resistance metre}}$$

$$= \frac{62.5}{4.6587}$$

= 13.415 metre

= 13 metre 42 cm.

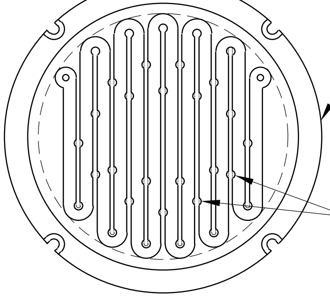
An additional length of 25 mm should be provided for fastening purpose.

The length of the wire is 13.67 metres. It should be accommodated within a limited space to provide concentrated heat.

Heater plate

It is made of porcelain/China clay with grooves to house the Nichrome wire. Porcelain withstands high temperature and remains as a good insulator even at a high temperature, say 1300°C. The coiled Nichrome heating element is housed in the grooves.

Fig 1



The grooves are designed with projections at various places as shown in Fig 1. The projections prevent the heating element from coming out of the grooves.

As the heater base plate is brittle, care should be taken while mounting or dismounting it from the frame to avoid breakage. The plate thickness varies from 10 mm to 25 mm depending upon the wattage. The ends of the coiled element are terminated with brass bolts and nuts in the plate itself.

Body or frame

The body or frame is provided to house the heater plate in it. It is made of cast iron or M S sheet painted or electroplated. The socket is fixed to the body. (Fig 4) An insulated handle is fixed on the body for safe handling.

Connecting leads

The lead wires should be having a larger cross section made of bare copper, or Nichrome wire insulated with porcelain beads or glass beads as shown in Fig 2. The beads are available in different sizes. The beads can be replaced by glass wool or asbestos sleeves. The leads are connected to the socket terminal and the heater plate terminal as shown in Fig 3.

Fig 2

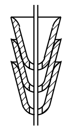
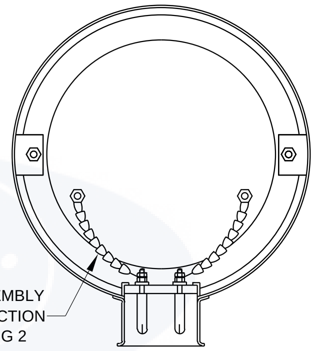


Fig 3

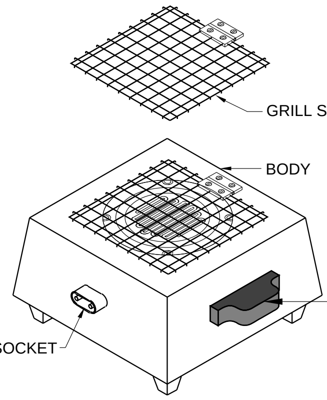


Grill stand

It is made of Chromium/Nickel plated MS rods and hinged to the body. It supports the vessels kept on the heater and acts as a barrier between the exposed heater element and the vessel. (Fig 4) For safety this grill should have electrical continuity to the body, and both must have earth connection.

As oil or paint in the hinges interferes with earth continuity, they should be avoided. Properly earthed grill and body will enable the fuse to blow in case of accidental contact of live parts with them, thereby avoiding shock to the user.

Fig 4



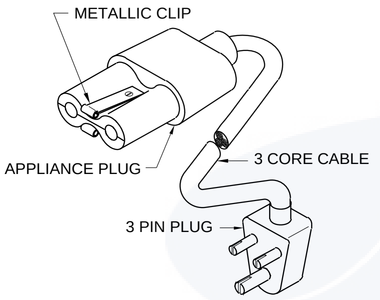
Heater socket

This is used for inserting the power supply appliance plug. The socket shown in Fig 4 has two male terminals, one for the phase and the other for the neutral. However, for safety, the heater body should be connected to the general mass of earth through the earth continuity conductor. For this, the appliance plug shown in Fig 5 has two spring loaded, metallic clips on either side of it which makes the contact with the metallic enclosure of the socket when plugged.

As rusting prevents proper contact of these clips with the socket, these clips and socket are made of nickel plated brass. If the spring tension of the clip is lost, it should be replaced; otherwise the earth contact will not be proper and the appliance will not be safe for use.

The appliance socket and pin should have tight fitting to avoid sparks and overheating. When sparks occur, the terminal points will get corroded and lead to loose connection. Such socket and Plugs should be replaced. A three-core flexible cable as shown in Fig 5 should be used for connecting the heater socket and power supply plug.

Fig 5



APPLIANCE POWER CORD

Safe installation

The insulation resistance between the heater element and the body should be one megohm or more.

The switch which controls the wall socket should be in the phase of the supply to ensure isolation of supply to the heater when the switch is 'off'.

User's safety practice

The user should avoid spillage of food articles on the heater as it will result in blowing off the fuse as well as breakage of the heater element/plate. The user should not drop metal articles on the heater as the live elements may come in contact with the body.

Precautions to be followed while repairing a heater

Check for overheated terminals of sockets and plugs. Check the power cord (cable) for continuity and insulation. Check the cable near the entry points of the plugs for breakage or signs of overheating. Too rigid portion of the cable insulation will indicate overheating and too much flexibility is an indication of breakage of conductor.

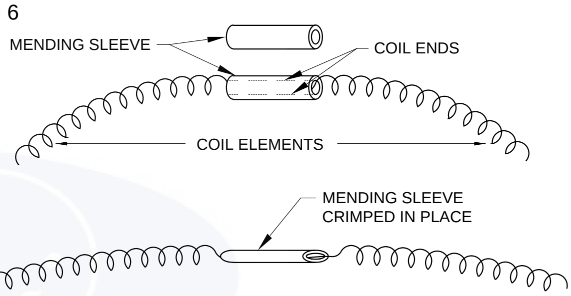
Check the body for the rust, particularly at the socket inner surface and at the fixing holes. Rusted sockets, or earth clips of plugs should be replaced. Never paint them as the paint forms insulation and earth continuity will be disrupted. But the rust in the fixing holes should be removed and should be repainted.

If necessary, replace the screws with bigger size brass screws. Heavily pitted, welded terminals of socket and plugs should be replaced and even new plugs should be checked for proper tight fitting in the sockets.

Check the heater plate for any breakage. Broken plates need to be replaced. Earth continuity of body and grill plate should be checked. Insulation resistance between the live parts and body should not be less than 1 megohm.

Sometimes, the wireman may have to repair a broken heating element. If a spare is not available readily, a temporary repair of the broken element could be done using mending sleeves. Do not solder the ends. As the solder temperature is much less than the temperature developed by the heater element, the solder will melt and open the joint. The heating element ends should be cleaned before inserting those ends into the hollow of the mending sleeves and then crimped. Refer to Fig 6.

Fig 6



As a rule the heat generated by the heater is not fully utilised for our purpose and some losses are taking place. The efficiency of the heater is therefore less than 100%. The efficiency of the heater is the ratio between the heat actually utilised and the heat produced by the heater.

$$\text{So, Efficiency} = \frac{\text{Heat Utilised}}{\text{Heat Generated}}$$

$$\left(\begin{array}{c}\text{Therefore, the}\\ \text{percentage efficiency}\end{array}\right) = \frac{\text{Heat Utilised}}{\text{Heat Generated}} \times 100$$

The heat generated is calculated using Joule's law. Accordingly we have

$$H = \frac{I^2Rt}{J} \text{ calories or } 0.24\ I^2Rt \text{ calories}$$

where I is current in amperes

R is resistance in ohms

t is time in seconds

J is the mechanical

equivalent of heat = 4.2.

The bigger unit of heat is the kilo-calorie.

Calorie

It is the amount of heat required to raise the temperature of one gram of water to one degree celsius.

1 Calorie = 4.2 joule or watt second

Heat obtained by a substance = $ms(T_2 - T_1)$ calories

where m - mass in grams

s - specific heat of the substance

$(T_2 - T_1)$ - raise in temperature (degrees celsius).

Example

An electric heater is marked 1000 W 230V. It is found to take 8 minutes to bring 1 kg of water from 20°C to boiling point (100°C). Determine the efficiency.

Given data

Mass of water m	= 1 kg or 1000 grams
Initial temperature T_1	= 20°C
Boiling temperature T_2	=100°C
Raise in temp$(T_2–T_1)$	= 100°C–20°C = 80°C
Time t = 8 minutes	= 480 sec.
Heater wattage	= 1000 W
Heater voltage	= 230 V

Specific heat of water is 1.

Heat utilised by water = ms $(T_2–T_1)$

= mass x sp. heat x $(T_2–T_1)$

=1000 x 1 x 80 = 8000 calories.

Heat generated = 0.24 x I^2Rt calories

= 0.24 x 1000 x 480.

(where I^2R = 1000)

$$\text{Therefore efficiency} = \frac{\text{Heat Utilised}}{\text{Heat Generated}} \text{ x } 100$$

$$= \frac{8000}{0.24 \text{ x } 1000 \text{ x } 480} \text{ x } 100$$

= 70%(approx.).

Non-automatic electric iron

Objectives: At the end of this lesson you shall be able to
- **name the parts of an electric iron and their functions**
- **state the precautions to be observed while using an electric iron**
- **list the possible faults which may occur in an electric iron**
- **state the six basic steps to be followed, as a general procedure, to effect an efficient and prompt repair.**

The electric iron will probably be the first appliance that an individual will be called upon to repair when entering the appliance service field. While there are many different types and styles, they all work on the same principle.

Types of irons

There are three general types of irons,

i the non-automatic

ii the automatic, and

iii the steam iron.

The automatic iron is rapidly replacing the non-automatic iron.

Working principle of an electric iron and its parts

In non-automatic type irons the temperature is not regulated. As such the user has to switch ON or OFF the iron as per the heat requirement.

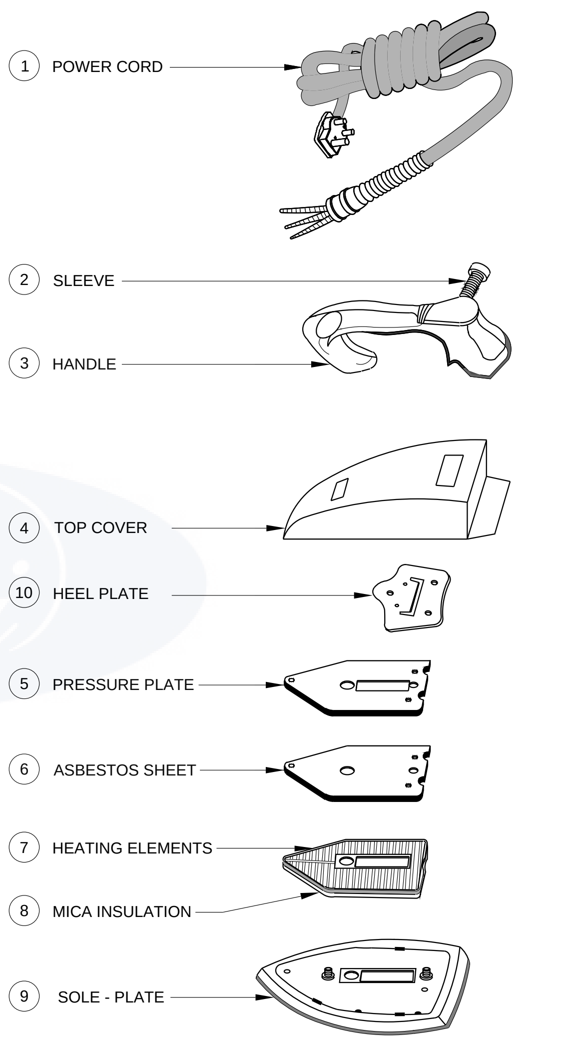
An electric iron is a heating device in which the heat is concentrated on a smooth, flat, bottom surface which is pressed over the clothes to be ironed. This flat bottom surface is called the sole-plate.

The sole-plate is heated by a mica insulated element made of ribbon shaped Nichrome (resistance) wire, placed in or on the sole-plate. Thus, the iron converts electricity into heat at the sole-plate. The heat at the sole-plate is used to iron the clothes.

General Parts

Before you study the method of servicing irons it would be good to learn the names of their principal parts as shown in Fig 1.

Fig 1



Cords (1)

The 3-core power cord used for an electric iron is called domestic flexible cable and is extremely flexible. Each core will be having multi-strand wires and will be insulated with rubber and the three insulated cores are interleaved with fine cotton threads. All the three cores are enclosed in rubber or PVC sheathings and covered with braided silk.

As the end of the cord (near the electric iron terminals) will be subjected to strain and stress due to the movement of cable while ironing, the cord is protected by the use of a strain relief rubber sleeve or PVC cord guard (2) as shown in Fig 1.

Handles (3)

Handles are made of Bakelite. Sometimes handles are split to provide access to the terminal covering and an entrance for the cord. When disassembling an iron for repair, the handle or its part is usually the first piece to be taken out.

Cover (4)

This part covers the heating element's internal connections of the iron. It also serves as a shield to protect the user's hands from the generated heat and electric terminals.

Pressure plate (5)

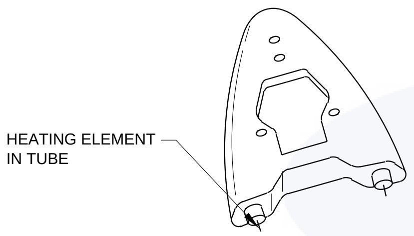
The purpose of the pressure plate is to keep the heating element firmly against the sole-plate. If the pressure/sole plate combination is loose, the element will expand and contract due to heat and will get spoiled quickly. Often the pressure plate has an asbestos insulation sheet, of the same shape. (6) The asbestos sheet is placed just above the heating element to prevent the heat developed in the element from travelling upward due to conduction and radiation. The pressure plate must be of a good fit. (Fitted with two nuts)

Heating elements (7)

There are two types of heating elements. One is made of ribbon resistance wire wound around a sheet of mica as shown in Fig 1 (7). This type of element is placed on the top of the sole-plate. The other type of element is made up of round resistance wire coiled on a ceramic form and cast directly into the sole plate as shown in Fig 2.

The flat type element is replaceable whereas the cast type heating element has to be replaced along with the sole plate only. In this type of irons, a pressure plate is not necessary.

Fig 2



Sole-plate (9)

The transfer of heat from the heating element to the material being ironed is done by the sole-plate. The material being pressed can be easily damaged if the sole-plate is not smooth and free from scratches. If the sole-plate is found scratched, it can be buffed, electroplated and polished.

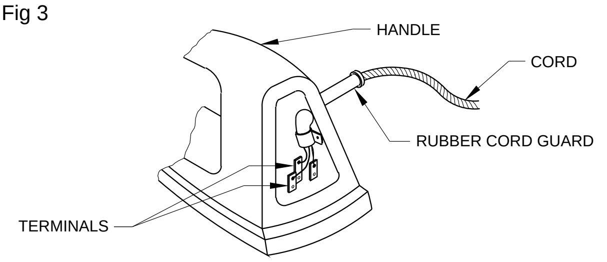
Heel plate (10)

The purpose of the heel plate is to enable the iron to stand when the iron is tilted back on the rear of its handle. The heel plate is not intended for high temperature to reach.

Terminals

This is the point at which the heating element of the iron is connected to the cord. (Fig 3)

Fig 3



Electric irons are available for operation on 240V domestic electric supply and are of different wattages, 350 W, 500 W, 600 W, 750 W and 1000 W.

Precautions to be observed while using an electric iron

While purchasing an electric iron see that it is provided with a 3-pin plug and the product bears B I S (ISI) mark. The user needs a stable ironing table and a nearby 3-pin socket for easy operation. Check whether the earth connection of the 3-pin socket is effective and the switch of the socket controls the phase line. Never leave the electric iron unattended as the children may touch the hot iron and get blisters or the heat developed may end in fire hazards.

While purchasing an electric iron, look for the one with an undetachable power cord.

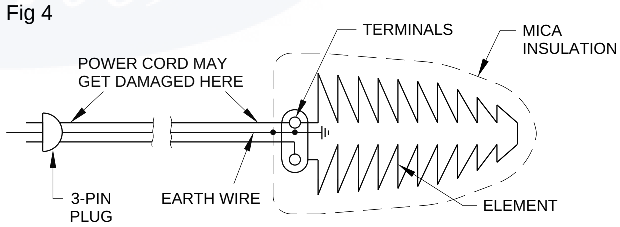
Modern irons use a permanently attached cord rather than the easily misplaced detachable cords. One advantage of the permanent cord is that the wall plug is the only electric disconnecting point in the circuit.

With detachable cords, resistive oxides may form at the terminals. The oxides which are resistive in nature, in course of time will develop sparks in contact points of the plug and sockets, burn the terminals and cable, as well as reduce the current input to the heating element.

Probable faults in an electric iron

The electric circuit of any iron is very simple. In many irons it is nothing more than a heating element with a cord and plug attached to connect it to an outlet.

Fig 4



Note that the only troubles possible in this circuit are short circuits and open circuits. Figure 4 shows the possible parts of the circuit which may become defective and the following paras give the explanation. This is a schematic diagram only.

3-pin plug

In many cases the plug terminal connections become loose and end up in overheating of the pins of the plugs and the terminals of the socket. A check on the colour and tightness of the pins will reveal the possible defects. Any broken or damaged plug should be replaced immediately to avoid shocks and accidents.

Power cords

Only 3-core cables of domestic flexible type should be used and they should have a minimum current capacity of 5 amps. In general the cable breaks or damages at the plug ends or at the terminal ends of the iron due to constant movement of the ironing operation.

To reduce the strain of the cable at these ends, rubber (PVC) cord guards should be used. In certain cases the user may inadvertently allow the cable to touch the heated sole plate, thereby the cable gets damaged. Such damaged cable needs to be replaced immediately to ensure safety.

Earth connection

It is often necessary to check the earth connection of the body of the iron and its continuity to the 3-pin socket through the cable to avoid shocks.

A rusted earth terminal connection or a loose earth wire is a potential hazard to the user.

Heating element

An open circuit in the heating element makes the iron useless. On the other hand a partially shorted element produces less heat at the sole-plate and excess heat at the cable plug and socket. In both the cases the element has to be changed.

Mica and asbestos insulation

When the mica insulation is damaged, it either blows the fuse of the electric iron circuit or gives a shock to the user when the earth connection is not perfect. Check the soundness of the mica and asbestos insulation whenever the electric iron is dismantled and use a new mica and asbestos sheet replacing the old one. Damaged or ineffective asbestos sheet could be identified by the excess transmission of the heat to the cover and body while the iron is in use.

The Terminals

They should be often checked for loose connection and overheating. Washers and properly threaded screws will help to reduce the overheating.

Repair procedure

There are six basic steps you should follow to effect an efficient, prompt repair of iron.

1 Conduct a visual examination.

2 Listen to the customer's complaint.

3 Conduct preliminary tests.

4 Repair the iron.

5 Make the final tests.

6 Prepare the iron for delivery.

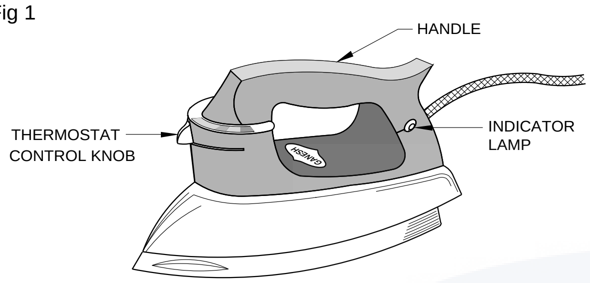
These basic steps will not necessarily be rigid but provide a good working procedure for repairing all types of appliances.

Automatic electric iron

Objectives: At the end of this lesson you shall be able to
- **state the difference between non-automatic and automatic irons**
- **describe the construction of a bimetal thermostat**
- **illustrate the working of an adjustable thermostat**
- **list the applications of the thermostat**
- **explain the cause of pitting and oxidation of contact points**
- **list the possible faults, their causes and corrective action to be taken in an automatic iron.**

The difference between an automatic iron and the ordinary (non-automatic) iron is that the automatic type has a thermostatic device to regulate the temperature. The other parts are more or less the same in both the types of irons. (Fig 1)

Fig 1



AUTOMATIC ELECTRIC IRON

Automatic irons are fitted with a thermostatic switch to regulate the heat to a specific predetermined value. The thermostatic switch disconnects the supply when the predetermined value is reached and reconnects the supply when the iron cools down. A turning knob with a dial just below the handle, marked as rayon, cotton, silk, wool etc. can be operated to select the preset tempera-ture, depending upon the particular fabric to be ironed. A lamp fitted into the handle goes off when the desired temperature is attained.

The electric components of the dry iron includes a heating element, a thermostat, an indicating lamp and a cord set.

Thermostats

A thermostat is a switch which can be designed to close or open a circuit at predetermined temperature. One of the simplest and most dependable components in the modern heating appliances is the BIMETAL THERMOSTAT. It controls the temperature in stoves, toasters, food warmers, irons etc. It serves as a safety device to prevent overheating of the appliances.

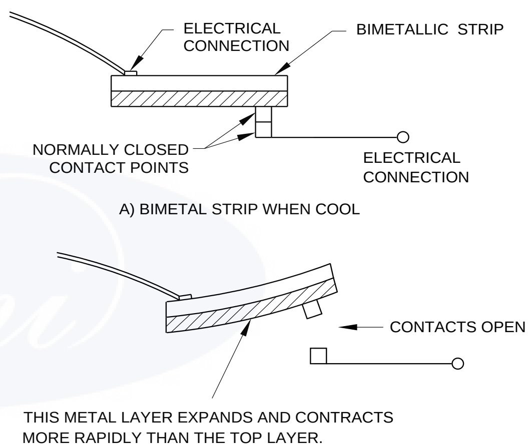
Bimetal thermostat (Fig 2)

In the thermostat there is a bimetal strip made of two strips of metal with different expansion rates welded together. The metal strip expands when heated and contracts when cooled. One metal in the bimetal strip has a high rate of expansion when heated, and the other has a low rate.

When a bimetal strip is heated, both the metals in the strip expand but the one at the bottom as shown in Fig 2 (b) with a higher rate of expansion) expands faster and forces the upper half to curl up or bend away from the contact point. The strip curls or bends enough to break the contact, opening the circuit.

As the strip cools, it straightens and restores contact with the stationary point. The bending of the bimetal strip on heating, is towards the side that has the smaller expansion rate.

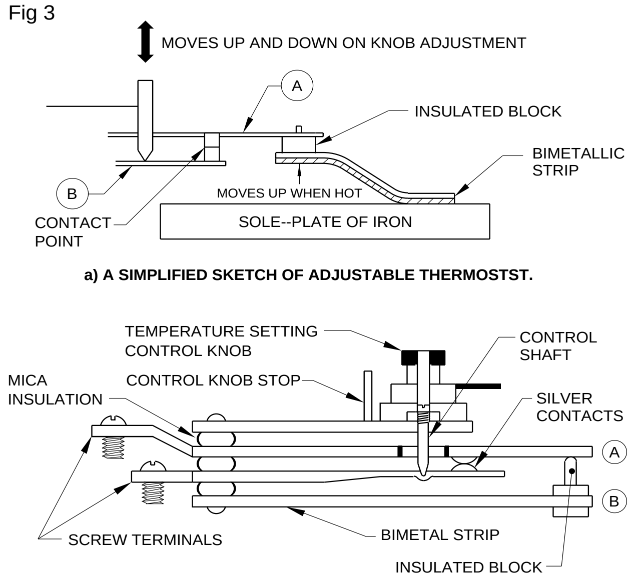
Fig 2



A SIMPLE BIMETAL THERMOSTAT

Adjustable thermostat (Fig 3)

Fig 3



a) A SIMPLIFIED SKETCH OF ADJUSTABLE THERMOSTST.

b) OPEN FRAME BIMETALLIC ADJUSTABLE THERMOSTAT.

The operation of the thermostat is as follows. The strip B (Fig 3 (a) part B) along with the silver contact is designed such that it has upward tension whereas the control shaft moves the strip B either upward or downward depending upon the temperature setting.

The strip A (Fig 3(a) part A) along with its silver contact is designed such that it has downward tension. But its downward movement is restricted by the insulated block.

In the 'OFF' position of the temperature setting control knob, the strips A and B will be away from each other, keeping the silver contacts in an opened condition, thereby, keeping the heating element circuit open.

When the temperature setting control knob is set to minimum position, the control shaft moves up and allows the strip B and its silver contact to move upwards to some distance and make contact with the silver contact of the strip A.

Thus the heating element circuit is closed, the iron heats up. The bimetal strip which is also heated, bends upwards and the insulated block pushes the strip A, thereby, separating the silver contacts and the heating element circuit opens.

When the iron cools down, the bimetallic strip also cools the and comes back to the straight position. The downward movement of the insulated block allows silver contact strip A to come in contact with the silver contact strip B; thereby the circuit is closed and the iron heats up.

This cycle goes on and off in that setting.

At the highest temperature setting, the distance between the strip A and the insulated block of the bimetal strip will be more and it takes more time to switch OFF the heater element, and, thereby, the temperature of the iron will be more.

The knob adjustment does not determine the amount of current that flows into the appliance but usually controls the ON-OFF cycle of the unit; thereby, increases the heat required for wool or reduces the heat for rayon.

Bimetal thermostats open and close slowly and as a result the contacts are prone to arcing.

The mica insulation between the two strips A & B act as a condenser and the arc is suppressed by the condenser action. Sometimes, the mica gets deteriorated and allows the arc to exist between the contacts. Each time the contacts open, they cause a small arc which leaves a deposit of oxide on the contact surface.

Corroded contact points increase the arcing and lose electrical conductivity. Eventually the contacts no longer allow the current to flow. This can occur even though they may seem to be touching each other.

Generally, a good thermostat will show zero ohms resistance, or at most a few ohms. When a thermostat indicates high resistance or infinity, it should be replaced. Do not try to bend the strips A or B unless otherwise you know what you are doing is correct.

Troubleshooting in an automatic iron

Follow the troubleshooting chart to repair an automatic iron.

TROUBLESHOOTING CHART
(DRY IRON)

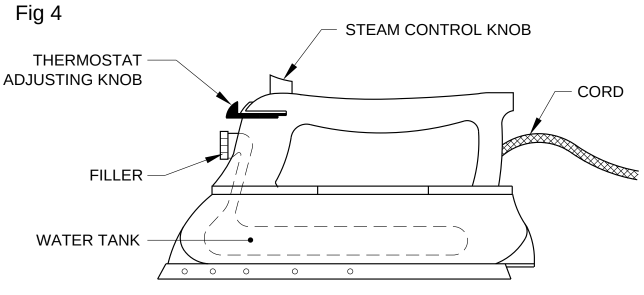
Trouble	Possible causes	Corrective action to be taken
No heat	No power at outlet.	Check outlet for power.
	Defective cord or plug.	Repair or replace.
	Loose terminal connections. Broken lead in iron.	Check and tighten the terminals. Repair or replace lead.
	Loose thermostat control knob.	Clean and tighten.
	Defective thermostat.	Replace thermostat.
	Defective heater element.	Replace the element if separate. If cast in, replace sole-plate assembly.
	Open thermal fuse.	Replace.
Insufficient heat	Low line voltage. Incorrect thermostat setting.	Check voltage at outlet. Adjust and recalibrate thermostat.
	Defective thermostat. Loose connection.	Replace thermostat. Clean and tighten connections.
Excessive heat	Incorrect thermostat setting.	Adjust and recalibrate thermostat or replace.
	Defective thermostat.	Replace thermostat.

Trouble	Possible causes	Corrective action to be taken
Blisters on sole-plate	Excessive heat.	First repair the thermostat control. Then replace or repair the sole-plate, depending on its condition.
Tears clothes.	Rough spot, nick,scratch, burr on sole-plate.	Remove these spots with fine emery and polish the area with buff.
Iron cannot be turned off.	Thermostat switch contacts are welded together	Check the thermostat switch contact. Open them by force. The contact points should be in open condition at off position of the control knob.
Power cord	Loose connection. Broken wire.	Clean and tighten. Repair or replace.
Sticks to clothes.	Dirty sole-plate. Excessive starch in clothes. Wrong setting of the thermostat knob. Iron too hot for fabric being ironed.	Clean. Iron at a lower temperature. Use less starch next time. Set the knob to correct temperature. Lower the thermostat setting.
Iron gives shock.	Disconnected earth connection. Weak insulation of heating element. Earth continuity with common earth not available.	Check earth connection and connect properly. Check insulation resistance of heating element; if necessary replace element. Check the main earth continuity and connect properly.

Steam/spray irons (IS 6290)

Electrically there is no difference between steam irons and dry irons. A steam iron has a small reservoir mounted above the heating element. A control valve on this allows the water to drip slowly into recesses in the sole-plate. A check valve keeps the water from going back up into the tank. When the water hits the hot position of the sole-plate, it is converted to steam and goes out through holes in the bottom of the sole-plate. Fig 4 shows a diagram of the construction of a typical steam iron.

Fig 4



OUTLINE OF A TYPICAL STEAM IRON

Method of repair

In most of the steam irons, the heating element is sealed along with the sole-plate. When the element is found to be open or shorted, the sole-plate along with the sealed heating element has to be replaced. Apart from defective power cord set and thermostat as found in the irons, the steam iron may develop problems in the water/steam container parts due to the following reasons:

i) The consumer might have used tap water instead of distilled water to fill the water tank in steam irons. This may result in deposit of salts in the tank and clog the entry and exit points.

ii) The consumer might have left the iron with water for some period resulting in salt and rust formation.

The salt deposit can be removed by filling the tank with diluted vinegar and plugging the iron to the power supply. A number of attempts may have to be made to clear the deposits.

Room heater

Objectives: At the end of this lesson you shall be able to
- **state the application of a room heater**
- **read the constructional diagram and list out the procedure of dismantling room heaters**
- **state the care and maintenance required while servicing room heaters**
- **identify the parts of room heaters from the schematic/constructional diagram.**

Electric room heaters

Electric room heaters, as shown in Figs 1 & 2 are commonly used in and around the home and are usually called space heaters or room heaters since their primary function is to heat the air space in the room or area in which they are placed during cold weather seasons.

As these room heaters are to be used in houses they should be well protected against shock hazards, and protection to children by properly closed grills and heat resistance surface, as well as other necessary additional features required to avoid fire accidents.

Types of room heaters

There are several types of electric space/room heaters available in the market.

Depending on the method of air circulation, space/room heaters are of two general types, namely, natural draft and forced draft. In natural draft heaters, there is no provision for the hot air to be forced and circulated; the heat radiated by the elements and the heated air distributes itself throughout the room.

In forced draft heaters, the air is blown by an electric fan through electrically heated elements and absorbs the heat. The heated air is then distributed throughout the room by the draft of the fan.

Room heaters (Natural draft type)

In these heaters, the heat produced is radiated by means of a chromium plated, well-polished reflector.

The natural draft type heaters are of two types.

i Bowl type room heater and

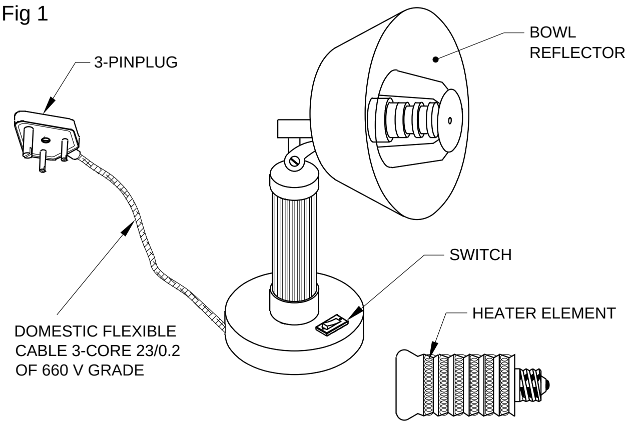
ii Rod type room heater

Bowl type heaters

In this heater a bowl shaped reflector as shown in Fig 1 is used. The reflector which is mounted on a sturdy base and is provided with wire guards to prevent accidental contact with the cone-shaped heating element. This is the most common type of heater.

It is light in weight and may easily be carried about and connected to any socket outlet. This heater consists essentially of a screw-in type of heating element holder. The resistance (Nichrome) wire is wound on a cone shaped porcelain former and is mounted in the centre of the reflector bowl.

Fig 1



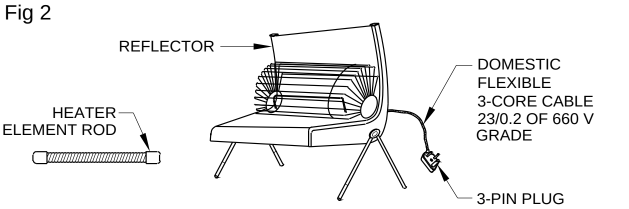
BOWL TYPE ROOM HEATER

The reflector bowl due to its parabolic shape radiates heat in a cone shaped wide beam just as a reflector type lighting fixture radiates light.

Rod type room heater

These are also known as radiant heaters. In general the spiral Nichrome wire is wound over a porcelain bar. Two ends of the element are brought out to the terminals. The rod is fixed in the connector by means of screws and supply is given to the end terminals. To increase the efficiency a polished reflector is used behind the rod, as shown in Fig 2, which radiates the heat efficiently.

Fig 2



ROD TYPE ROOM HEATER

The number of the heater elements may be one or more than one.

Room heaters (Forced draft type)

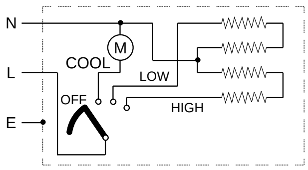
Fan or blower type or forced draft heaters have a motor operated fan in addition to the heating element. It is used for heating large rooms or locations where warm air must be circulated through greater areas than could be heated by natural draft type room heaters by convection and radiation.

These heaters may have one or more heating elements, and an electric fan, which blows the air through the heating unit and circulates the hot air in a given area. Costly room heaters are available with thermostats for room temperature control and may have different heat settings through a switch.

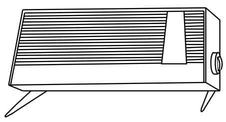
It consists of a fan motor of about 1/60 hp, 240 r.p.m. two elements of 1000W/ 500W each and a special rotary switch as shown in Fig 3. The fan only will be working and circulates the cool air into the room when the switch makes contact at first position.

At second position the fan works, and only one heater element delivers low heat, and at the third position, the fan works along with two heater elements to produce maximum heat.

Fig 3



CIRCUIT DIAGRAM

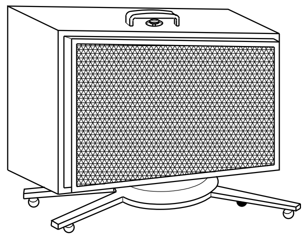


HOT AIR CIRCULATOR

Oscillating type room heaters

An oscillating type electric room heater is shown in Fig 4. This heater oscillates about 120 degrees and radiate heat to the surroundings. This heater, as compared with the earlier version, has an additional oscillating mechanism.

Fig 4



AN OSCILLATING TYPE ELECTRIC ROOM HEATER

Safety

The body of the room heaters should be earthed to avoid shock. Damaged power cords should never be used. When not in use the heaters should be disconnected from the supply. Avoid any inflammable material coming in contact with the heater element. Keep the room heaters of any type away from the children.

Electric toasters

Objectives: At the end of this lesson you shall be able to
- **state the function of a toaster and its normal operating temperature**
- **classify and explain the construction and operation of toasters**
- **state the function of a thermal compensator.**

Toasters

Basically, a toaster is made up of a rack to hold the bread slice, and a heating elements located at the sides of the bread. The object is to heat the bread until it is toasted to the desired colour.

The longer the bread is heated, the darker it will become. Therefore, time plays an important role in getting the desired degree of toasting.

Normal operating temperature range of the appliance

The normal working temperature of a toaster heating elements varies from 385°C to 900°C. The toasting zone temperature is about 260°C.

Rating of toasters

The toasters are rated for 600 W, 750 W, 1000 W and 1250 W to work from 230 volts to 250 volts 50 Hertz supply.

Types of toasters

Toasters are available in two types.

i Non-automatic, and

ii Automatic.

In some toasters, the user must keep watching the bread while it is being toasted so that he can turn off the heat when the bread slice turns to the desired colour by trial and error method.

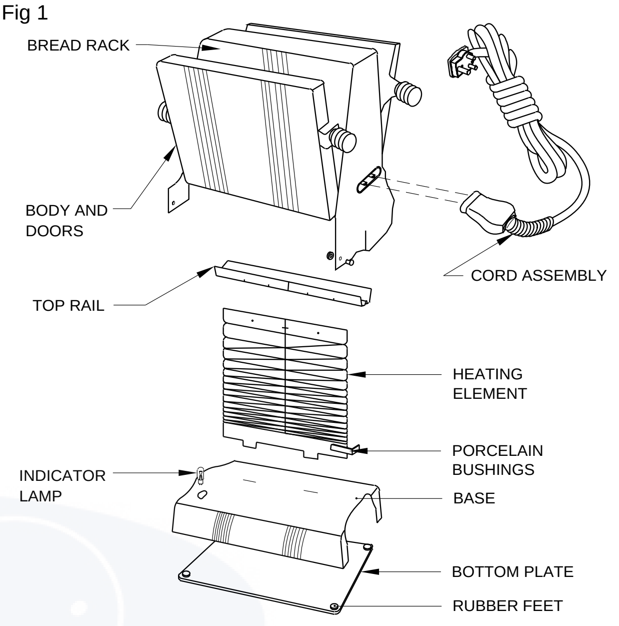
This type of toaster is classified as a non-automatic toaster because the timing and switching off of the heat is left completely up to the user. An automatic toaster does all the necessary operations by itself.

Non-automatic toasters

Typically, the non-automatic toaster consists of a metal shell containing a bread rack and a series of heating elements. The doors on either side are hinged at the bottom, and swing out from the top and downward to a horizontal position.

Fig 1 shows the parts of a non-automatic toaster. Bread is placed on the doors, which are then closed, thus bringing one side of each slice of the bread close to the heating element mounted in the centre of the toaster shell. When one side is toasted, the door has to be opened manually.

Fig 1



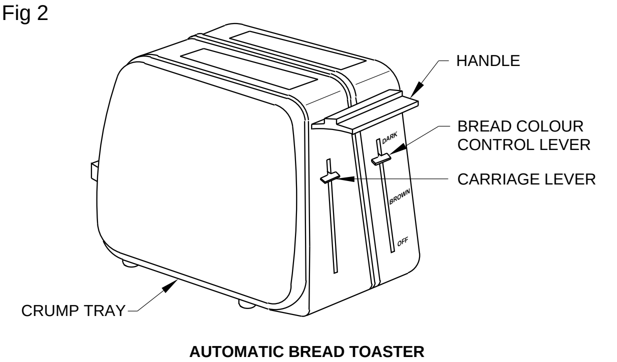
NON - AUTOMATIC TOASTER PARTS

The bread has to be turned manually for toasting the other side by following the same procedure.

The non-automatic toaster has neither switches nor thermostats. Non-automatic toasters have been replaced almost universally by the automatic type.

Automatic toasters (Fig 2)

Fig 2



AUTOMATIC BREAD TOASTER

Automatic toasters are built in two and four bread slice sizes. They are often referred to as 'automatic pop-up toasters', and these toasters automatically perform the operation required for toasting.

Basically automatic toasters are simple appliances with three working parts.

A **bread carriage** moves up and down inside the toaster walls and usually has an external control lever. (Fig 2) The carriage when at down position operates a switch that turns the toaster 'on' and vice versa.

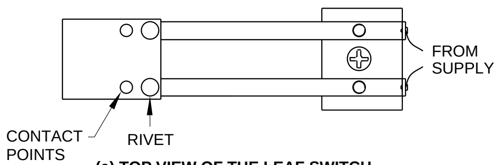
Heating elements,made of flat Nichrome wires, are positioned on both sides of the toaster wall. When current flows through them, they radiate heat for toasting.

A **mechanical timer** inside the toaster is linked to a toast color control outside. The control enables the user to adjust the toasting time for different types of breads or to suit the user's preference.

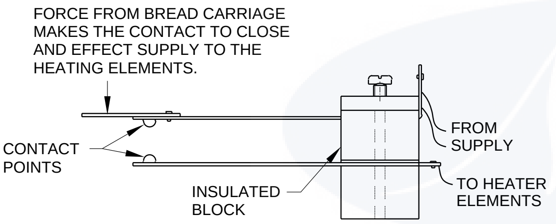
Operation of automatic toasters

When the carriage lever is pressed down, the heating element switch (Figs 3a & b) contacts are closed, and they remain closed until the bread carriage is released by the clock timer mechanism. Thus, the unit is energized from the time the carriage lever handle is depressed and the unit is de-energised when the carriage comes up.

Fig 3



(a) TOP VIEW OF THE LEAF SWITCH



(b) FRONT VIEW OF THE LEAF SWITCH

According to the set position of the colour control lever, the time of toasting the bread is controlled by the clock timer.

Clock-type timer for colour control

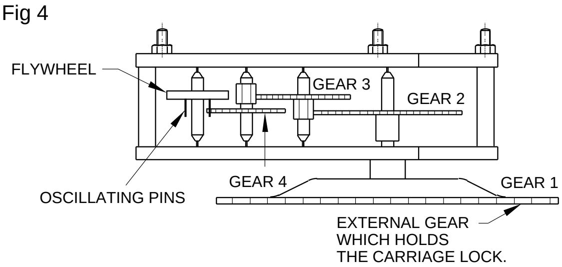
A clock timer is commonly used in automatic pop-up toasters. This control arrangement uses a spring-actuated clock to control the toasting cycle.

As shown in Fig 4, the external gear which holds the carriage lock is a part of a gear train. Free rotation of the external gear is restricted by the train of gears and the fly wheel with oscillatory pins. Oscillating pins delay the movement of gear 4, consequently the gear chain 3, 2 and 1.

When the carriage is pushed down, the carriage lock as shown in Fig 5, engages the gear 1 (external gear) and the carriage spring which is energised tries to move the gear 1. But the movement of gear 1 is delayed by the flywheel oscillating mechanism, ie. the time taken by the gear 1 to rotate a given distance of required movement.

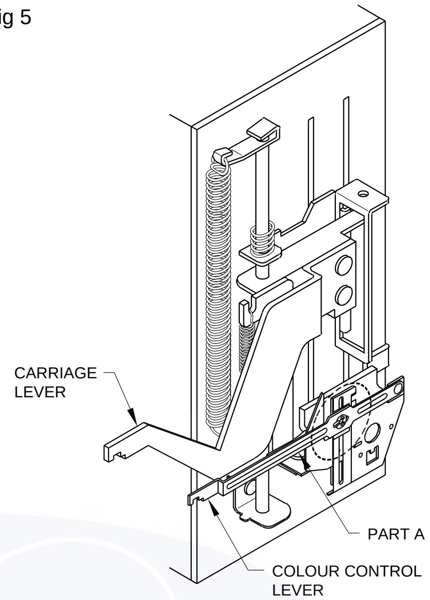
The distance of the required movement of gear 1 is again controlled by the eccentric plate attached to the colour control lever.

Fig 4



TRAIN OF GEARS

Fig 5



The movement of gear 1 in clockwise direction makes the carriage lock to move up and to touch Part 'A' of the colour control lever at a particular setting. As the eccentric plate dimension is bigger than the periphery of the gear 1, the spring-loaded carriage lock moves out of the gear teeth and gets disengaged and the carriage moves up due to carriage spring tension.

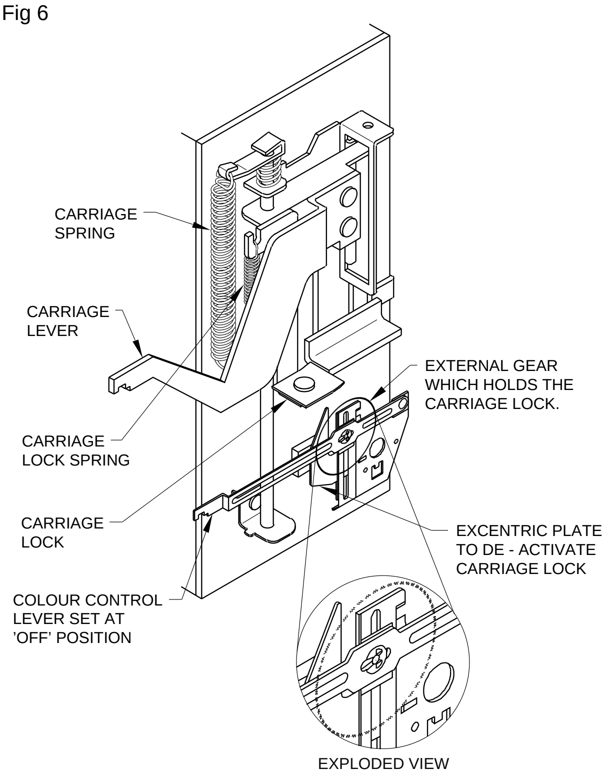
The eccentric plate contour along with its position makes it possible to adjust the clock timing to change from light to dark colour control. When the colour control lever is in the down (Off) position the carriage lock has no hold and the toaster cannot be switched on as shown in Fig 6.

Advanced type of automatic bread toaster

In most of the cases at the initial period of toasting, the toaster is cold and takes some additional time to toast the bread. On the other hand when the toaster is under operation, the interior of the toaster is hot and it takes lesser time for the bread to get toasted.

To compensate this, a thermostat is added to the clock timer mechanism. Further, remember that high heat (thermostat set for high heat) from the toaster with lesser clock timing will produce blackened bread slices with soft interior. Alternatively less heat (thermostat set for low heat) from the toaster for long clock timing will produce a toast light in colour but dry all the way through. Uniform toasts, right from the beginning to end of toasting is impossible without changing the colour control.

Fig 6



Clock timer with colour control cord and thermal compensator

To make the system fully 'automatic', a thermal compensator is added to the clock timer control.

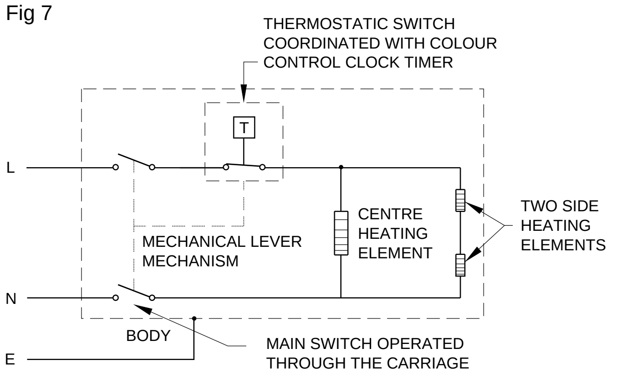
As the toaster temperature rises, the bimetallic blade moves the eccentric plate downwards towards the light colour position and trips the load carriage early.

Thus the time cycle is varied automatically to suit the starting temperature of the toaster. The toast color control is the same as that used on the standard clock timer model, but with this later design it is possible to get uniform toast whether it starts hot or cold without changing the color control or preheating. To have a reliable operation, some of the toaster manufacturers have incorporated a solenoid switch thermostat and a clock timer.

There are many variations in these arrangements in a modern toaster and the trainees are advised to study the toaster thoroughly before attempting to repair it.

The Fig 7 shows the schematic diagram of a modern toaster.

Fig 7



Each of the outside heater elements is of half the resistance rating when compared to the centre heating element.

Servicing of toasters, care and maintenance

The main job of servicing a toaster will consist of replacing the line cords, heating elements, bimetal strips and small mechanical parts. In some cases, only an adjustment will be necessary.

This requires a careful study of the mechanism.

In all appliance repair work, it is most important that you observe the order in which the various parts are disassembled. This will save time during reassembly.

Troubleshooting in automatic toasters

The common defects and method of troubleshooting are given in the trade practical.

Hair dryers

Objectives: At the end of this lesson you shall be able to
- **list/name the types of hair dryers**
- **name the parts of a hair dryer from the constructional diagram**
- **describe the working of a hair dryer**
- **list the possible faults, their causes, and suggested corrective action**
- **state the method of care and maintenance of hair dryers.**

Electric dryer is used to dry wet hair of human being quickly. It has become a very popular appliance. Though the modern hair dryer comes in a tremendous variety of sizes, shapes and styles, the basic working principle is the same. There are two types of hair dryers.

i Portable type hair dryer

ii Saloon (bonnet) type hair dryer

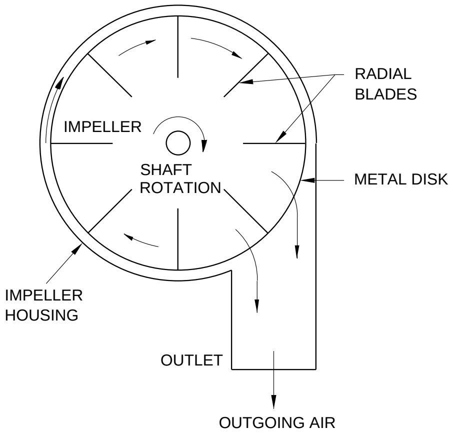
Both the dryers supply hot air to dry the wet hair on the common principle of blowers with a heating element.

Construction and working of a portable hair dryer

The three major parts are the motor with the fan, the electric heating element and the selector switches to control the motor speed and heat.The fan should probably be called a blower; the blade is shaped like the impeller on a vacuum cleaner and mounted in a housing which is connected to the outlet duct as shown in Fig 1.

An exploded view of the bonnet type hair dryer is shown in Fig 2. Most motors are of single speed, shaded pole motors particularly in the smaller models. Some of the larger and more elaborate types have multiple speed motors or solid state control units on universal motors.

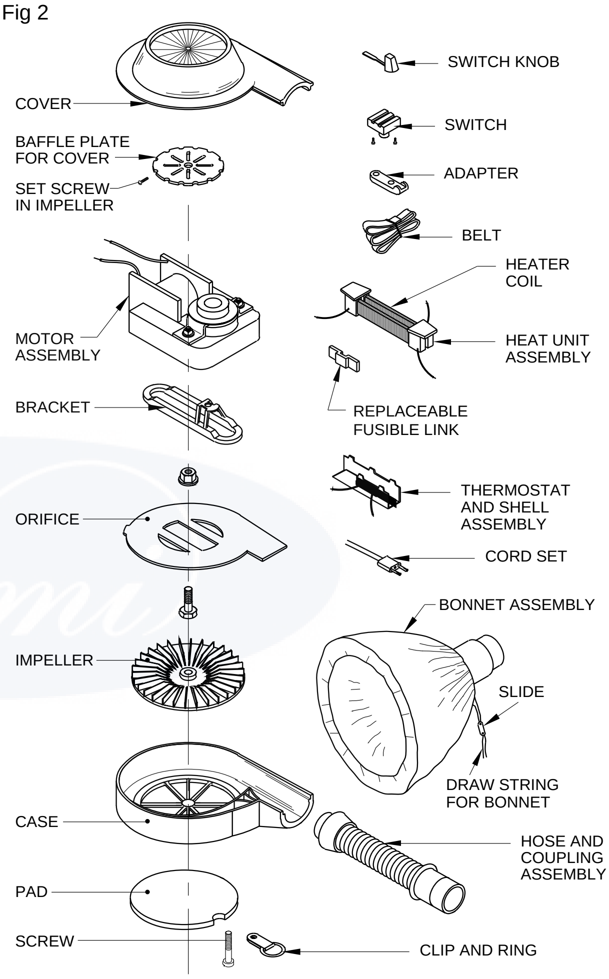
Fig 1



The heating element is of the open wire type, wound on thin mica cards. Each element has a special thermostat strip mounted near the air nozzle which senses the temperature of the air flow.

The thermostat switch is normally closed, and is open if the hot air blown outside the heater circuit becomes too hot. A fuse is connected in series between the tempera-ture control switch and the heater element.

Fig 2



EXPLODED VIEW OF BONNET TYPE HAIR DRYER

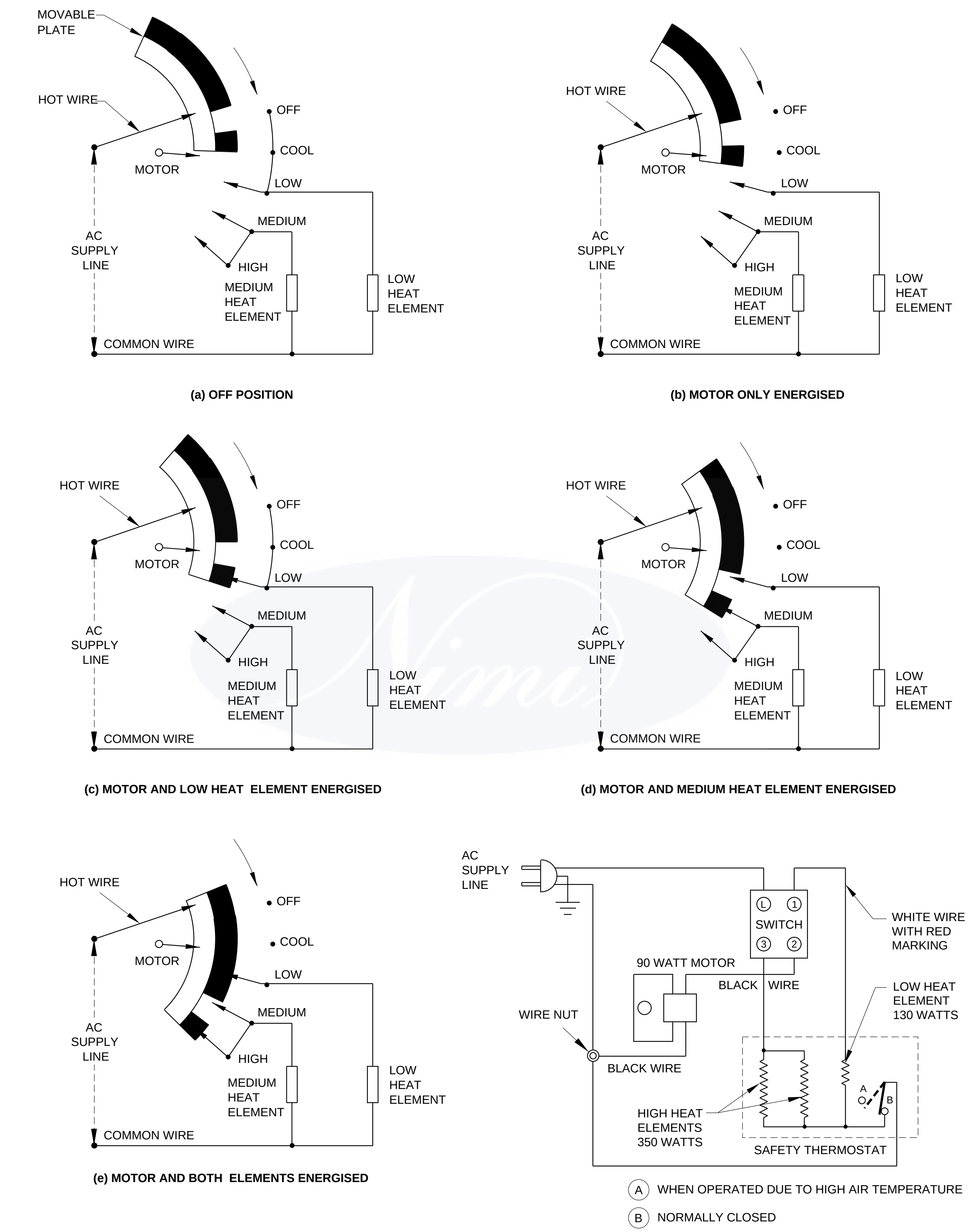
The majority of hair dryers seem to use a three-section heating element controlled by a selector switch. The switch has three positions - low, medium and high, and their working principle is shown in Fig 3 along with the circuit diagram.

The selector switch will always be connected to the motor and then to the heater circuit so that the heating element cannot be turned on unless the motor is running. This is a safety measure.

Servicing of hair dryer

The common faults in hair dryers, their causes and the action to be taken to correct the faults are given in Table 1.

Fig 3



(a) OFF POSITION

(b) MOTOR ONLY ENERGISED

(c) MOTOR AND LOW HEAT ELEMENT ENERGISED

(d) MOTOR AND MEDIUM HEAT ELEMENT ENERGISED

(e) MOTOR AND BOTH ELEMENTS ENERGISED

FULL CIRCUIT DIAGRAM OF HAIR DRYER

TABLE 1

Service Chart

Complaints	Causes	Test and remedy
Unit gives no heat at any position and/ or motor does not operate.	1 Blown of fuse.	1 Replace with proper capacity fuses.
	2 Broken wire/loose connection in power cord or in the circuit	2 Check all wiring connection and cord set for its continuity. Solder the broken wire or change the cable/power cord.
	3 Defective switch.	3 Check the switch for proper operation. If faulty, replace the switch.
	4 Open circuited temperature control/defective thermostat.	4 Check the temperature control/thermostat. If faulty, replace it.
	5 Open circuited windings.	5 Solder the joints of the open circuited end of the winding; if not possible, rewind.
	6 Short circuited windings.	6 Rewind.
Unit operates intermittently.	1 Loose connections.	1 If you find any such loose connection, reconnect them. Replace the temperature control or thermostat if all connections are tight and intermittent cycling continues.
	2 Intermittent switch operation (that is it turns one time and refuses to operate the next time.)	2 The easiest way to clean the switch is to spray a cleaning liquid into the switch, work the switch several times, then recheck the switch. If it still does not work properly, replace it.
Unit gives no heat at any position, but motor runs.	1 Leads of heater open.	1 Check the heater leads for proper connections.
	2 Open in heater circuit.	2 Check the heater contacts on thermostat for contamination. Check the fuse link and heater element for continuity. The thermostat must be in closed position before a continuity check can be made. Allow the hair dryer to cool so that the contact could be closed.
Motor does not run but heater operates.	1 Defective switch.	1 Change the switch.
	2 Bent impeller/fan.	2 Check the bearings and fan/impeller for bind. Lubricate the bearings, if required, with very small amount of light oil.
	3 Defective thermostat.	3 Check the thermostat for proper cut off. Also check the thermostat or temperature control for continuity.
	4 Open circuited windings.	4 Solder the joints of the open circuited winding. If it is not possible, rewind.
	5 Improper connections.	5 See that the connections are proper as per the connection diagram.
Appliance is noisy.	1 Improper mounting.	1 Check the tightness of the motor mounting.
	2 Improper fitting of impeller.	2 Check and fit the impeller on the shaft in proper position.
	3 Warped impeller/fan blade.	3 Check for a warped impeller or fan blade. If faulty, replace it.
	4 Loose parts in blower compartment.	4 Re-fasten them.

Complaints	Causes	Test and remedy
Heat selection is improper.	1 Defective heating element. 2 Defective selector switch.	1 Check the wiring as shown in the wiring diagram and connect it. 2 Check the heater element; if faulty, replace it. 3 Check the selector switch; if faulty, replace it.
Air flow is insufficient.	1 Drag on motor or impeller/fan blade. 2 Binding motor/ striking impeller fan blade. 3 Obstruction in air duct. 4 Air leakage.	1 Check the objects that are causing drag on the motor or impeller/fan blade. 2 Straighten or replace motor shaft/ striking impeller. 3 Clean the internal parts. 4 Check for an excessive air leakage around the air duct and repair it.
Thermostat cuts unit off repeatedly.	Blockage of air flow.	Check the fan hose, bonnet opening. If full flow of air is felt, the thermostat may be defective. Replace it.
Sparking at brush position.	1 Loose brushes. 2 Commutator pitted. 3 Shorted winding	1 Check the spring tension of brushes. Adjust if necessary. If the brush length is 1/3rd of its original size replace it. 2 Clean the commutator, and if necessary, use smooth sandpaper for cleaning. 3 Check the winding. If found defective, rewind.

Care and maintenance of hair dryers

There are many different varieties of hair dryers in the market. It is very difficult, therefore, to give one procedure for disassembling and assembling all of them. Hence, it is advisable to try to obtain the manufacturer's service manual/instruction to help the disassembling process, use the troubleshooting procedure given in Table 1 and assemble the unit according to the instructions. The power cord has to be inspected at intervals and changed, if found in damaged condition. Dropping the hair dryer on to the ground will result in damage to the dryer hood.

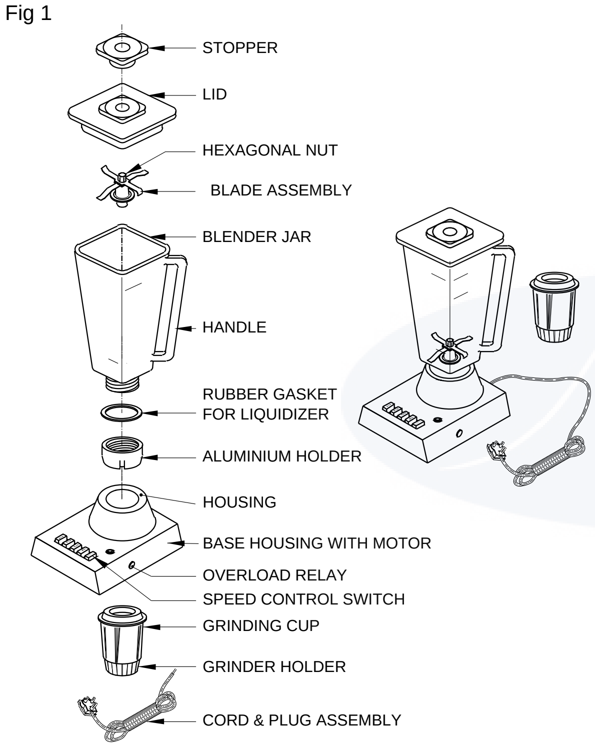
The hair dryer hood material is made up of very thin plastic. If it is torn, it can often be satisfactorily patched with 1/2 inch wide vinyl plastic tape of the same colour or could be fixed using synthetic glues. Hair dryers need servicing once in six months to extend their efficiency and life which will also increase safety to the user.

Food mixer

Objectives: At the end of this lesson you shall be able to
- **name the principal parts of a food mixer**
- **maintain and service the mixer**
- **list their common problems, causes, and suggest remedial measures.**

Food mixers, blenders, grinders, juicers and possibly a few other appliances can all be lumped into the same category, as far as their general design and construction are concerned. They are used to grind food items, mix them and make fruit juices etc., They all use a medium sized universal motor. An exploded view of a mixer is shown in Fig 1.

Fig 1



EXPLODED VIEW OF A FOOD MIXER

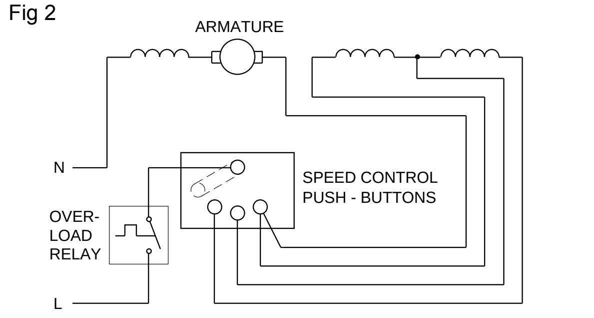
The motor housing differs widely depending on the manufacturer. Every such housing part takes care of vibration-free running. For two or more speeds required, the tapping is taken out from the field coil winding.

Safety features such as overload trip, jar mounting lock (fixing) and proper lid closing are included in the appliances.

An AC universal motor is housed in the base. The jar contains the cutting knives which is the heart of the blending action. A schematic diagram of a typical mixer is shown in Fig 2.

A food mixer power rating ranges from 100 to 650 watts. The revolution of the food mixer is 3000 to 14000 revolutions per min. The desired blending speed is selected on the control switch. When the desired blending is obtained, the user should switch off the mixer.

Fig 2



SCHEMATIC DIAGRAM OF A TYPICAL PORTABLE 3 - SPEED FOOD MIXER

The time rating of running the mixer varies from 1 minute to 60 minutes depending upon the type.

A tapped field coil as shown in Fig 2 enables speed selection through a rotary or push button switch.

The food mixer normally runs at 3 speeds.

Maintenance and servicing of a food mixer

The design of the food mixer differs from manufacturer to manufacturer and one model to other. The following are the general instructions to maintain or service a food mixer.

The manufacturer's service manual, if available, will be of great help. Read it a number of times and follow the instruction whenever the mixer comes for repair or maintenance. First listen to the complaint from the customer and make a note of it. Visually check the mixer right from the plug to the speed selector switch connections and enter the details in the maintenance card.

Test the mixer with and without the power cord for the continuity and insulation resistance. Enter the details in the same card. The insulation resistance value either for the mixer with the power cord or for the individual part should not be less than 1 megohm.

The metal bodied mixer should have effective earth connection to the body, the power cord should be 3-core and the plug and socket should be of 3-pin/socket type with effective earth. But double insulated (PVC body) mixers may have two core cable and 2-pin plug type. A damaged plug or power cord should be replaced.

Check the brush tension and make it normal. Check the brush length; if found short by 2/3rd of its original length, replace it with the same specification brush or a brush obtained from the manufacturer of the mixer.

Check the switch for its proper function. Better to replace a faulty one with a new one having the same specification.

Before opening the motor assembly, check the couplings for their proper form. Check the play of the shaft and vertical movement to get an idea of the condition of the bearings. Tight bearing may be due to misalignment, bend in the shaft, dried grease or lubricant, dirt, damaged commutator or due to damaged bearing.

Overheating due to bearing problems will be indicated by the change of colour of the shaft near the bearing to blue colour. While removing the motor assembly remember the holding nuts in the centre shaft, the coupling etc. provided in line with the shaft on left handed threads. Clockwise rotation will tighten them. Certain types of mixies may have right hand thread. Check these differences.

Check the winding for burnt smell or discoloured look. Ascertain through the tests whether the winding is shorted, open or has lost its insulation resistance value. If required rewind or get the rewinding done from outside agencies.

Always remember the sequence in which you opened the parts. It will help you to reassemble them without difficulty.

At this stage prepare the hints following the constructional details/sketch for the particular make and model you are working on which will be of great help in future.

Check the play between the bushings and the shaft. If the gap is too much it will be better to change the bushings. Lubricate the bearings with a thin oil as recommended by the manufacturer. One or two drops of thin oil will be sufficient. As the speed of the mixer is in the range of 3000 to 14000 r.p.m. a thin oil like thin spindle oil is recommended.

The ebonite washers and rubber gaskets may be replaced with new ones. While replacing see the order in which these washers and gaskets were fitted earlier and refix them in the same order.

A record may be maintained with all the required details so that if the same mixer or similar mixer comes for repair it will be easy to repair it.

Any part to be replaced should be of the same specification or from the original manufacturer preferably.

Make certain that each bearing is free on the shaft but not very much slack.

While tightening the screws on the motor housing, spin the armature with your fingers at intervals during the assembling process to ensure that it is not getting bound.

Reassemble the switch and do all the connections.

Reassemble the base plate, tighten the screw.

Reassemble the blade with the washer inside the jar and with the bottom coupling. If the coupling of the jar is not snugly fitting to the male coupling of the motor assembly, the jar coupling will get easily damaged at frequent intervals. Correct height alignments could be made by replacing or alternate sequencing of the fibre washers.

Fix the jar/container on the drive coupling.

Connect the supply cord as per the circuit diagram.

Test the mixer for continuity and insulation resistance. Minimum acceptable insulation resistance value is 1 megohm.

Connect the supply, and test for its working.

Ceiling fan

Objectives: At the end of this lesson you shall be able to
- **explain the construction of a ceiling fan**
- **describe the causes for the common faults and their remedy**
- **describe the dismantling procedure for the ceiling fan.**

Ceiling fan

The function of a fan is to circulate air for cooling purposes. The capacity of the fan is usually expressed in its sweep and wattage. Ceiling fans are installed in houses, offices, educational institutes etc., for human comfort.

Construction

The ceiling fan consists of a:

i rotating part
ii stationary part.

The rotating part consists of (Fig 1):

i Body
ii Fan blades
iii Bearings
iv Squirrel cage winding. (Rotor)

The stationary part consists of:

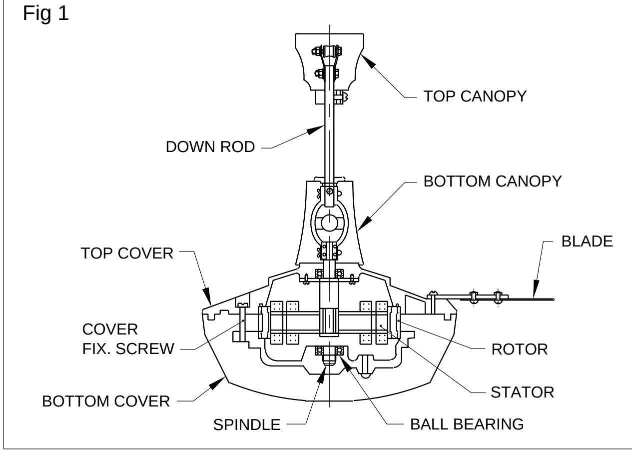
i Canopy
ii Shackle, bolt, nut and split pin
iii Suspension rod (Down rod)
iv Terminal block
v Capacitor
vi Stator winding.

The stator winding has

i an auxiliary winding
ii a main winding.

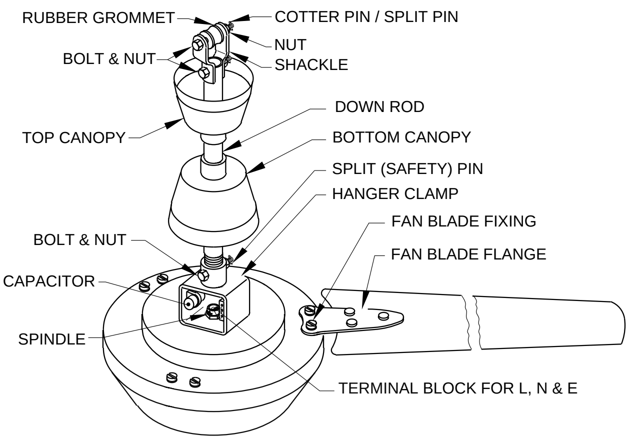
The parts of a ceiling fan are shown in Figs 1 & 2.

Fig 1



The rotor and the bottom cover are integral and die-cast in high conductivity aluminium alloy so as to give better accuracy which improves the efficiency of the cooling system.

Fig 2



The fan motor has a capacitor connected to the auxiliary winding to have good starting torque.

The top cover is made of die-cast aluminium.

The fan blades are made of aluminium sheet. The size will depend on the area of the room, its usage and appearance. The performance of the fan depends on the number of blades and their pitch angle which varies from say 10 to 15^o. Ceiling fans are available with three, four blades.

The size of the fan is generally determined by its sweep. **Sweep** is the distance between the tips of the blades when they make a circle during rotation. The following sweeps are available 900 mm, 1050 mm, 1200 mm and 1400 mm.

The body (rotor) and the blades are freely rotated with the help of ball-bearings or bush-bearings which are housed on the top and bottom cover of the fan. The blade is fixed to the top cover by clamps and bolts.

The entire unit is then hung from the ceiling with a suitable G I pipe threaded on both sides and tightened with suitable check nut and with a split pin so as to avoid falling of the entire unit while running because of slackened nut and bolts. The ceiling fan must be fitted to the ceiling hook with shackle and bolt and nut and secured by split pin.

The auxiliary winding is connected in series with a capacitor and the main winding is connected across the supply. Normally the auxiliary winding will have a higher resistance and lower inductance than the main winding. These two windings create a rotating magnetic field, when a supply is given to the winding.

The capacitor used is an electrolytic, non-polarised type. The capacitor value varies according to the sweep of the fan i.e. from 2 micro-farad to 5 micro-farad and rated to 400 V AC.

Regulator

The speed of the fan can be varied by changing the applied voltage.

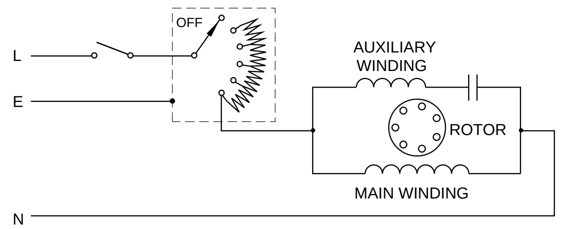
The most common method is to vary the applied voltage

- by tapped series resistors
- by tapped series inductors.

Tapped inductors are not being manufactured now as the use results in low power factor in the circuits.

The schematic diagram of a fan with a resistance regulator is shown in Fig 3.

Fig 3



FAN CONNECTION USING A RESISTANCE TYPE REGULATOR

As per National Electrical Code, the metal body of all fan regulators should be earthed.

Care and Use

Manufacturers are very careful to balance the fan blades and other moving parts of the fan. The technician should also be careful in assembling and working around the fan so as not to damage the blades or disturb their balance.

Carelessness in handling will cause the blades to wobble or vibrate, which will end up in noisy operation and also shorten the life of the fan. Check the blade attachment screws periodically since loose screws can cause noise, wobble and accidents.

Normally each fan has its own set of blades which are factory balanced. Changing one set of blades to another may sometimes result in unbalancing.

Dismantling and assembling of fans

1 Disconnect the supply by switching off the control switch and removing the circuit fuse or switching off the main isolating switch.

2 Remove the blades by reaching to the height of the ceiling fan by climbing a stable elevation (ladder or table).

3 Disconnect the wires from the ceiling rose.

4 Lower the top canopy.

5 Bring down the fan after removing the split pin, the cotter and the rubber grommet from the shackle and clamp.

6 Disconnect the supply cord from the terminal block and separate the down rod along with the canopies from the condenser house.

7 Note down the connection and colour of wires, if any, and disconnect the fan terminal from the terminal block.

8 Remove the decorating cup if available in the bottom of the body by unscrewing in anticlockwise direction and remove the false cover.

9 Remove the split pin and set screw.

10 Remove the condenser (capacitor) from the housing.

11 Mark and unscrew the cover fixing screws and separate out the bottom cover and the rotor.

12 Pull out the rotor and the stator from the top cover.

13 Inspect all the removed parts.

14 Replace the defective components.

Assembling

Assemble the dismantled parts in the reverse order to that of dismantling. Check the screws are tightly fitted and split pins lock in position.

Before installing the ceiling fan care has to be taken to test the fan for its insulation resistance between the winding and the body.

GENERAL FAULTS AND REMEDY

Fault	Causes	Remedy
Noise	It is due to worn out bearings and absence of lubricating oil or grease.	The bearings must be replaced if worn out; otherwise lubricate with proper lubricant.
	Humming or induction noise is due to non-uniform air gap owing to the displacement of the rotor.	Dismantle and reassemble properly.
Low speed	It is due to defective or leaky capacitor.	Replace the capacitor with one of the same value and voltage.
	Low applied voltage.	Check the voltage and adjust if possible.

Fault	Causes	Remedy
Jamming of the rotor	It is due to misalignment.	Dismantle and assemble property after proper lubrication.
Not starting	Low applied voltage.	Check the voltage and adjust it , if possible.
	Supply failure.	Check the supply points at switch, regulator ceiling rose and the terminal of the fan.
	Open in winding.	Check for the continuity of auxiliary and main windings.
	Condenser open or short.	Check the capacitor with a Megger.
	Open in regulator resistor/switch.	Check for open or loose contact in the resistor or contacts.

Table fan

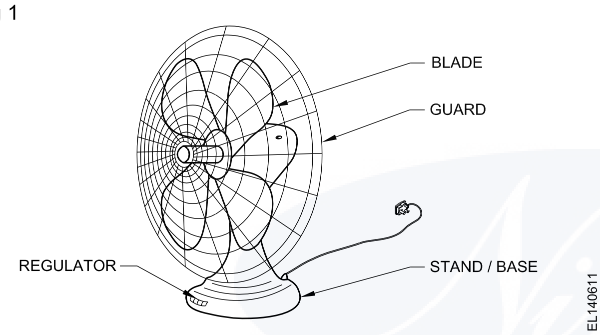
Objectives : At the end of this lesson you shall be able to
- **describe the construction and working of a table fan**
- **list the faults and remedies in a table fan**
- **describe the safe procedure of dismantling and assembling a table fan.**

Table fan

The table fan is also called the desk fan which can be oscillating or non-oscillating. They are commonly mounted on a heavy base and are furnished with a set of blades.

Oscillating fans are so termed because they oscillate in a back and forth motion as the motor of the fan rotates. In this manner they can move a larger volume of air in the room or area in which the fan is placed. The table fan is a portable fan which can be kept on the table or wherever air circulation is needed. (Fig 1)

Fig 1



The table fan motor is mostly of a capacitor start or split phase, single phase induction type.

Construction: The table fan has parts that are stationary and rotating.

The stationary part consists of:

- guard (front and back)
- body and stand
- oscillating unit and gearbox
- regulator
- winding (stator)
- capacitor
- bush bearings (or)
- captive ball bearings.

The rotating part consists of:

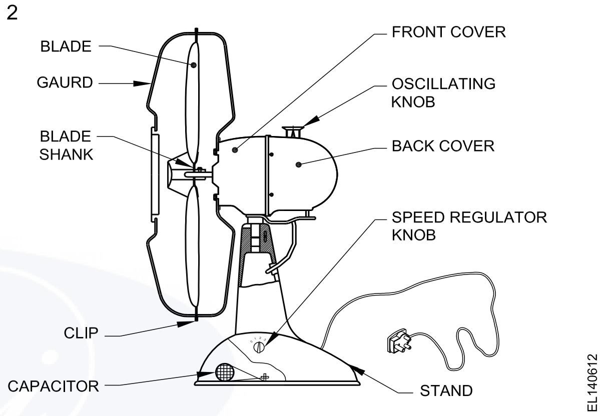
- squirrel cage rotor
- fan blades.

Construction: The body of the table fan is usually made of diecast iron or aluminium alloy. The body is fitted or mounted to the heavy base stand, made of diecast iron or aluminium.

The body consists of stator windings. There are two sets of coils called starting and running windings. The windings are placed in slots of laminated iron core. The winding ends are brought out to the terminal block or connector. A flexible cable from it connects to the supply main via the regulator. The regulator, capacitor, and the switch are fitted in the space provided at the stand.

The front and rear of the the fan guard's are made out of wire mesh which covers the blade. It prevents the external objects coming in contact with the blade thus preventing an accident. The blades' assembly is fitted to the rotor shaft with a bolt as shown in Fig 2.

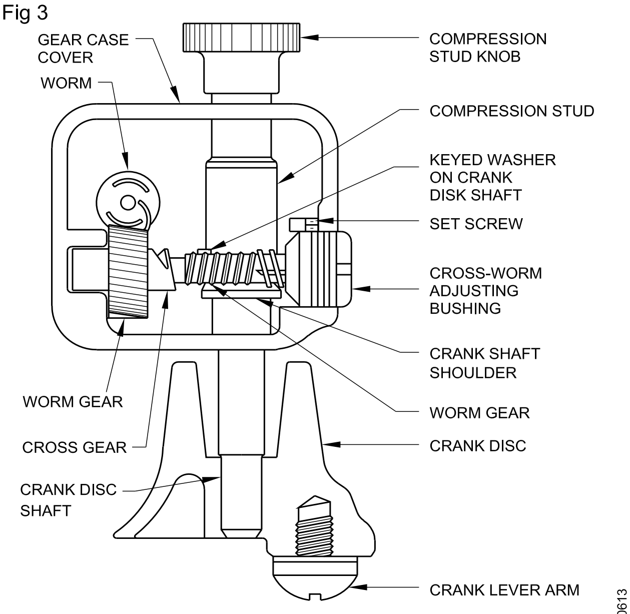
Fig 2



The blades are fabricated out of aluminium for light weight. Modern table fans have moulded blades of plastic material. The sweep of the blade varies from 100mm to 400mm. The number of blades varies from two to six. The speed of the fan is limited to 1000 r.p.m.

Oscillating unit:

Fig 3



OSCILLATING MECHANISM

The oscillating unit mechanism (Fig 3) consists of a worm gear of a motor shaft that engages a gear on a short jack with the gear on the vertical shaft. A disc attached to the lower end of the vertical shaft rotates at a very slow speed and by means of a stout lever attached to the disk at one end and the motor at the other end, the fan is caused to oscillate. This principle is employed in most oscillating fans. Some models use a vertical shaft with a knob that is built into the gear mechanism with a clutch device. This design permits the fan to be used either as a stationary or oscillating model.

Bearing: Most of the fan motors use phosphor bronze sleeve bearings mounted in the bell housings, and use felt wicks to supply oil to a small hole drilled through the bearing wall. The felt receives oil from a hole in the bell housing. Most of the fan motors use a captive ball bearing to locate the rotor. It is held in place by spring clips in the bell housing and is self-aligned.

Faults and remedy: The faults in a table fan may be

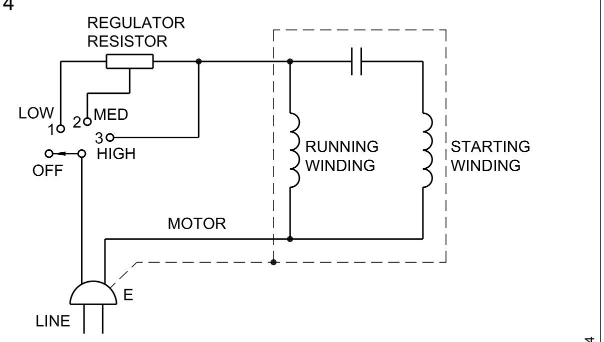
- mechanical fault
- electrical fault.

Servicing: As was mentioned earlier, a fan consists of a motor, blade assembly and selector control switch. Most fans use a series-inductor or resistor in the speed control system. The majority of the three-speed fans employ the tapped series resistor control. As shown in Fig 4, in a three-speed fan not all the series resistors are used except in the low position.

Then, if the fan motor will run only on high or medium speed but not on low speed, the problem is usually in the portion of the series resistor between the medium and low terminals. Or, if the fan motor runs only in the high position, the trouble is in the series resistance between the high and medium terminals. Also check for a dirty switch and a loose contact or wire. Often a dirty switch contact will cause one or more speeds to go dead.

If a fan runs on any one speed, the chances are that the motor is in good operating condition. For example, if it will runs on medium but not on high or low, the switch is almost surely faulty. Most of the time, cleaning the control switch contacts with a contact cleaner will solve the problem. If it does not, replacement of the switch is the only answer. If a resistor is found by a continuity test to be either open or shorted, it should be replaced.

Fig 4



SCHEMATIC DIAGRAM OF A THREE-SPEED FAN MOTOR. THERE ARE NO ELECTRICAL CONNECTIONS TO THE ROTOR OF THIS MOTOR

A fan that runs slowly may have shorted field winding or it may have a defective speed control. Lack of proper lubrication can also cause a fan to operate more slowly than normal. For specific information on lubrication, check the user's guide or the service manual.

If the fan motor refuses to run at all, check the cord-set. The cord set because of constant pulling, might have opened wires; the line cord itself may have problems near the plug.

The wires may be broken inside the insulation. Since most of the plugs are of the moulded-on type, the only repair usually is to cut off about 8 or 10 cms of the cord and instal a replacement type line plug. If the jacket of the cord itself is worn out, frayed, or broken in places, replace it.

If the fan is not oscillating the cause may be with the compression stud, worm gear and pinion and also the spur gear (broken teeth). Sometimes bent shaft causes the oscillation to stop.

Condition of fan and suggested action

Motor does not run.

- Check the cord-set, selector switch, winding and connections for continuity.
- Check for binding rotor.

Motor does not respond properly when the selector switch is operated.

- Check the speed control switch.
- Check the series resistance or the reactance choke.

Motor runs hot, slowly or intermittently; fan consumes above-normal power.

- Check for shorted winding. If defective, replace the complete motor winding.
- Check for bent rotor shaft.
- Check for bound or frozen bearings. Clean and lubricate the bearings.

Fan is noisy or vibrates.

- Check the blade for distortion, breakage, warpage, imbalance and misalignment.
- Check the blade for loose hub or elements.
- Check the bearings for dirt or lack of lubrication.
- Check the rotor shaft. If it is loose or bent, replace the rotor.
- Check for steel chips in between stator and rotor. Remove the rotor and blow out the winding with compressed air, if any chips are found.
- Check for loose guards.
- Check whether the rotor is rubbing with the stator.
- Check for loose or missing screws.
- Check to see that the blades are out of balance.

Fan does not oscillate.

- Check the compression stud, worm gear and pinion.
- Check the spur gear for broken teeth.
- Check for a bent rotor shaft.
- Check the spur gear pin for proper setting. If it is loose, either knurl the end slightly and press it into place or replace the complete gear assembly.

Fan has magnetic hum.

- Check the air gap for unevenness. If the gap is incorrect, loosen the field screws and correct the position of the field.
- Check the armature for a bent shaft.
- Check for worn out or loose bearing fit. If bearings are defective, replace them. When replacing, clean the gear case of all old grease. The bearing swivel stud washers and rotor shaft should be lubricated with a light film of SAE-30 motor oil.

Bearings of the oscillating mechanism rattle.

- Check for worn out bearings, particularly at the motor end.
- Check the rotor shaft for excessive wear.
- Check for proper grease. Clean out the gear case and replace with the grease recommended by the service manual.

How to dismantle?: Follow the manufacturer's instructions and drawing. If they are not available, the steps suggested here may be be of use.

- Open the front guard by sliding up the guard clips. Pull out the decorating cup.
- Unscrew the blade set by unscrewing the screw on the blade shank bush at the back.
- Unscrew four numbers of hexagonal head bolts/ screws and take out the back guard.
- Unscrew the oscillating knob-fixing screw and remove the knob.
- Unscrew the back cover fixing screw at the back and take out the back cover.
- Disconnect all connecting leads from the motor terminal after proper marking.
- Unscrew the link-fixing screw to the rotating pivot.
- Unscrew the pivot pin-holding screw from the stand.
- Remove the motor from the stand. Take care of the steel ball.
- Unscrew the three grub screws from the front cover where the back cover sits. Separate and remove the back cover with the gearbox from the front cover by lightly tapping the spindle backward. Take out the rotor.
- Unscrew the three screws fixed on the back cover to remove the gearbox.
- Now check up the components. These should be repaired/replaced as the case may be.
- Unscrew the bottom base screw at the bottom of the stand and remove the base plate. Check up the connections, resistor switch etc. Repair/replace the defective parts.

The assembling is to be carried out step by step in the reverse order to that of dismantling.

PVC conduit wiring

Objectives: At the end of this lesson you shall be able to
- **distinguish between the different types of conduits used in wiring**
- **state the gauge, diameter and length of the metallic and non-metallic conduits available in the market**
- **state the variations in the conduit wiring system**
- **compare metal and PVC conduit wiring**
- **state the different types of accessories used in non- metallic conduits wiring**
- **select a suitable size of conduit for a specific number and size of cables.**

In general, a conduit is defined as a tube or channel. Tubular conduit is the most commonly used material in electrical installations. When cables are drawn through the conduit and terminated at the outlet or switch points, the system of wiring is called conduit wiring.

Types of conduits

There are four types of conduits used for wiring.

- Rigid steel conduit
- Rigid non-metallic conduit
- Flexible steel conduit
- Flexible non-metallic conduit

Rigid steel conduit:

This can be further divided into:

- heavy gauge screwed conduit and
- light gauge conduit.

Heavy gauge screwed conduit: This can be either solid-drawn or seam - welded. A solid-drawn conduit is expensive, and hence, its use is restricted to gas-tight, explosive-proof installations. Seam - welded conduit is the one commonly used in modern domestic, commercial and industrial wiring.

Light gauge conduit: This is constructed from a length of flat, thin sheet steel which is manufactured to form a tube. The seam, which is often left open, does not provide a weatherproof installation. Hence, the use of a light gauge conduit is restricted to indoor-conduit wiring to have protection for inlaid cables. This conduit itself should not be used as earth continuity conductor; separate earthing conductors are, therefore, necessary.

Size of metal conduits: Commercially metal conduits are available in lengths of 3.00 metres and in diameters from 16 mm to 65 mm.

Normally the conduit pipe size refers to the outer diameter, whereas for G.I. pipes, the sizes are referred to in terms of the internal diameter.

All metallic conduits get corroded in damp and chemical environment. Hence conduits are to be protected against corrosion by galvanising them, when used for outdoor work or where dampness is present. For dry environments black enamelling on the conduit would be sufficient.

Non-metallic conduits: These are made of fibres, asbestos, polyvinyl chloride (PVC), high density polyethylene (HDP) or polyvinyl (PV). Of the above, PVC conduits are popular owing to their high resistance to moisture and chemical atmosphere, high dielectric strength, low weight and low cost. These conduits may be buried in lime, concrete or plaster without harmful effects.

TABLE 1

Nominal size of conduit in mm	Wall thickness of heavy gauge conduit in mm	Wall thickness of light gauge conduit in mm
Metal 16	1.6	1
19	1.8	1.0
25	1.8	1.2
32	1.8	1.2
38	2.0	---
50	2.24	---
64	2.5	---
Non- metal 16 to 64	2 or more than 2	Less than 1.5

However, light gauge (lower than 1.5 mm wall thickness) PVC pipes are not as strong as metal conduits against mechanical impact. Special PVC pipes called heavy gauge, high impact types are available in the market which can withstand heavy mechanical impact as the wall thickness of the pipes is more than 2 mm.(Refer Table 1)

There are some PVC conduits called heavy gauge, high temperature type which are of special base material made to withstand temperatures up to 85°C. These PVC conduits are available in 4 m length.

Flexible conduits: Apart from rigid conduits, flexible conduits are also used for protecting cable-ends connected to a vibrating machine. In the case of metal flexible conduits, steel strips are spirally wound to form a tube. However, these flexible conduits cannot be relied on as the sole means of earthing due to the manufacturing method as well as material. Hence earthing conductors should run either externally or internally to the flexible conduit to form the earth connection.

Variation in conduit-wiring system: There are two types of conduit-wiring systems as stated below, for either metal of non-metallic types.

- Surface conduit-wiring system done on wall surfaces.
- Concealed (recessed) conduit-wiring system done inside the concrete, plaster or wall.

Selection of the type of conduit: Metallic or PVC conduits are equally popular in electrical installations.

Selection of the type of conduit depends upon the following criteria.

- Location-outdoor or indoor
- Atmosphere-dry or damp or explosive or corrosive
- Working temperature
- Physical damage due to mechanical impact
- Weight of conduit-runs
- Cost

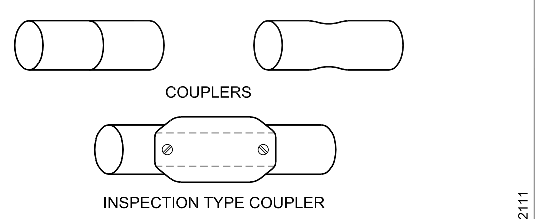
A comparison between metal and PVC conduit wirings given in Table 2 will help in choosing the right type of conduit for a specific installation.

Non-metallic conduit accessories: Non-metallic conduit fittings and accessories shall be fabricated or moulded to the required shape. They shall be so designed and constructed that they can be fitted with the corresponding conduit sizes without any adjustment, and ensure ready limited mechanical protection to the cables. These fittings and accessories are used for conduit extension and tappings or to assist the pulling conductors.

Inspection type, non-metallic fittings and accessories are permitted to be used only with surface-mounting type wiring. Inspection fittings shall be so constructed that the screws used for fixing the cover do not deform the conduits or damage the insulation of the cables enclosed.

PVC fittings and accessories couplers (Fig 1): Normally push-type couplers are used and the conduit shall be pushed right through to the interior of the fittings. Inspection type couplers are used in straight conduit-runs to assist in the inspection of the straight cables.

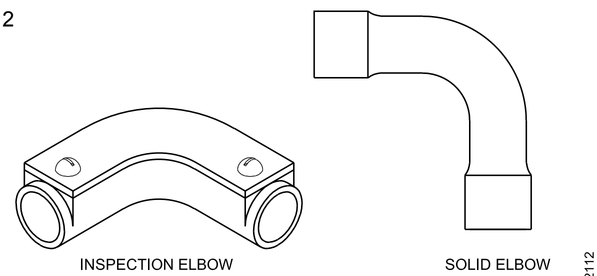
Fig 1



TYPES OF COUPLERS

Elbow (Fig 2): The axis of any elbow shall be a quadrant of a circle plus a straight portion of each end. Elbows are used at sharp ends of nearby walls or roofs and walls.

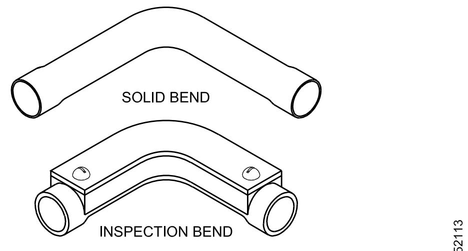
Fig 2



TYPES OF ELBOWS

Bends (Fig 3): A bend gives a diversion of 90°C in the turn of a conduit, and a normal bend shall be a large sweep. Inspection-type bends are used to assist in the inspection at the corners and for drawing cables.

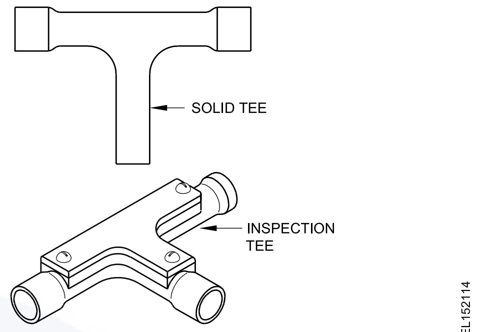
Fig 3



TYPES OF BENDS

Tees (Fig 4): Tees are used to take diversion from the main line either to drop to switch points or to the light points. It may be either an ordinary type or an inspection type. Inspection-type tees are used to assist in the inspection in case there is a need.

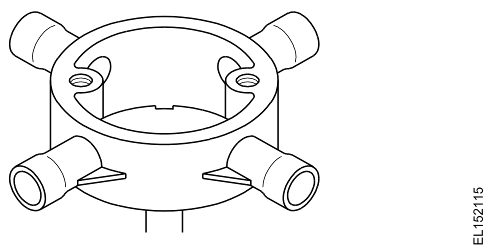
Fig 4



Boxes

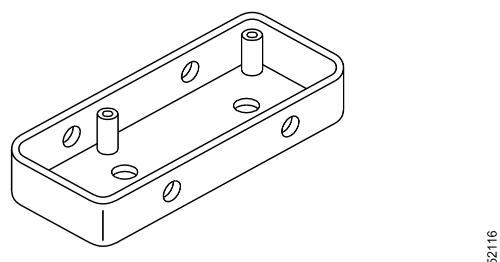
Circular boxes (Fig 5): Small, circular boxes shall be provided with two machine screws of a diameter not less than 2.8 mm for fixing the covers. Large, circular boxes have four machine screws of a diameter not less than 4 mm for fixing a cover. They are available in single-way, two-way, three-way and four-way as well as back outlet types which can be used as per necessity in the wiring.

Fig 5



Rectangular boxes (Fig 6): These boxes shall be provided with two machine screws of a diameter not less than 2.8 mm for fixing the cover. They can be used as a junction box or a switchboard, for fixing flush-type switches.

Fig 6



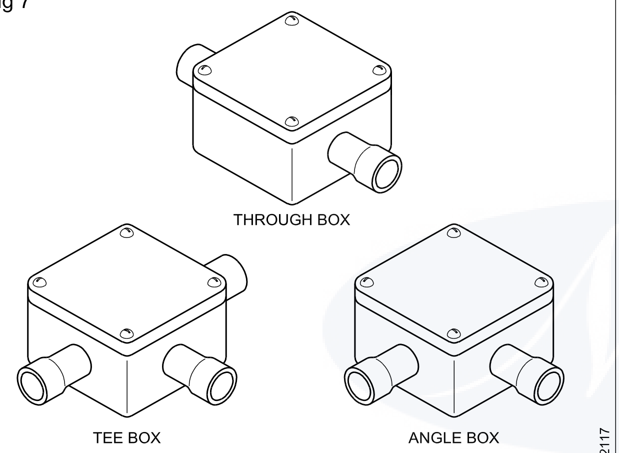
RECTANGULAR BOX

TABLE 2

Metal conduit	PVC conduit
1 Provides good physical protection to cables.	Comparatively poor.
2 Weighs more for a given length.	Lighter.
3 Needs skill and time for installation.	Needs less skill and time.
4 Risk of electric shock due to leakage.	No risk as PVC is an insulator.
5 Good earth continuity available through the	Not possible.Separate earth wire is required. pipe itself.
6 Can be used in gas-tight and explosive-proof installation.	Not suitable.
7 Not resistant to corrosion, needs protective coating.	Resistant to corrosion.
8 Large ambient temperature range.	Suitable for limited temperature range. At temperatures above 60^{0}C, the conduit starts melting. At very low temperatures the conduit cracks.
9 Fire-resistant.	Not fire-resistant.
10 More costly.	Less costly.

Apart from the above types, various other types are used as junction boxes. (Fig 7)

Fig 7



TYPES OF BOXES (JUNCTION BOXES)

Selection of conduit size: Non-metallic conduit pipes, used in wiring, should have a minimum size of 16 mm in diameter. Where a large number of conductors are to be drawn, the size of the diameter depends on the size of the conductor and the number of conductors.

Table 3 gives details of numbers and the size of conductors that can be drawn in each size of a non-metallic conduit.

Example: For selection of a PVC conduit :

When 2.5 sq mm 250V grade, single core cables of six numbers are to be drawn in a single run we can use 25 mm non-metallic conduit. (Table 3) When 6 sq mm. 250V single core 6 cables are to be drawn in a single pipe, we can use 32 mm PVC pipe. (Table 3)

TABLE 3

Size of conduit and permissible number of cables of 250 V grade

Size of cable		Size of conduit(mm)					
Nominal cross-sectional area mm^2	Number and diameter in mm of wires	16	19	25	32	38	51
		(Number of cables, max. in straight run)					
1.0	1/1.12 Cu	5	7	13	20	-	-
1.5	1/1.40 Al/Cu	4	6	10	14	-	-
2.5	1/1.80 Al/Cu	3	5	10	14	-	-
4	1/2.24 Al/Cu 7/0.85 Cu	2	3	6	10	14	-
6	1/2.80 Al/Cu 7/1.06 Cu	-	2	5	8	11	-
10	1/3.55 Al 7/1.40 Cu	-	-	4	7	9	-
16	7/1.70 Al/Cu	-	-	2	4	5	12
25	/2.24 Al/Cu	-	-	-	2	2	6
35	7/2.50 Al/Cu	-	-	-	-	2	5
50	7/3.00 Al 19/1.80 Al/Cu	-	-	-	-	2	3

Cu - For copper conductors only. Al - For aluminium conductors only.

Dynamically induced EMF

Objectives: At the end of this lesson you shall be able to
- **state the principle of a DC generator**
- **explain Faraday's Laws of Electromagnetic Induction**
- **explain the method of producing dynamically induced emf, its magnitude and direction**
- **explain the fleming's right hand rule.**

Generator:An electrical generator is a machine which converts mechanical energy into electrical energy.

Principle of the Generator:To facilitate this energy conversion, the generator works on the principle of Faraday's Laws of Electromagnetic Induction.

Faraday's Laws of Electromagnetic Induction: There are two laws.

The first law states:

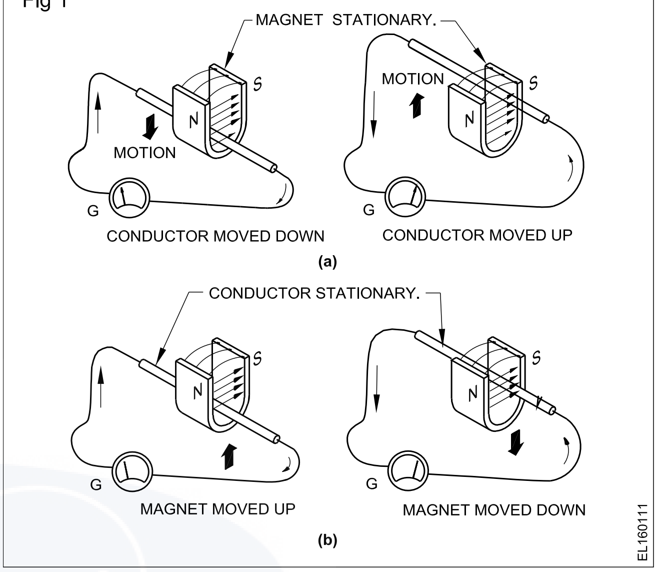
- whenever the flux linking to a conductor or circuit changes, an emf will be induced.

The second law states:

- the magnitude of such induced emf(e) depends upon the rate of change of the flux linkage.

$$e \propto \frac{\text{Change of flux}}{\text{Time taken for change}}$$

Fig 1



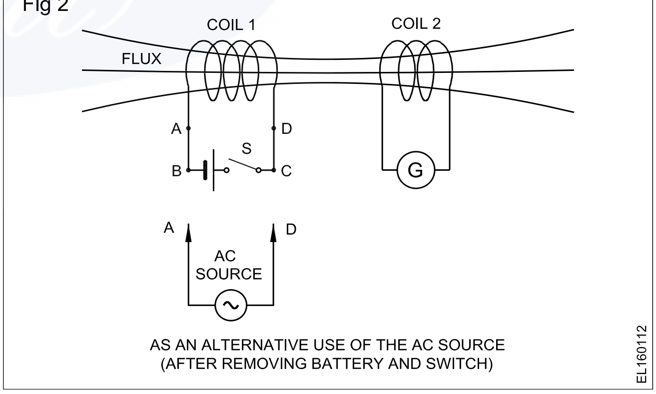
Types of emf: According to Faraday's Laws, an emf can be induced, either by the relative movement of the conductor and the magnetic field or by the change of flux linking on a stationary conductor.

Dynamically induced emf: In case, the induced emf is due to the movement of the conductor in a stationary magnetic field as shown in Fig 1a or by the movement of the magnetic field on a stationary conductor as shown in Fig 1b, the induced emf is called dynamically induced emf.

As shown in Figs 1a & 1b, the conductor cuts the lines of force in both cases to induce an emf, and the presence of the emf could be found by the deflection of the needle of the galvanometer `G'. This principle is used in DC and AC generators to produce electricity.

Statically induced emf: In case, the induced emf is due to change of flux linkage over a stationary conductor as shown in Fig 2, the emf thus induced is termed as statically induced emf. The coils 1 and 2 shown in Fig 2 are not touching each other, and there is no electrical connection between them.

Fig 2



According to Fig 2, when the battery (DC) supply is used in coil 1, an emf will be induced in coil 2 only at the time of closing or opening of the switch S. If the switch is permanently closed or opened, the flux produced by coil 1 becomes static or zero respectively and no emf will be induced in coil 2. EMF will be induced only when there is a change in flux which happens during the closing or opening of the circuit of coil 1 by the switch in a DC circuit.

Alternatively the battery and switch could be removed and coil 1 can be connected to an AC supply as shown in Fig 2. Then an emf will be induced in coil 2 continuously as long as coil 1 is connected to an AC source which produces alternating magnetic flux in coil 1 and links with coil 2. This principle is used in transformers.

Production of dynamically induced emf: Whenever a conductor cuts the magnetic flux, a dynamically induced emf is produced in it. This emf causes a current to flow if the circuit of the conductor is closed.

For producing dynamically induced emf, the requirements are:

- magnetic field
- conductor
- relative motion between the conductor and the magnetic field.

If the conductor moves with a relative velocity 'v' with respect to the field, then the induced emf `e' will be

= BLV Sinθ Volts

where

B = magnetic flux density, measured in tesla

L = effective length of the conductor in the field in metres

V = relative velocity between field and conductor in metre/second

θ = the angle at which the conductor cuts the magnetic field.

Let us consider Fig 3a in which conductors A to I are placed on the periphery of the armature under magnetic poles. Assume for this particular generator shown in Fig 3a, the value of BLV = 100V.

Accordingly the conductor A induces an emf

= BLV Sin θ where θ = zero and Sin zero is equal to zero

= 100 x 0 = zero.

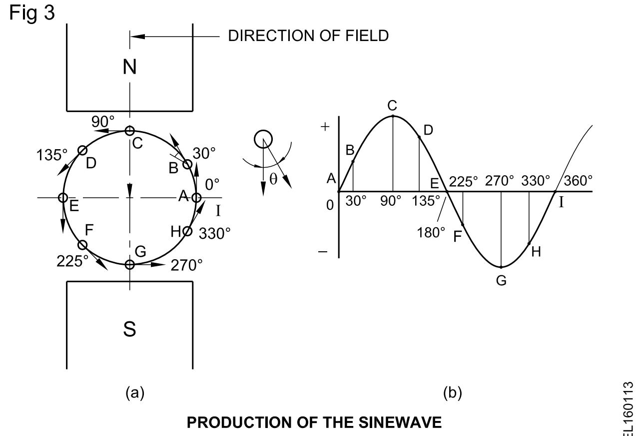
emf induced in
Conductor B = BLV Sin 30°
= 100 x 0.50
= 50 volts.

emf induced in
Conductor C = BLV Sin 90°
= 100 x 1
= 100 V.

emf induced in
Conductor D = BLV Sin 135°
= BLV Sin 45°
= 100 x 0.707
= 70.7 volts.

emf induced in
Conductor E = BLV Sin 180°
= Sin 180°= 0
= 100 x 0
= zero.

Fig 3



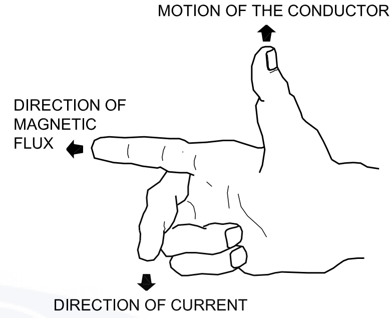
PRODUCTION OF THE SINEWAVE

Likewise for every position of the remaining conductors in the periphery, the emf induced could be calculated. If these values are plotted on a graph, it will represent the sine wave pattern of induced emf in a conductor when it rotates under N and S poles of uniform magnetic field.

The emf induced by this process is basically alternating in nature, and this alternating current is converted into direct current in a DC generator by the commutator.

Fleming's right hand rule: The direction of dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 4 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e. towards the observer or away from the observer.

Fig 4

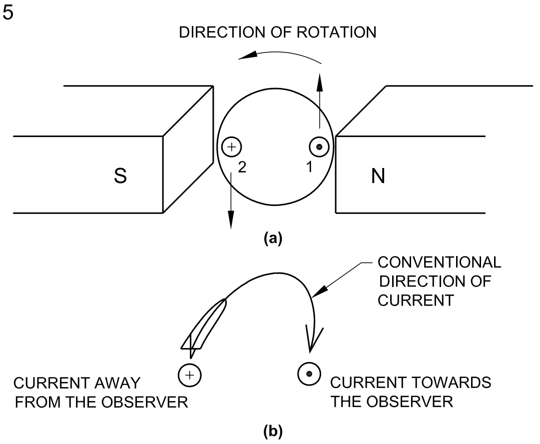


Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 5a.

Applying Fleming's right hand rule, we find that the conductor 1 which is moving upwards under the north pole will induce an emf in the direction towards the observer indicated by the dot sign and the conductor 2 which is moving down under the south pole will induce an emf in the direction away from the observer indicated by the plus sign.

Fig 5b indicates the current direction in the form of an arrow. The dot sign indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

Fig 5



DIRECTION OF THE INDUCED CURRENT

A simple generator

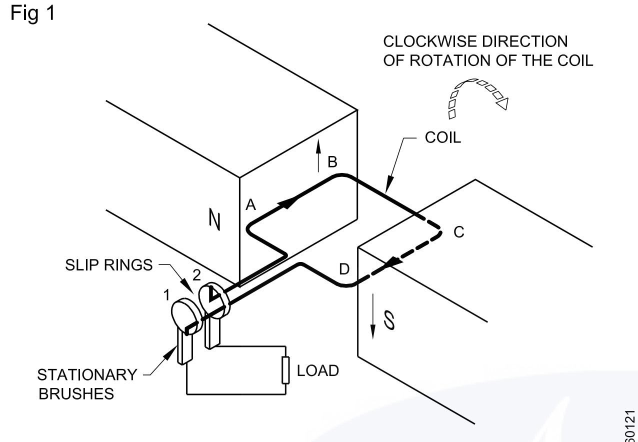
objective: At the end of this lesson you shall be able to
- **state the functioning of generator - slip rings and split rings (commutator).**

Introduction

A generator produces electrical power with the help of the rotation of a group of conductors in a magnetic field. It uses the principle of electromagnetic induction to convert the input mechanical power into electrical power.

Slip rings: Let us consider a simple AC generator having a single loop of wire and rotated within a fixed magnetic field, as shown in Fig 1.

Fig 1



SIMPLE AC GENERATOR

Let each end of the single loop coil be connected to copper or brass rings called slip rings. These slip-rings are insulated from each other, insulated and mounted on the shaft. In a broader sense this rotating assembly (coil,shaft & slip-ring) is called armature. The wire loop (armature coil) is connected to an external circuit by means of two brushes which are positioned to rub against the slip-rings. As the armature is rotated at a uniform angular velocity, the generated voltage in the loop conductor will actually be of alternating voltage.

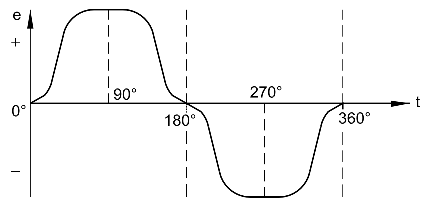
For the clockwise rotation indicated, the direction of generated voltage and the resulting current in the coil side under the north pole will be directed from A to B making the slip-ring 2 negative. This is readily confirmed by using Fleming's right hand rule. Similarly the direction of the induced voltage and the resulting current under the south pole is to be directed from C to D making the slip- ring 1 as positive. When the conductor AB moves from the north pole to the south pole, the direction of induced emf in it will reverse, so that the current will now flow from B to A making the slip-ring 2 positive. At the same time coil side CD has moved into the north pole region and its induced emf is reversed and current will flow from D to C making the slip-ring 1 negative.

Thus for one half of a revolution (for a two-pole generator) the emf is directed around the coils A to B & C to D. For the other half of the revolution the emf is directed around the coil D to C and B to A. The current in the externally connected load resistor via the stationary brushes in contact with the pair of slip rings `1'and `2' will be alternating (AC) in nature.

Wave-shape of the induced voltage: When the output voltage is plotted against electrical degrees we get the output wave-form.

The output wave-form obtained across the load, according to the pole shape shown in Fig 1, will not be of sinusoidal shape due to un-uniform magnetic field but of rectangular shape as shown in Fig 2.

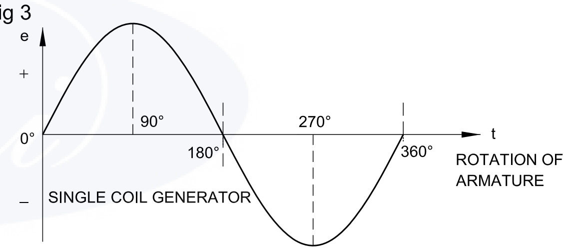
Fig 2



WAVE-FORM SHOWS COIL ROTATES UNDER UN-UNIFORM MAGNETIC FIELD

However, if the magnetic field is uniform, the output wave-form will be of sinusoidal shape as shown in Fig 3.

Fig 3



WAVE-FORM SHOWS COIL ROTATES UNDER UNIFORM MAGNETIC FIELD (SINE WAVE)

Simple generator with split-rings: A direct current generator is simply an AC generator provided with split rings instead of slip-rings.

The split ring is a ring made up of hard drawn copper cut into two segments, insulated from each other and the shaft in which it is mounted. A commercial generator uses a number of split rings called **commutators.** The split ring is a device for reversing the brush contact with the armature coil terminals, every time the induced current in the coil reverses, so that the output current taken by the brushes remains always in the same direction.

As shown in Fig 4a, if the armature rotates clockwise the split ring rotates with it, and the brushes and the poles are stationary in their position. As shown in Fig 4a, when the moving coil is in the horizontal position, the induced current will flow through the coil from ABCD to the segment `B' via the positive brush and load to the negative brush and segment A. The direction of current flow in the external circuit is shown in Figures 4a and c.

When the armature rotates so that the coil just assumes a vertical position as in Fig 4b, the brushes will short-circuit both the segments. The induced emf is zero and no current flows through the load circuit for a short moment.

When the armature rotates and the coil assumes the position as indicated in Fig 4c, the coil side AB will enter the south pole region and its induced emf will reverse, compared to the direction it had while moving under the north pole region as shown in Fig 4a.

But when this happens the split ring segments `A' and `B' will also have exchanged their positions since they rotate along with the coil.

As the emfs in the coil sides AB and CD reverse their polarity, the split ring segments to which they are connected simultaneously change their positions under the stationary brushes. As a result, the polarity of the brushes remains fixed and the current direction through the load remains as shown in Fig 4c which is the same as shown in Fig 4a.

Fig 4

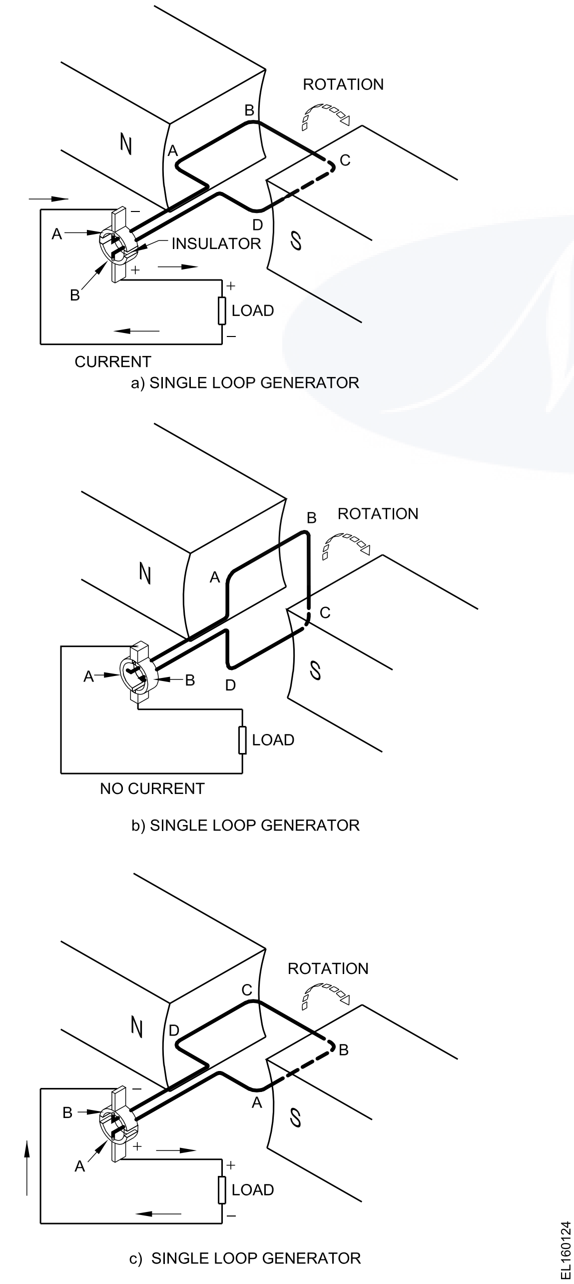
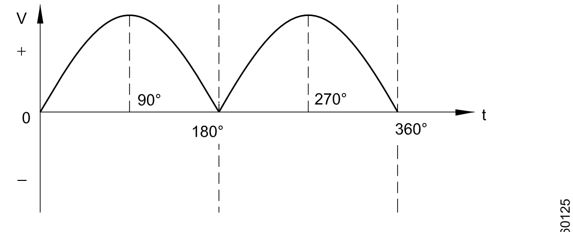


Figure 5 represents the generated voltage of a simple DC generator. The voltage is uni-directional due to the split ring action.

The induced emf by a single loop (one turn) coil is very small in magnitude and pulsating in nature as shown in Fig 5. Coils, having a number of turns in series, multiply the generated emf by the same number. However to get a steady (DC) current it is necessary to increase the pulses produced in the armature; thereby their average value is constant.

Fig 5



VOLTAGE PRODUCED IN A LOOP UNDER UNIFORM MAGNETIC FIELD

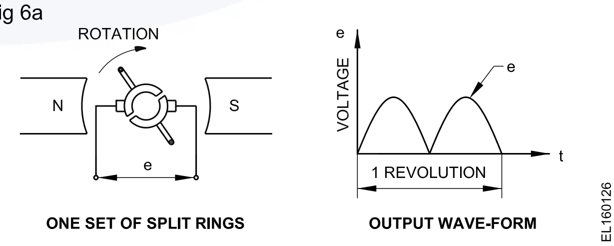
There are two ways to increase the number of pulses during each rotation of the armature.

- Increase the number of field poles.
- Increase the number of separate coils (multi-coil) in the armature.

The multi-coils necessitate a multiple segment split-rings which is called a commutator.

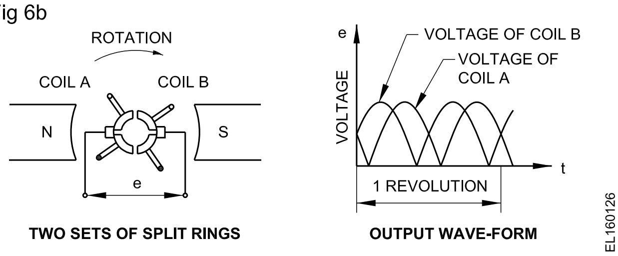
Fig 6 represents the generated voltages and their wave shapes when the armature has different number of split rings, i.e. commutator segments. The practical generator will have more number of commutator segments as shown in Fig 6c, and the induced emf will be as shown in the adjoining graph.

Fig 6a



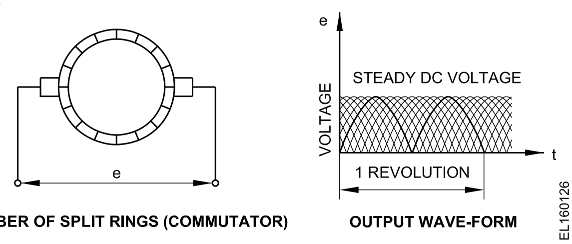
ONE SET OF SPLIT RINGS OUTPUT WAVE-FORM

Fig 6b



TWO SETS OF SPLIT RINGS OUTPUT WAVE-FORM

Fig 6c



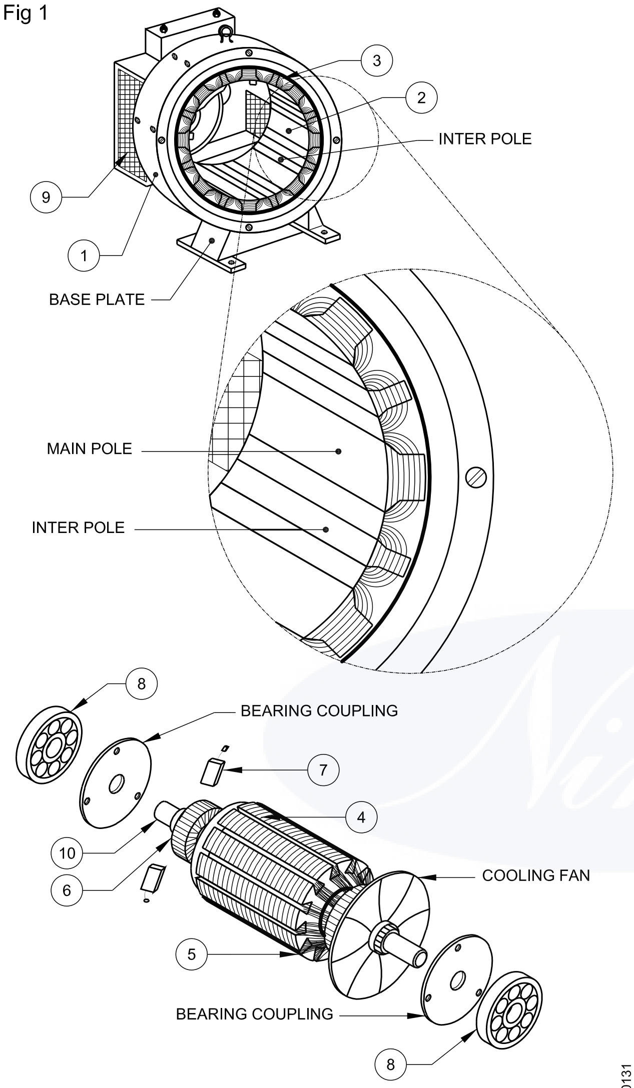
A NUMBER OF SPLIT RINGS (COMMUTATOR) OUTPUT WAVE-FORM

Parts of a DC generator and their functions

Objectives: At the end of this lesson you shall be able to
- **describe the parts of a DC generator and their functions.**

A DC generator consists of the following essential parts as shown in Fig 1.

Fig 1



PARTS OF A DC MACHINE

1 Frame or yoke
2 Field poles and pole-shoes (Figs 3,4 & 5)
3 Field coils or field winding (Fig 6)
4 Armature core
5 Armature windings or armature conductors
6 Commutator
7 Brushes
8 Bearings and end plates (Figs 14 & 15)
9 Air filter for fan
10 Shaft

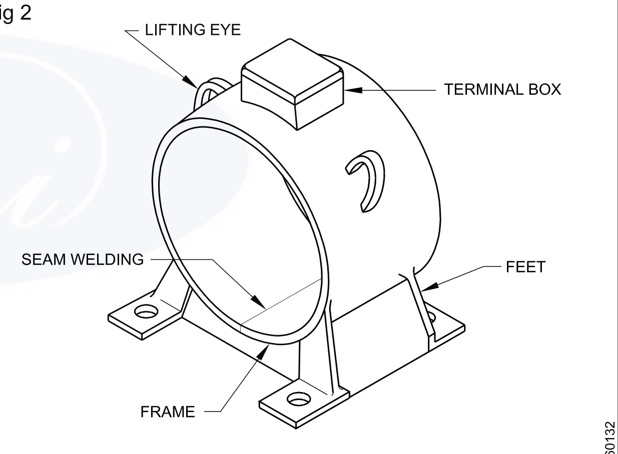
The yoke, the pole cores, the armature core and the air gaps between the poles and the armature core form the magnetic circuit, whereas the armature conductors, field coils, commutators, and brushes form the electrical circuit.

Yoke: The outer frame or yoke serves a dual purpose. Firstly, it provides mechanical support for the poles and acts as a protecting cover for the whole machine as shown in Fig 1. Secondly, it provides the low reluetance magnetic path to `the magnetic circuit to complete through it.

In small generators where cheapness rather than weight is the main consideration, yokes are made of cast iron. But for large machines usually cast steel or rolled steel is used. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel, and then welding it at the seams. The feet, the terminal box etc. are welded to the frame afterwards as shown in Fig 2. Such yokes possess sufficient mechanical strength and have high permeability.

Poles cores and pole shoes (Fig 3): The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes; (i) they spread out the flux in the air gap uniformly and also, being of a larger cross-section, reduce the reluctance of the magnetic path, and (ii) they also support the field coils.

Fig 2

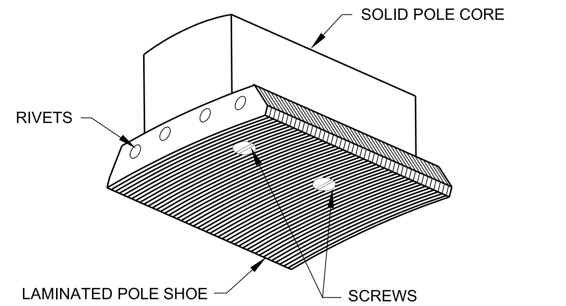


YOKE

There are two main types of pole construction.

The pole core itself may be a solid piece made out of either cast iron or cast steel but the pole shoe is laminated and is fastened to the pole face by means of countersunk screws as shown in Fig 3.

Fig 3

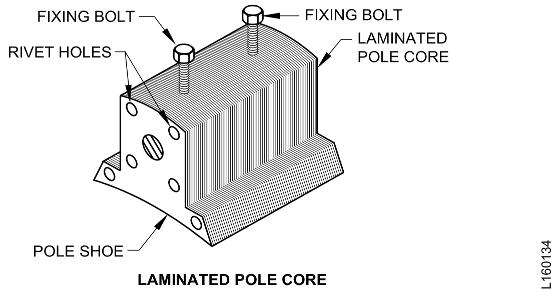


SEPERATE POLE SHOE BOLTED TO POLE CORE

In modern designs, the complete pole cores and pole shoes are built of thin laminations of annealed steel which are riveted together under hydraulic pressure. The thickness of laminations varies from 1mm to 0.25mm. The laminated poles may be secured to the yoke in any of the following two ways.

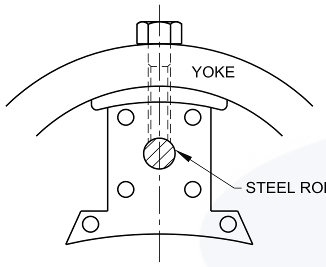
Either the pole is secured to the yoke by means of screws bolted through the yoke and into the pole body as in Fig 4 or holding screws are bolted into a steel bar which passes through the pole across the plane of laminations as in Fig 5.

Fig 4



LAMINATED POLE CORE

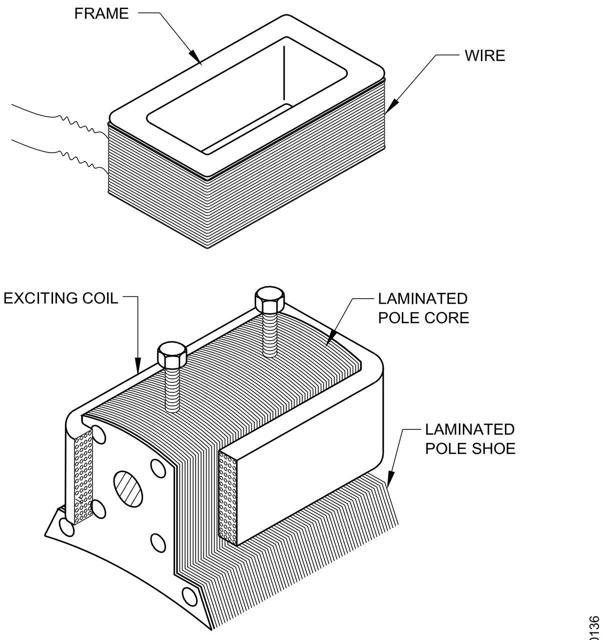
Fig 5



HOLDING SCREW BOLTED IN TO STEEL BAR POLE CORE ASSEMBLY

Pole coils (Field coils): The field coils or pole coils, which consist of copper wire or strip are former-wound for the correct dimension. Then the former is removed and the wound coils are put into place over the core as shown in Fig 6.

Fig 6



POLE ASSEMBLY

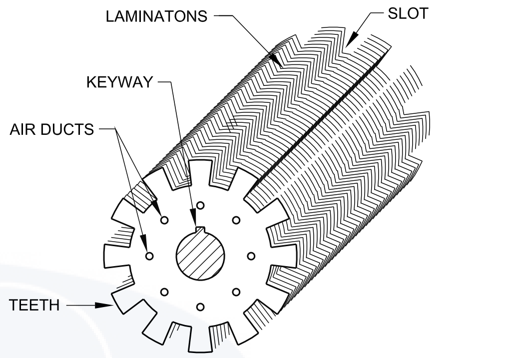
When a current is passed through the coils, they magnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

Both thick gauge wire winding (series) and thin gauge winding (shunt) are wound, one over the other with separate insulations, and the terminals are brought out separately.

Armature core: The armature core houses the armature conductors and rotate in the magnetic field so as to make the conductors to cut the magnetic flux. In addition to this, its most important function is to provide a path of very low reluctance to the field flux, thereby allowing the magnetic circuit to complete through the yoke and the poles.

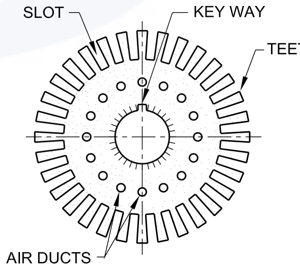
The armature core is cylindrical or drum-shaped as shown in Fig 7, and is built up of circular sheet steel discs or laminations approximately 0.5mm thick as shown in Fig 8.

Fig 7



ARMATURE CORE MADE OF LAMINATION

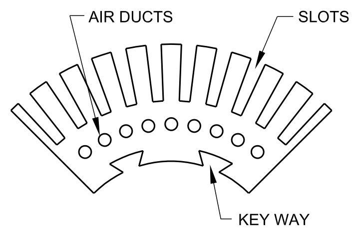
Fig 8



ARMATURE CORE LAMINATIONS

The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shift. Usually these laminations are perforated for air ducts which permit axial flow of air through the armature for cooling purposes. Such ventilating holes are clearly visible in the laminations shown in Figs 7,8 and 9.

Fig 9



SEGMENTAL LAMINATION

Up to armature diameters of about one metre, the circular stampings are cut out in one piece as shown in Fig 8. But above this size, these circles, especially of very thin sections, are difficult to handle because they tend to distort and become wavy when assembled together. Hence, the circular laminations, instead of being cut out in one piece, are cut in a number of suitable sections of segments which form part of a complete ring.

A complete circular lamination is made up of four or six or even eight segmental laminations. Usually, two keyways are notched in each segment and are dovetailed or wedge-shaped to make the laminations self-locking in position as shown in Fig 9.

The purpose of using lamination is to reduce the loss due to eddy currents. Thinner the laminations are, greater the resistance offered against eddy current loss.

Armature windings: The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape with a coil puller. Various conductors of the coils are insulated from each other.

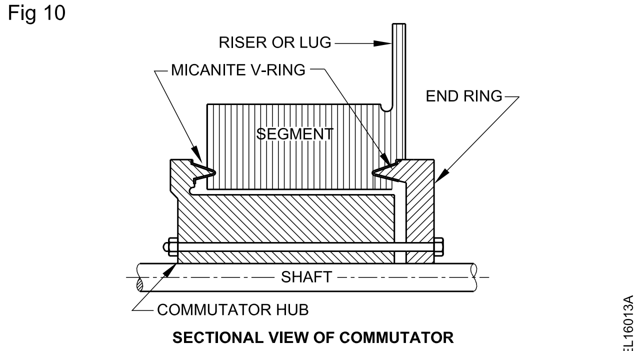
The conductors are placed in the armature slots which are lined with tough insulating material. After placing the conductors in the slot, this slot insulation is folded over the armature conductors, and is secured in place by special, hard, wooden or fibre wedges.

Commutator: The function of the commutator is to facilitate collection of current from the armature conductors. It rectifies i.e. converts the alternating current induced in the armature conductors into uni-directional current for the external load circuit.

It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity, hard-drawn or drop-forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils.

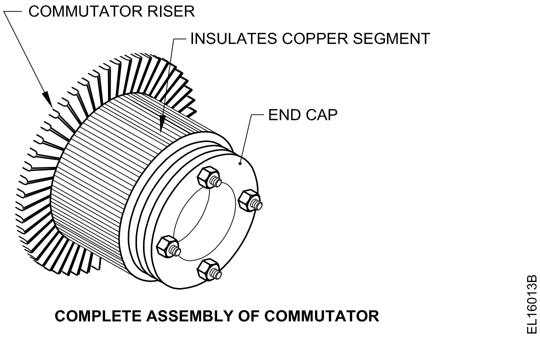
Each commutator segment is connected to the armature conductor by means of a copper lug or riser. To prevent them from flying out under the action of centrifugal forces, the segments have V-grooves, these grooves being insulated by conical micanite rings. A sectional view of a commutator is shown in Fig 10, whose general appearance when assembled is shown in Fig 11.

Fig 10



SECTIONAL VIEW OF COMMUTATOR

Fig 11



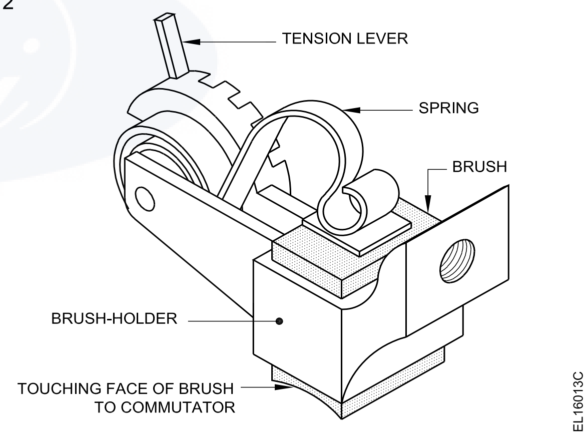
COMPLETE ASSEMBLY OF COMMUTATOR

Brushes: The brushes whose function is to collect current from the commutator are usually made of carbon and graphite and are in the shape of a rectangular block.

These brushes are housed in brush-holders, shown in Fig 12, which have a box-holder for the brush, a spring to maintain the brush tension and a hole to fix the holder to the rocker arm. The brushes can slide in the rectangular box, open at both ends.

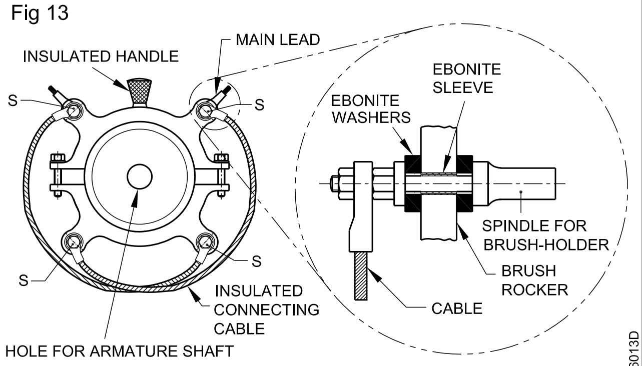
The brushes are made to bear down on the commutator by a spring whose tension can be adjusted by changing the position of the tension lever in the notches. A flexible, copper pigtail mounted at the top of the brush conveys the current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

Fig 12



Brush-rocker: The spindle is used to have a number of brushes connected in a large machine. There may be only two brushes for a small machine. All the spindles are insulated and attached to the brush rocker.

Fig 13

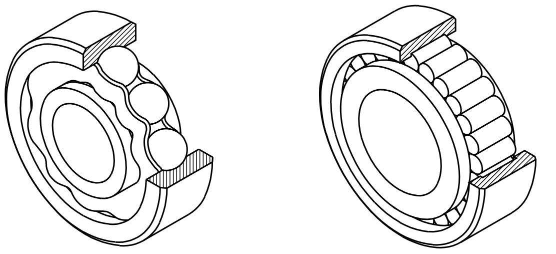


BRUSH-HOLDER S-SPINDLE FOR BRUSH-HOLDER

The brush-rocker may either be supported by a bearing cover in a small machine or by brackets attached to the yoke as shown in Fig 13. The brush position to the neutral axis can be set by changing the position of the brush-rocker.

Bearings (Fig 14): Because of their reliability, half-bearings are frequently employed, though for heavy duties roller bearings are preferable. The ball and rollers are generally filled with hard oil for quieter operation and for reduced bearing wear. When sleeve bearings are used, these are lubricated by ring oilers fed from an oil reservoir in the bearing bracket.

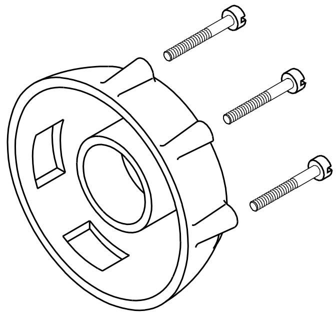
Fig 14



EL16013E

End plates (Fig 15): The bearings are housed in these end plates, and they are fixed to the yoke. They help the armature for frictionless rotation and to position the armature in the air gap of the field poles.

Fig 15



END PLATE 2-OFF

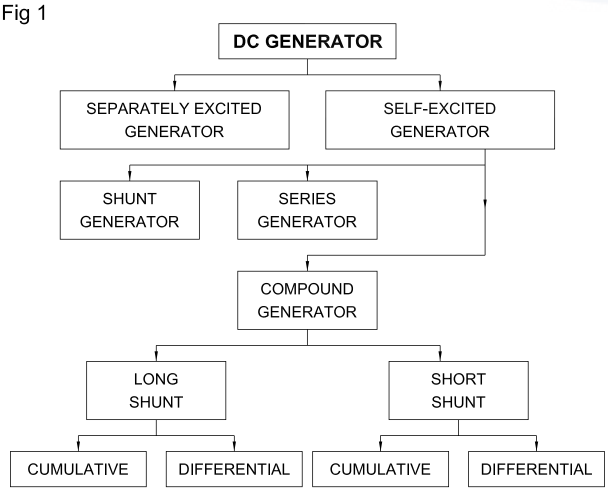
EL16013F

Types of DC generators

Objective: At the end of this lesson you shall be able to
• **classify and identify the different types of DC generators and their terminal markings.**

Types of DC generators: The type of a DC generator is determined by the manner in which the field excitation is provided. In general, the methods employed to connect the field and armature windings, fall into the following groups. (Fig 1)

Fig 1

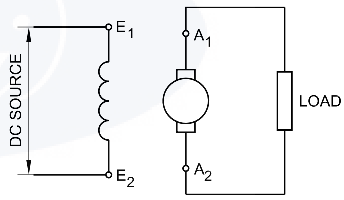


EL160141

Separately excited generator: The field excitation for a separately excited generator, shown in Fig 2, is supplied from an independent source, such as storage battery, separate DC generator or rectified DC supply from an AC source.

The field excitation voltage may be the same as that of generated (armature) voltage or may differ. Generally, the excitation voltage will be of low voltage, say 24, 36 or 48V DC.

Fig 2



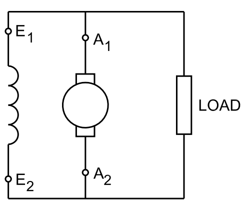
CONNECTION DIAGRAM OF SEPARATELY EXCITED DC GENERATOR

EL160142

Self-excited generator: The field excitation is provided by its own armature. In this type of generators, initially the voltage is built up by residual magnetism retained in the field poles. Self-excited generators may be further classified as shunt, series and compound generators.

Shunt generator: The field winding is connected to the armature terminals as shown in Fig 3. (i.e. shunt field winding is connected in parallel with armature winding). The shunt field contains many turns of relatively fine wire and carries a comparatively small current only which is a small percentage of the rated current of the generator.

Fig 3



SHUNT GENERATOR

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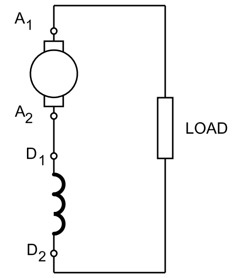
Series generator: The field winding is connected in series with the armature winding as shown in Fig 4. The series field winding has a few turns of heavy wire. Since it is in series with the armature it carries the load current.

Fig 4

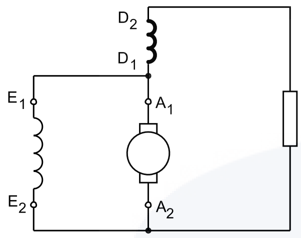


SERIES GENERATOR

Compound generator: The field excitation is provided by a combination of shunt and series field windings.

Short-shunt compound generator: This is a generator in which the shunt field is directly across the armature as shown in Fig 5.

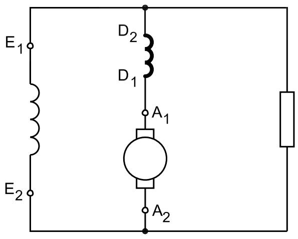
Fig 5



SHORT SHUNT COMPOUND GENERATOR

Long-shunt compound generator: This is a generator in which the shunt field is connected after the series field as shown in Fig 6.

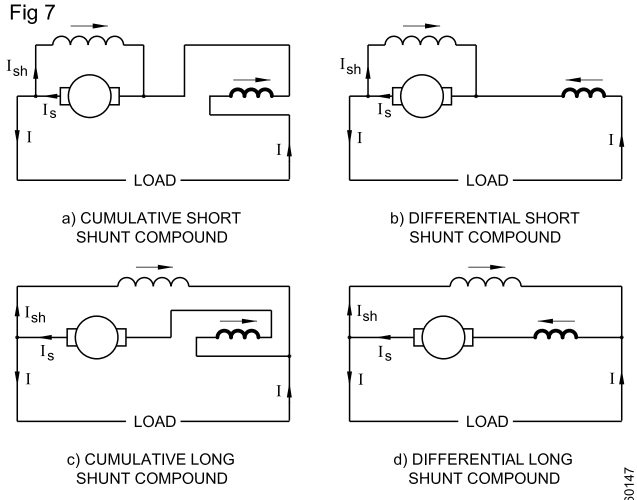
Fig 6



LONG SHUNT COMPOUND GENERATOR

Differential and cumulative compound generator: The compound generators can also be further classified as cumulative and differential. In cumulative compound generators the magnetising forces of the shunt and the series field ampere-turns are cumulative, i.e. they both tend to set up flux in the air gap in the same direction. However, in case the ampere turns of the shunt widning oppose those of the series winding, the machine is said to be differentially compound would generator. Both the types are shown in Fig 7.

Fig 7

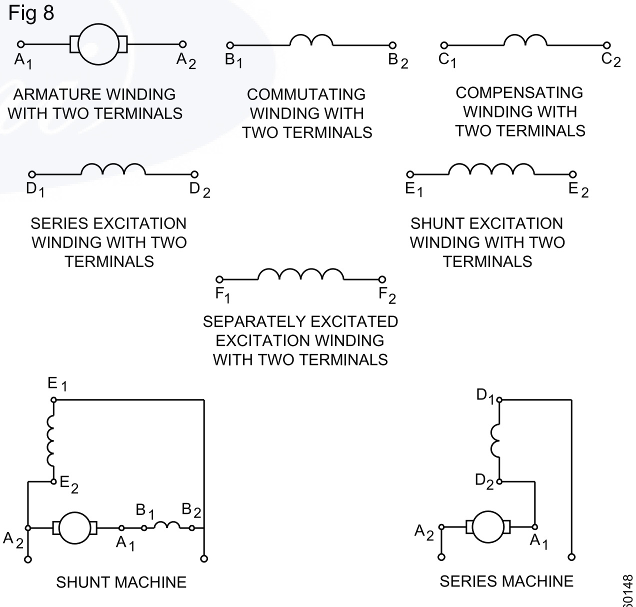


TYPES OF DC COMPOUND GENERATORS

Terminal markings : As per BIS 4718-1975 the terminal markings for DC commentator machines shall be according to the marking principles stated below.

- Windings are distinguished by capital letters.
- End points and intermediate points of windings are distinguished by a numerical suffix.
- Winding letters for DC windings are chosen from the earlier part of the alphabet.(Fig 8)

Fig 8



TERMINAL MARKING OF DC MACHINES AS PER BIS

Test a DC machine for continuity and insulation resistance

Objectives: At the end of this lesson you shall be able to

- **state the necessity of measuring the insulation resistance of an electrical machine**
- **state the frequency of tests**
- **state the required conditions for the tests**
- **state the reasons for the low value of insulation resistance in the machines**
- **state the method of improving the insulation resistance of DC machines.**

Necessity of measuring insulation resistance: The most important aspect in the maintenance of DC machines is taking care of the insulation. Electrical insulation of DC machine windings is designed for the satisfactory operation at the specified voltage, temperature and to retain the electrical and mechanical strength and the dimensional stability over many years of operation.

The insulation resistance of DC machines in service should be checked periodically, preferably every month. The possibility of reduction in the value of insulation resistance is due to the continuous working of the machine under full load condition, the heat generated in the winding and local atmospheric moisture, dust and dirt. If they are not checked in time, the insulation becomes weak and the winding will loose its dielectric property, and will ultimately lead to failure of the machine.

Periodical checks and measurement of insulation resistance and improvement thereof to the required level will ensure prevention of failure of insulation, and thereby, the breakdown of the machine.

A common device for measuring insulation resistance is a direct indicating insulation tester or Megger. The measurements are made at voltages 500/1000 volt DC depending upon the voltage rating of the machine.

Measurement of insulation resistance: Insulation resistance shall be measured between the winding and frame (earth), and between windings.

For low and medium voltage rated machines, the insulation resistance, when the high voltage test is applied, shall not be **less than one megohm** as per B.I.S. 9320 - 1979. The insulation resistance shall be measured with a DC voltage of about 500 V applied for a sufficient time for the reading of the indicator to become practically steady, such voltage being taken from an independent source or generated in the measuring instrument.

When it is required to dry out windings at site to obtain the minimum value of insulation resistance, it is recommended that the procedure for drying out as specified in IS:900-1965 may be followed.

Frequency of test: Periodical checks or tests are predetermined in preventive maintenance programmes with a forethought. The planning of the preventive maintenance (PM) schedule should be based on the past experience of maintenance personnel, and the recommendations made by the machine manufacturer. Usually the measurement of insulation resistance is a must during the period of overhauls.

The duration of overhaul will be once in 6 months, ideal for DC machines where they are working continuously. Overhauling is done once a year, for such of those machines as are not working continuously. The overhauling is done during plant shut-down periods.

However in DC machines where the overhaul interval is too long, or delayed, it is advisable to have constant vigil and check the insulation resistance at least once a month regularly, and maintain a record of the values of the insulation resistance tests as shown in Table 1.

Required conditions for test: The high potential dielectric test and the insulation resistance test are the principal methods of evaluating insulation capability and condition of the machine. The insulation resistance test is often used as a measure of the condition of the winding. Insulation resistance is the ratio of the applied voltage to the leakage current which passes in the circuit at some specified time after the voltage is applied. Direct, rather, than alternating voltages are used for measuring insulation resistance.

TABLE 1

Insulation resistance test

Date	Time	Weather condition	Duty cycle	Test between terminals	Insulation resistance	Remarks

The principal currents affecting insulation resistance on application of the test potential for sufficient time are (1) leakage current over the winding surface (2) conduction in current through the insulation material and (3) absorption current in the insulation. The first two currents are steady with time, but the last current delays approximately exponentially from an initial high value.

Such insulation resistance measurements are affected by surface conditions (dirt or moisture on the windings), moisture within the insulation wall and the insulation temperature. The magnitude of the test potential may also affect the insulation value, especially if the insulation is not in good condition. Therefore, it is desirable to use insulation resistance as a measure to determine the condition of the machine over a period of years, and to make readings under similar conditions each time and record the values in the test card of the machine in a table similar to Table 1.

However, before testing the winding for insulation resistance, it is recommended that the continuity test should be conducted in the armature and field windings to ensure soundness of the respective circuits. As sometimes continuity tests will not reveal internal short circuits, resistance measurement test is recommended, and a record should be maintained for comparison at intervals.

Reasons for low value insulation resistance: The low value of insulation resistance in DC machines is due to excess heat developed in the winding due to their routine working with full load condition or overloading at times or frequent starting with loads. In addition to this, high ambient temperatures are also the reason for low insulation resistance. The other possibility is accumulation of unnecessary local dust and dirt, carbonisation due to brush, local atmospheric moisture, acids and alkalies present in the surroundings of the machine etc.

All these are collectively or individually responsible for the weakening of insulation resistance of the winding. Because of these conditions the dielectric property of the insulating material gets reduced, which, in turn, results in low or poor insulation resistance, responsible for the breakdown of the winding due to insulation failure.

Method of improving insulation resistance: On identifying the weak insulation resistance, during the course of preventive maintenance observation in a DC machine, it is necessary to improve the insulation resistance to restore it to a safe value.

Improvement of insulation resistance could be done by any one of the following methods after cleaning the dust and dirt from the machinery.

- By blowing hot air through the machines.
- By heating the machine with carbon filament or incandescent lamps.
- By dismantling and varnishing the winding of the machine.

The following steps are to be adopted for dismantling and varnishing.

- Measure the insulation resistance value between the windings and the frame of the machine and record the value.
- Mark and dismantle the machine.
- Remove dirt and dust in the field winding by blowing dry air with the help of an electric blower.
- Clean and remove dirt, dust and carbon on the armature with special attention to the commutators.
- Clean the brushes, brush-holders and rocker arms.
- Measure the insulation resistance of the winding with an insulation tester; note the values.
- Heat and dry the field coils and armature by external measures.
- Apply insulating varnish of air-drying type to field coils and armature conductors.
- Dry the varnish coating on field coils and armature by external means.
- Measure the insulation resistance and note the improved value of insulation resistance.
- Assemble the machine.
- Measure the insulation value between the windings and the frame of the machine; record the values. Compare these results with those of the first step and make sure the present value shows improvement.
- Connect the machine to the system and run it to check its normal working condition.

Reference: BIS 9320-1979.

Armature circuit resistance and its relation with different types of windings and brush resistance

Objectives: At the end of this lesson you shall be able to
- **state the different types of armature winding and determine the number of parallel paths in armature**
- **explain the armature circuit resistance - total armature conductor resistance - parallel path - brush resistance - brush voltage drop - grade of brushes.**

Armature windings: We have seen earlier, when a single loop conductor is rotated through a magnetic field, an alternating voltage is induced in it. This alternating voltage can be changed into direct voltage (rectified) by the commutator.

In practice, there are several coils in the armature, each with a large number of turns laid in the slots of the armature core. This arrangement of the coil is called **armature winding**. The ends of the coils are soldered to the commutator raisers, depending on the kind of winding i.e. lap or wave, which decides the number of parallel paths in the armature.

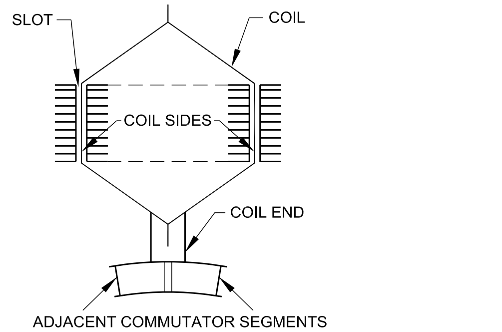
A preliminary knowledge about the different types of winding is essential to tackle problems related to the calculation of induced voltage in various types of generators.

Lap and wave windings could readily be identified by the manner in which the coil ends are connected to the commutator bars. As shown in Fig 1, in a simplex lap winding, the ends of a coil are connected to adjacent commutator segments.

Fig 2 shows the simplex wave winding in which the coil ends are connected to the commutator segments almost equal to the distance between poles of the same polarity.

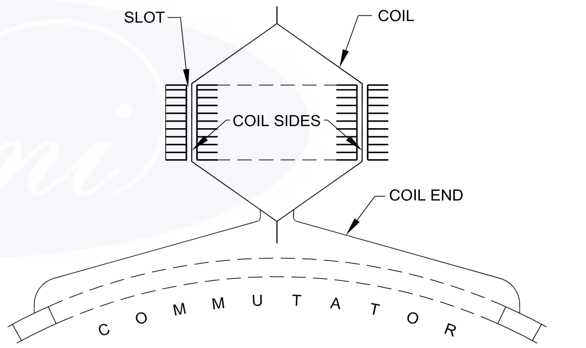
Table 1 shows the main differences between lap and wave winding.

Fig 1



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX LAP WINDING

Fig 2



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX WAVE WINDING

TABLE 1

Lap winding	Wave winding
The two ends of each armature coil are connected to adjacent commutator segments in the case of simplex, two segments apart in duplex and three segments apart in triplex.	The two ends of each coil connect to the commutator segments placed between adjacent poles of the same polarity.
There are as many parallel paths for current as there are field poles in the case of lap winding No. of parallel paths = Number of poles x plex of the winding.	There are two parallel paths regardless of the number of field poles in the case of simplex wave winding. Number of parallel paths in wave windings = 2x plex of the winding where plex for-simplex is 1, duplex is 2 and triplex is 3.
The number of brush positions is equal to the number of poles.	Only two brush positions are required regardless of the number of field poles.
Used for machines having low voltage and high current capacity.	Used in machines having low current and high voltage capacity.

DC armature circuit - voltage drop and its importance: One of the major reasons for the drop in voltage at the terminals of a loaded generator is due to armature voltage drop. This depends on the armature circuit resistance and the armature current. A thorough understanding of the armature resistance, apart from helping an electrician to calculate the efficiency of a DC machine, is of great help to check the correctness of the rewound armature without physically checking the number of turns and the size of the winding wire.

This is done in all established factories, where a record is maintained to indicate voltage drop across the armature of each DC machine, at a specified armature current. Any variation from this recorded value to the value obtained from the rewound armature (having the same grade of brushes), clearly indicates either the size of the winding wire or the number of turns has changed, and the performance of the machine will not be the same as earlier. Normally armature circuit resistance will be in the order of one ohm or below.

Voltage drop: This could be calculated by finding the total resistance of the armature conductors in series per parallel path and dividing it by the number of parallel paths, but in actual practice it is calculated by the voltage drop method.

Refer to the circuit shown in Fig 3.

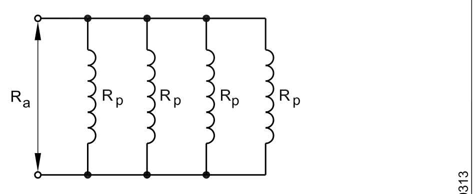
Let 'r' be the specific resistance of the armature conductors, 'a' be the area of the cross-section of the armature conductor in sq. cm.

'L' be the length of the conductor in cms.

'R_a' - armature resistance in ohms.

'R_p' - resistance per parallel path in ohms.

Fig 3



4-POLE SIMPLEX LAP-WOUND MACHINE WITH 4 PARALLEL PATHS

Method of calculating the armature resistance: Let P be the number of parallel paths in the armature,
Z be the total conductors in armature.
Then the number of conductors per parallel path = Z/P.

Resistance per parallel path $R_p = \frac{Z}{P} \times \frac{\rho L}{a}$

Armature resistance in ohms = R_a

$$R_a = \frac{R_P}{\text{No. of parallel paths}}$$

Example: In a DC 4-pole lap-wound machine the resistance of one conductor is 0.1 ohm; there are 48 conductors. Calculate the armature resistance.

Since it is lap-wound,

No. of parallel paths=No.of poles (assuming simplex winding).

Therefore, No. of parallel paths = 4.

Conductors per

$$\text{parallel path} = \frac{\text{Total No. of conductors}}{\text{No. of parallel paths}} = \frac{48}{4} = 12.$$

Resistance per parallel path = 12 x 0.1 = 1.2 ohms.

Therefore the total armature resistance for 4 parallel paths = 1.2/4 = 0.3 ohms.

In addition to this, the total armature circuit resistance includes brush resistance and brush contact resistance. Hence the value measured will be more than 0.3 ohms in the above example.

Brushes: The main function of the brushes is to transfer the energy present at the armature to the external circuit. Brushes are usually made from a compound of carbon and graphite. Graphite content provides a self-lubricating action as the brushes rub against the commutator.

The most important characteristics of brushes are specific resistance, friction coefficient, current-carrying capacity, maximum operating speed and abrasiveness.

Specific resistance is the resistivity of the brush material.

Friction coefficient is the ratio of the force on the surface to the force required to slide another surface over it, and is influenced by the brush temperature, pressure, current, atmospheric condition, mechanical condition, commutator material, surface films and speed.

The resulting high brush friction often causes the brush to chatter and chip. Since friction serves no useful purpose, low brush friction is preferred. Low brush friction will have a friction coefficient in the order 0.22 or below whereas a high brush friction will have a friction coefficient above 0.4.

Current-carrying capacity: It depends on the brush material, operating conditions, type of ventilation and operating temperature. If the temperature is high due to high current density, the brush life will be shortened.

Speed: The allowable speed depends upon the characteristics of the brush material, spring pressure, current density, types of brush-holders, brush angle and the area of contact of the commutator.

Abrasiveness: The ability of the brush to prevent excessive build up of film usually caused by corrosive or oily atmosphere is called the abrasiveness or polishing action.

Grade and types of brushes: There are four major brush families classified according to the manufacturing process.

- Graphite
- Carbon and carbon graphite
- Electro-graphite
- Metal graphite

Graphite: Graphite brushes are usually made of natural or artificial graphite. Natural graphite contains impurities. Artificial graphite is usually pure. It is used in fractional HP machines.

Carbon and carbon graphite: It has high hardness, high mechanical strength, cleaning action and long brush life.

Electro-graphite: It consists of various forms of amorphous carbon. These brushes usually have higher current density, lower strength, lower hardness and lower specific resistance. They generally have good commutating characteristic but may not always be used because of the lesser requirement of high current, and the requirement of severe mechanical conditions.

Metal graphite: It is generally made from natural graphite, and finally divided into metal powders. Copper is the most common metal constituent, but silver, tin, lead and other metals are sometimes used. The metal content ranges from approximately 10 to 95% by weight.

A high metal content provides greater current capacity, higher mechanical strength and also certain combined characteristics of contact drop and friction. It is used where high current and low voltages are involved. Its typical applications are for electroplating generators, battery chargers, welding generators and other high current equipment.

Whenever the brushes are to be changed, the same grade of brushes is to be procured and used to get the same performance characteristics from the machine.

As an accepted procedure, every electrician should identify the brush grade of each machine, either from service manuals or by visual inspection, and record it in the maintenance card of the machine for proper selection of replacement at a later date.

Brush contact resistance is the resistance offered between the brush and the commutator for the current flow. This resistance value depends upon the grade of brushes, material used for the commutator, contact area between the brush and commutator, and the brush tension. Normally the brush contact resistance is measured in terms of voltage drop at specific current ratings.

Table 1 shows the different grades of brushes and their characteristics.

TABLE 1

Characteristics of brushes

Grade of carbon	**Max. current density A/cm^2**	**Max.contact resistance ohms/cm^2**	**Pressure on commutator kg/cm^2**	**Voltage drop in volts**
Soft graphite	9 to 9.5 A/cm^2	–	0.12	1.6
Copper carbon	15 to 16 A/cm^2	0.00000465	0.15-0.18	0.25-0.35
Carbon	5.5 to 6.5A/cm^2	0.000062	0.22-0.27	2
Electro-graphite	8.5 to 9 A/cm^2	0.000031	0.22	1.7-1.8

EMF equation of DC generator

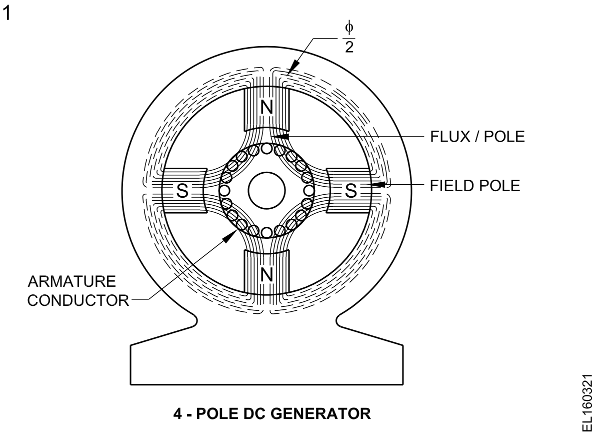
Objective: At the end of this lesson you shall be able to
- **derive and apply the emf equation and calculate the induced emf of a DC generator.**

When the armature of a DC generator, containing a number of conductors in the form of a winding, rotates at a specific speed in the magnetic field, emf is induced in the armature winding and is available across the brushes. The equation and the numerical problems given as examples will help an electrician to better his understanding about the construction of a DC machine.

Induced emf in a DC generator can be calculated as explained below.

Figure 1 is given for your reference.

Fig 1



Let Ø = flux/pole in weber
Z = total number of armature conductors = No. of slots x No.of conductors/slot
P = No. of poles in the generator

A = No. of parallel paths in armature
N = armature revolution per minute (r.p.m.)
E = emf induced in the generator.

Average emf generated per conductor in one resolution = Rate of change of flux (Faraday's Laws of Electromagnetic induction

$$\frac{d\varnothing}{dt} \text{ volt (since N = 1)}$$

Now, flux cut/conductor in one revolution, (dØ) = PØ Wb

No. of revolutions/second = N/60

Time for one revolution, (dt) = 60/N second

According to Faraday's Laws of Electromagnetic Induction, we have emf generated/conductor/second

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing N}{60} \text{ volt}$$

emf generated in `Z'conductors in the armature assuming they are all in series $= \frac{P\varnothing ZN}{60}$ volts.

The emf generated in the armature of the DC generator when there are `A' parallel paths in the armature

$$= \frac{P\varnothing ZN}{60\ A} \text{ volts.}$$

Could be written as $= \frac{\varnothing ZN}{60} \times \frac{P}{A}$ volts.

A = 2 - for simplex wave winding
= P - for simplex lap winding.

Example: A four-pole generator, having a simplex wave-wound armature has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine, when driven at 1500 r.p.m assuming the flux per pole to be 7.0 mWb?

Solution: $E = \frac{\varnothing ZN}{60} \times \frac{P}{A}$ volts.

Here, Ø= 7x 10^{-3} Wb, Z = 51 x 20 = 1020, P=4, N = 1500 r.p.m.

A = 2 as the winding is simplex wave.

$$E = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60} \times \frac{4}{2} = 357V.$$

An 8-pole DC generator has 960 armature conductors and a flux per pole of 20mWb running at 500 r.p.m. Calculate the emf generated when the armature is connected as (i) a simplex lap-winding, (ii) a simplex wave winding.

Solution

(i) Simplex lap winding

$$E = \frac{\varnothing ZN}{60} \times \frac{P}{A}$$

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{8} = 160V.$$

(ii) Simplex wave winding

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{2} = 640V.$$

Methods of measuring the speed of a rotating shaft

Objectives: At the end of this lesson you shall be able to
- **describe the method of measuring speed by the**
  - **revolution counter and stopwatch**
  - **tachometer**
  - **stroboscopic method.**

Measurement of speed: Speed is defined as a scalar quantity. Electricians must know how to measure the speed of rotating electrical machines. The speed of rotating machines is measured in two ways.

- Direct method (contact method)
- Indirect (non-contact) method

In practice both the methods are being used by electricians.

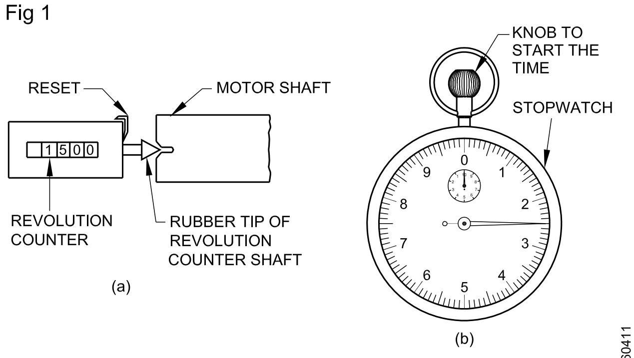
In the direct method two types of instruments as stated below are used for measuring speeds.

- Revolution counter and stopwatch
- Tachometer

Revolution counters: Revolution counters are of two types; one is a dial type counter, which is an earlier version and has become obsolete. The other type is a digital counter which is shown in Fig 1a. The spindle of the counter which is provided with a conical rubber bush is placed in the countersunk portion of the machine shaft for measuring speed.

The revolution counter counts the number of revolutions as long as its rubber brush is in contact with the shaft. To get the revolution per minute, it is necessary to have a timing device.

Fig 1



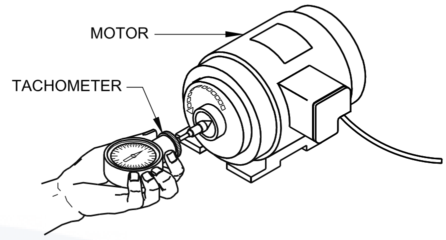
MEASUREMENT OF SPEED BY REVOLUTION COUNTER

Hence to measure the speed of the rotating shaft with the revolution counter, a stopwatch is also necessary. Just when the rotation of the shaft speed is transferred through friction to the counter, the stopwatch begins to tick. Both the revolution counter and the stopwatch are stopped at the same time and the number of revolutions indicated in the counter per minute gives the speed of the shaft in r.p.m. The accuracy of this method is not very great, as human reflexes are involved.

The second instrument used for direct measurement of speed is a tachometer as shown in Fig 2. The speed is directly shown by a needle over a calibrated dial.

The tachometer is used in the same way as that of the revolution counter except that a stopwatch is not required.

Fig 2

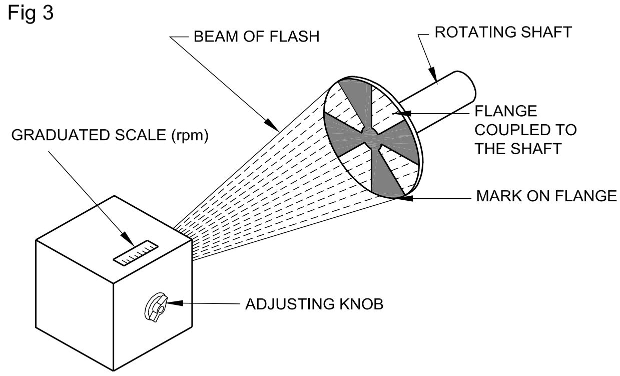


MEASURING THE SPEED BY USING TACHOMETER

Stroboscope: A device for observing moving bodies by making them visible intermittently, and, thereby, giving them the optical illusion of being stationary, is called a **stroboscope.** To make this principle clear, let us say a mark is made at one point on a rotating shaft and a light is made to flash over the mark.

If the time of moving the mark once around, and the gap between two consecutive flashes are the same, then the mark appears to be stationary, and, thereby the shaft appears to be stationary. Fig 3 shows the stroboscope and its light rays falling on a sectionized disc fitted on the rotating shaft.

Fig 3



STROBOSCOPE

The flashing light rays can be varied up to 50,000 flashes per second. The rate of flashing is controlled by a variable frequency electronic oscillator, calibrated for speeds in r.p.m.

While measuring speeds with this instrument, the rate at which the lamp flashes is varied until the sectionized disc, fitted on the shaft, appears to be stationary. The speed in r.p.m. can be read on the oscillator for that particular setting of the flash rate.

This instrument is used for speed measurement in small torque motors like precision tool motors, tape recorder motors etc. where direct contact type, speed measurement will load the motors and change their speed.

As the stroboscope makes the rotating part to appear stationary, the operator should always be careful not to touch the shaft. Stroboscope light effect could be seen in fluorescent lamps connected to AC supply. In 50 HZ supply, a fluorescent lamp flashes 100 times in a second which will not be noticed by us due to the visual limitations of the eye. But this effect could be noticed in moving objects. It is for this reason the fluorescent lighting can be a source of danger in a workshop. Hence it is recommended that the rotating machines should either be illuminated by incandescent lamps or by fluorescent lighting in which the stroboscopic effect has been eliminated.

Separately excited DC generator

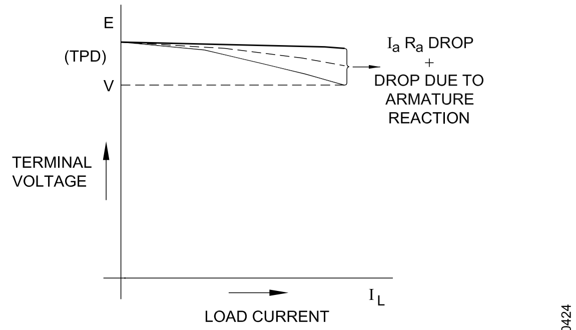
Objectives: At the end of this lesson you shall be able to
- **analyse the magnetisation characteristic of a separately excited generator**
- **explain the reasons for not building up voltage in a separately excited DC generator**
- **analyse load characteristics of a separately excited DC generator**
- **state the advantages of the separately excited generator over the self-excited DC generator.**

Introduction

A DC generator is the most commonly used separately excited generator, used for electroplating and battery charging. A separately excited generator is one in which the magnetic field is excited from an external DC source. The DC source may be a DC generator or a battery or a metal rectifier connected to an AC supply. Generally a potential divider is connected across the DC source, and the required DC voltage is supplied to the field as shown in Fig 1.

An ammeter is connected in the field circuit to measure the field current. The shaft of the generator is coupled to a prime mover. (Not shown in Fig 1)

Fig 4



EXTERNAL CHARACTERISTIC OF A SEPARATELY EXCITED DC GENERATOR

Magnetisation characteristic: This characteristic gives the relation between the field flux and the induced voltage in a generator. However, it is difficult to measure the field flux, and, hence, the field current is taken instead of the field flux.

The characteristic curve is drawn by keeping the field current in the `X' axis and the induced emf in the `Y' axis. To draw the characteristic curve, the connections are made as shown in Fig 1, and then, the prime mover is started and made to run at its rated speed, keeping the field switch `s' open.

The terminal voltage which appears at the armature terminals is measured and recorded. This small voltage E_r is known as **residual voltage** which is due to the residual magnetism available in the field cores.

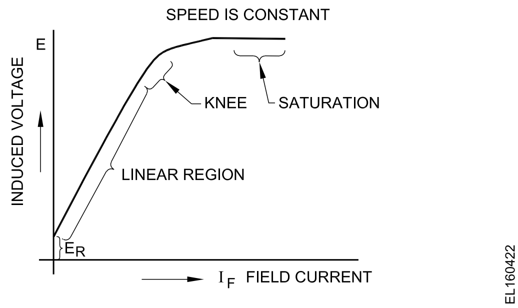
Throughout the experiment, the speed of the generator is held constant. Next, the field switch `S' is closed keeping the potential divider at its minimum position, and gradually the field current is increased in steps. For each step, the field current and the corresponding voltage at the armature terminals are noted. The readings are tabulated in Table 1.

TABLE 1

Sl.No.	Field current	Terminal voltage

If a graph is plotted between the field current and the terminal voltage, the curve will be as shown in Fig 2. The field current is taken on the X-axis and the emf E on the Y-axis. The curve drawn is known as the magnetisation characteristic of a separately excited generator.

Fig 2



A study of the curve indicates that it starts just above the origin, travels straight in the linear region indicating that the emf induced is directly proportional to the field current I_f.

As the poles are in the process of saturation, the relation between the terminal voltage and the field current no longer stands in direct proportion as indicated by the knee portion of the curve.

Finally when the poles get fully saturated the induced emf ceases to increase even at the increased field current which is indicated by the last portion of the curve and named as saturation region.

TABLE 2

Reasons	Remedies
A break or opening in the armature or field circuit.	Test the field and armature circuits for open circuit. Locate the fault and rectify.
A short circuit in the armature or field.	Test the field and armature for short circuit. Locate the fault and rectify.
Loose brush connections or loose brush contact.	Tighten the brush connections. Check up the brush tension. Adjust, if necessary. If the brushes are worn out, replace them.
A dirty or severely pitted commutator.	Clean the commutator for dirt, dust and greasy material. Use trichloroethylene. If the segments are pitted, dress them up.
The speed is too low.	Increase the speed of the generator to its rated speed.
The DC supply for excitation is absent.	Check the DC supply across the field winding terminals. If the supply is not there, check the supply source and rectify the fault Where AC main supply is converted as DC supply through rectifiers, the fault may be located in the rectifier circuit.

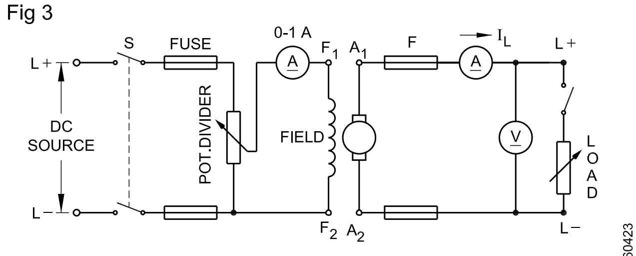
Reasons for not building up of voltage in a separately excited generator and their remedies

Sometimes a separately excited generator may not build up voltage. The probable reasons and remedies thereof are given in Table 2.

Load characteristic of a separately excited generator: The load characteristic shows the relation between the load current and the terminal voltage. Through this characteristic curve, we can determine the behaviour of the generator on load.

Fig 3 shows the method of connecting the separately excited DC generator to obtain the load characteristic. The generator speed should be brought to the rated value with the help of the prime mover and the voltage is built up to its normal rated voltage.

Fig 3



SEPARATELY EXCITED DC GENERATOR

Then the load switch is closed. Gradually the load is increased in steps. Each time, the load current I_L in amps and the corresponding terminal voltage `V' in volts are noted. The readings are tabulated in Table 3.

TABLE 3

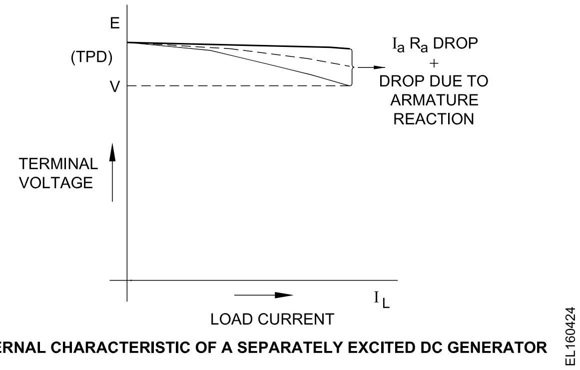
Sl.No.	Loadcurrent I_L in amps	Terminal voltage in volts

The graph shown in Fig 4 is the load characteristic or external characteristic of a separately excited generator having load current in the X axis and terminal voltage in the Y axis.

It is observed from the graph that a slight voltage drop occurs when the generator is loaded. This is due to the armature voltage drop (I_aR_a) and armature reaction.

If the voltage drop from no load to full load is very small, the separately excited DC generator can be regarded as a constant voltage generator.

Fig 4



EXTERNAL CHARACTERISTIC OF A SEPARATELY EXCITED DC GENERATOR

Advantages of a separately excited generator

- The terminal voltage remains almost stable when compared to the self-excited generators because the field circuit is independent of the induced voltage.
- As the field is independent, the I_aR_a drop in the armature will not affect the field flux.
- This generator can be used where a wide range of terminal voltage is required.

Disadvantage

- The disadvantage of a separately excited generator is the inconvenience of providing a separate DC source for excitation.
- Besides it is expensive.

Building up of voltage & magnetization characteristic of DC shunt generator

Objectives: At the end of the lesson you should be able to
- **explain the conditions and method of building up of voltage in a DC shunt generator**
- **explain the method of creating residual magnetism in the poles of a DC generator**
- **analyse the magnetization characteristic of a DC shunt generator**
- **estimate the value of field critical resistance in the DC shunt generator.**

Condition for a self-excited DC generator to build up voltage: For a self-excited DC generator to build up voltage, the following conditions should be fulfilled, assuming the generator is in sound condition.

- There must be residual magnetism in the field cores.
- The field resistance should be below the field critical resistance value.
- The generator should run at the rated speed.
- There must be a proper relation between the direction of rotation and the direction of field current. It could be explained as stated below.

The polarity of the induced voltage must be in such a direction as to produce the field current to assist the residual magnetism.

The polarity of the induced emf depends upon the direction of rotation and the polarity of the field poles depends upon the field current direction.

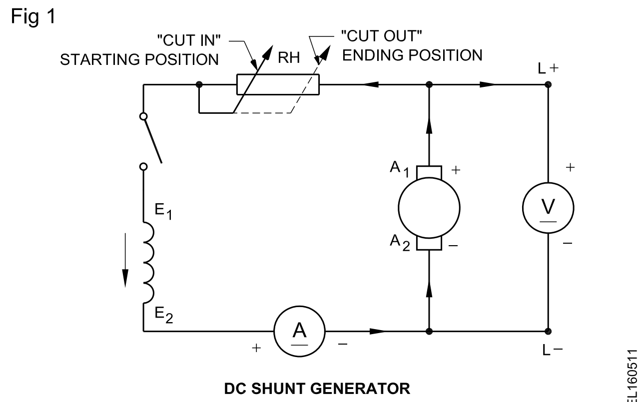
Even after fulfilling the above conditions, if the self-excited DC shunt generator fails to build up voltage, there may be other reasons as listed in Table 1.

TABLE 1

Sl.No.	Causes	Reasons	Remedies
1	A break or opening in the field or armature circuit.	Break or loose connection in the field or in the armature winding/circuit.	Locate the open circuit and rectify.
		High resistance in the field circuit beyond the field critical resistance value.	Reduce the resistance of the field regulator.
2	Loose brush connections or contacts.	Improper brush contact/loose brush connections.	Check the brushes for excessive wear, and replace them, if necessary. Check the commutator for pitting. If necessary, turn down the commutator. Always clean the commutator when poor brush contat is discovered. Check the brush tension and readjust it, if necessary Tighten any loose connections.
3	A dirty or severely pitted commutator.	Severe sparking due to overload.	In this case, follow the same procedure as outlined above.
4	A short circuit in the armature or field	Overload or excess heating.	Do a resistance check, ascertain, locate and remove the fault.

Method of building up voltage in a DC shunt generator: Fig 1 shows the circuit diagram for building up voltage in a DC shunt generator. When the generator is made to run at its rated speed initially, the voltmeter reads a small amount of voltage say, 4 to 10 volts. It is due to the residual magnetism. Since the field coils are connected across the armature terminals, this voltage causes a small amount of current to flow through the field coil. If the current flow in the field coils is in the correct direction, it will strengthen the residual magnetism and induce more voltage.

As such, the generated voltage will rise marginally. This rise in voltage, in turn, will further strengthen the increasing field current and induce more voltage. This rise in voltage, in turn, will further strengthen the increasing field current. This cumulative action will build up voltage until saturation is reached. After saturation, any increase in the field current will not increase the induced voltage. However, the whole procedure of building up of voltage takes a few seconds only.



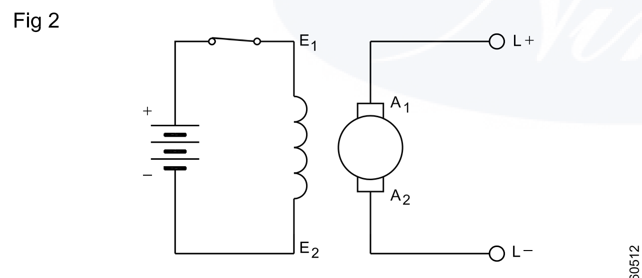
DC SHUNT GENERATOR

Method of creating residual magnetism: Without residual magnetism, a self-excited generator will not build up its voltage. A generator may lose its residual magnetism due to any one of the following reasons.

- The generator is kept idle for a long time.
- Heavy short circuit.
- Heavy overloading.
- The generator is subjected to too much heat.

When the generator loses its residual magnetism, it can be re-created as stated below.

Flashing of field: One of the methods to create residual magnetism is called the flashing of the `field'. This can be done by connecting the shunt field across a battery or any DC source for a few minutes as shown in Fig 2.



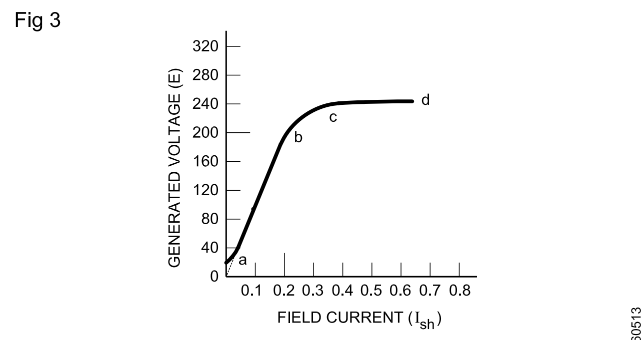
FLASHING OF THE FIELD

While flashing the field, the polarity of the magnetic field, now created, should be the same as that of the residual magnetic field it lost earlier.

In practice, this checking may not be possible. Alternatively note the polarity of the DC supply used for flashing the field and the corresponding field terminals. Run the generator in the specified direction at its rated speed.

Measure the residual voltage induced and its polarity. Check whether the polarity of the residual voltage is the same as that of the DC generator. If found reversed, flash the field again by connecting the supply voltage in reverse polarity.

Magnetisation characteristic of a DC shunt generator: The magnetisation characteristic curve shown in Fig 3 gives the relation between the field current and the induced voltage. Referring to the emf equation, the induced emf in a generator is proportional to the flux per pole and the



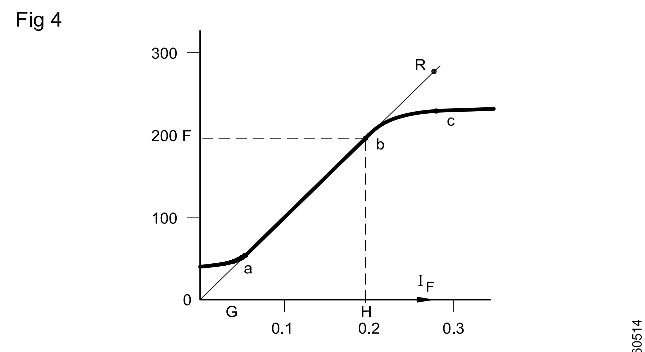
MAGNETISATON CHARACTERISTIC OF A DC SHUNT GENERATOR

revolutions per minute of the generator. At a constant speed, the generated emf becomes directly proportional to the field flux. In a given machine, the flux depends upon the field current.

The graph (Fig 3) illustrates this feature. Because of the residual magnetism, the curved part below point `a' does not start at zero. Between the points `ab', the curve is in almost a straight line indicating that the voltage in the area is proportional to the field current. Between points `b' and `c' a large increase in field current causes only a slight increase in the voltage.

It indicates that the field cores are reaching saturation and this part of the curve is called the `knee' of the curve. Between points `c' and `d', the curve is flat indicating that the increased field current is not able to increase the induced voltage. This is due to saturation of the field cores. Because of saturation, the field flux becomes constant, and the induced voltage will not be in a position to increase further. This curve is also called a no-load or open-circuit characteristic curve.

Critical resistance: If the shunt field circuit resistance is too large, it does not allow sufficient current to flow into the field to build up its voltage. In other words, it acts like an open field. Therefore, the field circuit resistance should be smaller than a value called critical field resistance. Critical field resistance is the highest value of resistance of the shunt field circuit with which a DC shunt generator can build up voltage. Beyond this value of resistance, the generator fails to build up voltage. The value of the critical resistance can be determined by drawing a tangential line to the open circuit characteristic curve as shown in Fig 4.



FIELD CRITICAL RESISTANCE

For example, by drawing the tangent on the open-circuit characteristic curve as shown by line OR of Fig 4, we find the tangent is parting at point `b' from the curve. By drawing ordinates from point `b' to x and y axis, the value of critical resistance (R_c) can be determined as below.

R_c = Field critical resistance

$$= \frac{\text{voltage represented by the tangent}}{\text{current represented by the tangent}}$$

$$= \frac{OF}{OH} = \frac{200\ V}{0.2\ A} = 1000 \text{ ohms.}$$

Field circuit resistance is the sum of the field resistance and field rheostat resistance. This value should be less than, say 1000 ohms (field circuit resistance) to enable the generator to build up voltage, if the generator is intended to self-excite. Normally this happens when the field regulator resistance is set at a high value.

DC shunt generator - Load characteristics and Application

Objectives: At the end of this lesson you shall be able to
- **describe the external and internal characteristics of a DC shunt generator and their application**
- **estimate the value of critical resistance of the load when the DC generator has to start with load.**

The external/load characteristic of a shunt generator:The external/load characteristic is important for judging the suitability of a generator for a particular purpose. When the DC shunt generator is loaded, it is found that the terminal voltage drops with increase in the load current.

In a shunt generator, the field current appears to be constant, and, hence, `V' also should remain constant and be independent of the load. But, it is not so practically. There are two main reasons for the drop in terminal voltage. They are :

- armature resistance drop (directly)
- armature reaction drop (indirectly).

Because of the above two reasons, the terminal voltage is reduced. This in turn affects the field current also. The decreased field current reduces the field flux which further reduces the induced emf.

Armature resistance drop: According to formula

Terminal voltage = Induced emf – armature voltage drop

$V = E - I_a R_a$

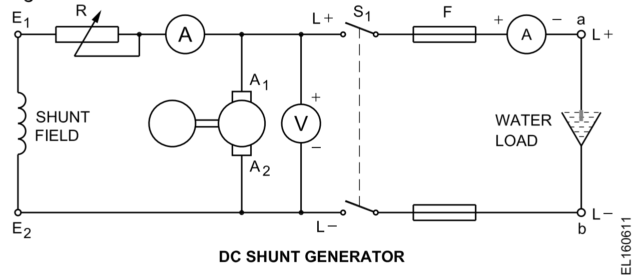
where I_a is the armature current
and R_a is the armature circuit resistance.

As such, when the load current is increased, more voltage is dropped in the armature circuit. Hence, the terminal voltage `V' decreases, under load condition.

Armature reaction drop: Due to the demagnetising effect of armature reaction, the main pole flux is weakened, and the induced emf (E) will be reduced in its magnitude.

The external characteristic gives the relation between terminal voltage and load current. Fig 1 gives the circuit diagram to determine this characteristic. The generator is first built up to its rated voltage. Then it is loaded in suitable steps up to full load. The terminal voltage and the corresponding load currents are noted for each step.

Fig 1



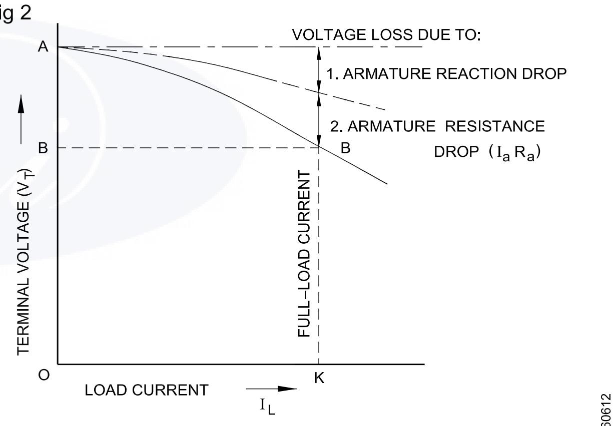
DC SHUNT GENERATOR

In this experiment, the field current has to be kept constant. This is due to the fact that when terminal potential decreases on load, the field which is connected across the armature will have a decreased current.
This effect, if allowed, will reduce the field flux, thereby, decreasing the induced voltage. This effect cumulatively reduces the terminal voltage further.

From the obtained values of the terminal voltage V_T and load current IL, the external characteristic curve is plotted as shown in Fig 2, keeping in V_T on `Y' axis and I_L on X axis.

From the curve it will be observed that the no-load voltage OA is maximum, and it falls to OB when loaded, to indicate that the full load current value is OK as noted in the name-plate of the generator.

Fig 2

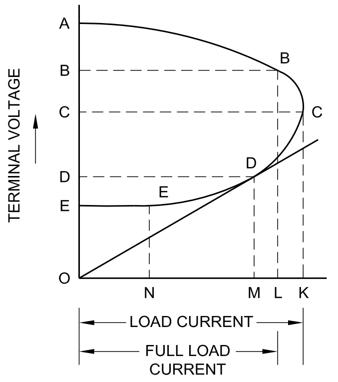


EXTERNAL CHARACTERISTIC CURVE OF DC SHUNT GENERATOR

Fall of voltage from no load to full load, which is due to armature reaction, and the armature voltage drop are found to be not appreciable. Normally the generators are designed to deliver full load current I_L, and the fall of voltage will be about 5 to 8 percent of the no-load voltage which can be regarded as negligible.

If the load current is further increased by decreasing the load resistance, the curve reaches a point `C' as shown in Fig 3. At this point, the terminal voltage falls to OC which will be an appreciable fall when compared to the no-load terminal voltage. At this point `C', though the load current is maximum (OK), the terminal voltage will be much less than the no-load voltage.

Fig 3



EXTERNAL CHARACTERISTIC CURVE (FULL CURVE)

EL160613

However, when the load resistance is further decreased the load current decreases to OM and V_T is reduced to `OD', that means the load current cannot be increased beyond OK and the point `C' is called the breakdown point.

It is the maximum possible current that a generator can supply. Beyond this point `C', the curve drops rapidly with decrease in the load resistance, indicating that the load current is also decreasing, instead of increasing. At point `E' the generator is virtually short-circuited, and all the voltage induced is dropped to near zero due to IaRa drop and armature reaction.

Rather, we can say OE is the residual voltage of the generator. Practically all the generators operate only on the portion `AB' of the curve where the efficiency of the generator is maximum.

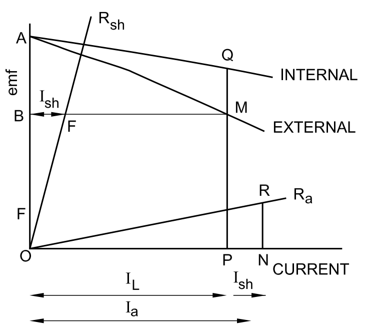
Internal characteristic: The internal characteristic gives the relation between induced voltage and the armature current. In a shunt generator,

$I_a = I_L + I_{sh} \qquad E = V_T + I_a R_a$

$$I_{sh} = \frac{V_T}{R_{sh}}.$$

So, E/I_a curve can be obtained from the external characteristic shown in Fig 2. By plotting `$I_{sh}$' horizontally against `V', we get Rsh line which is a straight line through the origin, but because of the high resistance of the shunt field it has a very steep gradient as shown in Fig 4.

Fig 4



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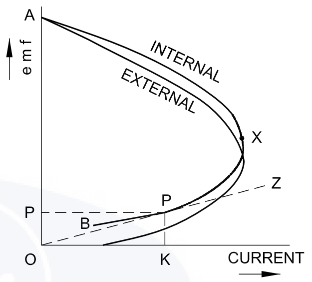
Also draw the armature resistance(R_a) line by plotting the drop in voltage against the armature current as shown in Fig 4. Take any point `M' on the external characteristic (Fig 4) and draw the perpendicular `MP'. Then for the given terminal voltage the load current I_L = OP. Draw 'MB' horizontally, then BF = I_{sh}, and mark off PN = BF in the 'X' axis.

Then ON = OP + PN = $(I_L + I_{sh}) = I_a$.

Draw a line vertically from N to meet the armature resistance line Ra at `R'. Then, the vertical line `RN' is equal to the drop in the armature and, therefore, if the line PM is extended further to point `Q', making MQ = RN, the total length `PQ' is the sum of the terminal voltage and total armature drop, which is equal to the emf generated. Thus a point `Q' on the internal characteristic is obtained, and the total (internal) characteristic can be drawn by joining points A and Q.

If the load resistance is decreased, then the curve turns back as in Fig 5. If the load resistance is too small, then the generator is short-circuited and there is no generated emf due to heavy demagnetisation of the main poles.

Fig 5



INTERNAL & EXTERNAL CHARACTERISTIC CURVE

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Load critical resistance: It is defined as the minimum value of load resistance with which the generator builds up voltage, and, just below this value of load resistance the DC shunt generator will fail to build up its voltage when started with the load.

When the DC shunt generator is started with the load, the terminal voltage may not raise beyond about 10V, the reason is the load resistance is so low, as if the generator is short-circuited. In Fig 5 the tangent line `OZ' to the internal characteristic APB is drawn.

Its slope will give the value of the load critical resistance. As the DC shunt generator will not build up emf when made to build up with load below this value of resistance, it is called the load critical resistance.

Load critical resistance in ohms =

$$\frac{\text{Voltage at point 'P'}}{\text{Load current at point 'P' (amps)}} = \frac{OP}{OK}$$

There are thus two critical resistances for a shunt generator, one for the field circuit and the other for the load external circuit.

Applications of DC shunt generator: According to the load characteristic of the DC shunt generator, the drop in voltage from no load to full load is not appreciable, up to its rated value of load current. Hence, it can be called a constant voltage generator. Therefore, it can be used for constant loads like:

- centrifugal pump
- lighting load
- fans
- battery charging and electroplating.

Armature reaction

Objective: At the end of this lesson you shall be able to
• explain the effect of armature reaction and its remedies.

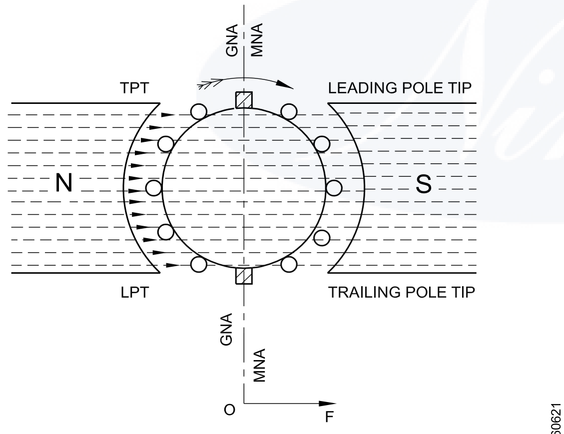
When armature conductors carry a lower load current, the mmf set up by the armature conductors interact with the main field flux in such a way that the field of the main field flux gets distorted and this is called cross-magnetizing effect.

However, the effect could be nullified by shifting the brush position of the generator by a small angle in the direction of rotation.

When the generator is loaded further, the pole tips get saturated which results in demagnetising the main field flux, thereby reducing the induced emf. This effect is called demagnetising effect.

Fig 1 shows the flux distribution by the main field flux only. Since there is no current in the armature conductors, the flux is uniform. The GNA (Geometrical Neutral Axis) and MNA (Magnetic Neutral Axis) are coincident with each other.

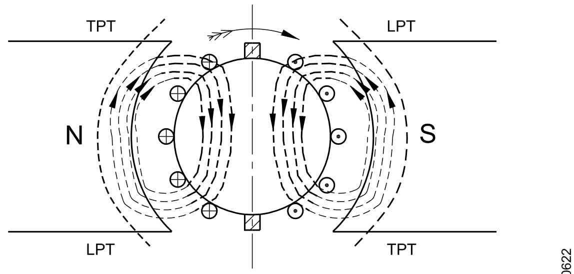
Fig 1



MAIN MAGNETIC FIELD OF A TWO - POLE DC MACHINE

Fig 2 shows the flux set up by the armature conductors alone. The current direction is marked as a plus sign(+), under the N.pole and dot (•) under the south pole as shown in the figure. The strength of this armature field (mmf) depends upon the armature current which, in turn, depends upon the load current.

Fig 2



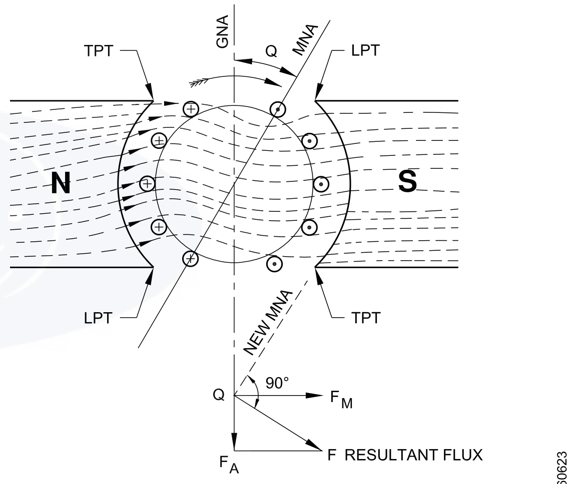
FLUX CREATED BY THE ARMATURE CURRENT

Cross-magnetising effect: Fig 3 shows the flux distribution by the combined effect of the main field and the armature mmf. The resulting field is found to have strengthened at the trailing pole tips and weakened at the leading pole tips.

Due to this cross-magnetizing effect, the magnetic neutral axis (MNA) is shifted from the geometrical neutral axis (GNA) by an angle Q in the direction of rotation.

The effect of the main field flux (FF) and the armature flux (F_A) are shown by vectors in Fig 3. The magnetic neutral axis (MNA) should be at right angle to the resultant flux (F).

Fig 3



CROSS - MAGNETISING EFFECT

Remedy: The effect of the cross-magnetisation can be neutralized by shifting the brushes from GNA to MNA with the help of the rocker arm. Of course the amount of shifting depends upon the magnitude of the armature current.

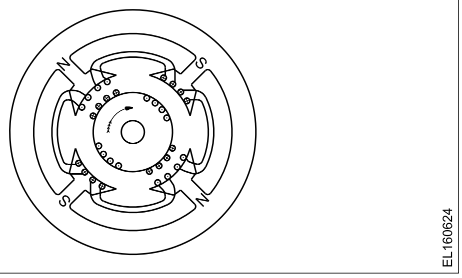
At the correct position of the brush, the induced emf will be maximum and the spark at the sides of brushes will be minimum.

Demagnetising effect: The uneven distribution of magnetic flux at heavy armature current results in a demagnetizing effect because strengthening on the trailing pole tip is only up to saturation of that tip.

After saturation the flux cannot increase at the trailing tips equally with the decrease in flux at the leading pole tips which causes the demagnetising effect, and hence, the induced emf reduces under heavy load condition.

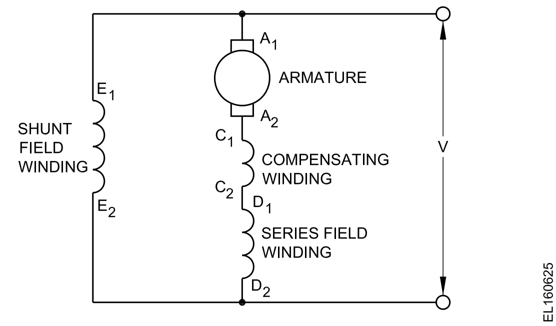
Remedy: To compensate the demagnetizing effect of the reduced induced emf, the ampere-turns are increased in the field winding itself to strengthen the main field for small machines. But, for large machines, the demagnetizing effect can be neutralized by providing compensating winding in the main pole-faces as shown in Fig 4, and connecting this compensating winding in series with armature as shown in Fig 5, which is for a compound machine.

Fig 4



Compensating winding: The demagnetizing effect due to armature reaction in large machines, which are subjected to fluctuation of load, can be neutralized by this winding.

Fig 5



This winding carries an equal current in the opposite direction to the current in armature conductors. So the flux set up by them is also in the opposite direction and of equal magnitude to that of the armature flux. Hence they neutralize each other, and thereby, the demagnetising effect is nullified at any load, even at fluctuating loads.

Commutation

Objective: At the end of this lesson you shall be able to
- **explain commutation and the methods of obtaining sparkless commutation.**

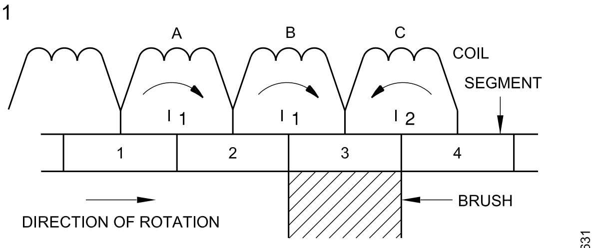
When a DC generator is loaded, the current flows through the armature winding, commutator and brushes to the external circuit. During this process, whenever a brush spans the two commutator segments, the winding element connected to those commutator segments is short-circuited.

The changes in current direction, which take place in the winding element, just before, during and after the short circuit is called commutation.

If the change in the current direction is gradual, then a smooth commutation takes place. On the other hand a sudden change in current in the winding element is called rough commutation which results in heavy sparking at the sides of brushes. If rough commutation is allowed to continue, the brushes and commutator get spoiled ultimately due to the excess heat produced by the sparks.

These changes in current are explained through the following figures. Fig 1 shows the current in the coil B flows in a clockwise direction, and the brush collects I_1 amps from the left side winding and I_2 amps from the right side winding.

Fig 1

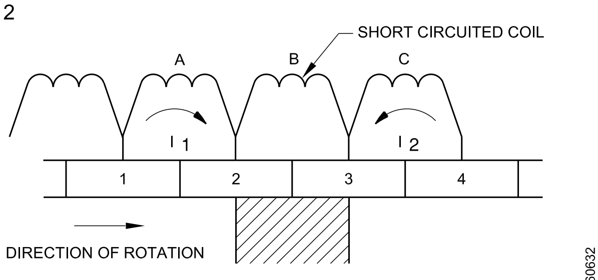


CURRENT COLLECTION - SEGMENT 3 IN CONTACT WITH THE BRUSH

Fig 2 shows that the brush short-circuits segments 2 and 3, and hence, coil B is short-circuited. Current I_1 in the left side winding passes to the brush through coil A, and the right side winding current passes through coil C. No current is in coil B as it is short-circuited.

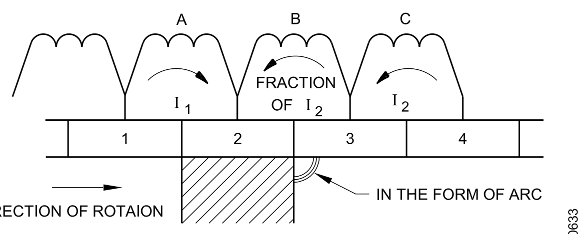
Fig 3 shows that the brush contacts segment 2 only, and the current in the left side winding passes to the brush through coil A. On the other hand the current in the right hand side (I_2) should now pass through coil B via segment 2 to the brush.

Fig 2



CURRENT COLLECTION-SEGMENTS 2 & 3 ARE IN CONTACT WITH THE BRUSH

Fig 3



CURRENT COLLECTION - SEGMENT 2 IN CONTACT WITH THE BRUSH

At this instant, the current in coil B, has to change its direction from clockwise to anticlockwise, but even though it changes it would not attain the full value of current after the short circuit. Therefore, a major portion of current I_2 from the right side passes to the brush through an arc from segment 3. This is due to the fact that the sudden change of current direction in coil B induces a statistically induced

(reactance) emf equal to $\frac{Ø}{t}$ or $\frac{I}{t}$

where Ø is the flux created by the current I in amps, and 't' represents the time of short circuit in seconds.

Further, the induced emf can also be calculated by knowing the reactance of the coil under commutation which depends upon the self-inductance of the coil, and the mutual inductance of the neighbouring coils.

For example, A 2-pole, 2-brush DC generator delivers 100 amps to a load when running at 1440 r.p.m., and has 24 segments in its commutator. Then to find the statically induced emf in the winding element soon after the short-circuit, we have the current from the left side of the brush - 50 amps and the current from the right side of the brush - 50 amps.

Hence the change of current is from 50 amps in the clockwise direction to zero, then to 50 amps in the anticlockwise direction amounting to 100 amps.

$$\text{Time taken for one revolution} = \frac{60}{1440} = 0.04166 \text{ seconds}$$

Time taken for short circuit

$$= \frac{0.04166 \text{ seconds}}{24 \text{ segments}} = 0.001736 \text{ seconds}$$

which is equal to time reqd. to pass one segment

Hence the statistically induced emf

$$= \frac{I}{t} = \frac{100}{0.001730} = 57{,}603V.$$

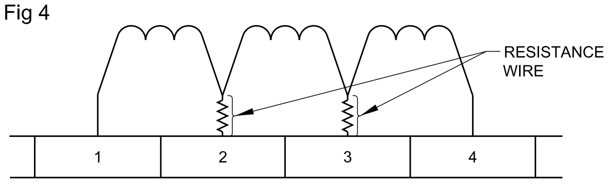
This induced emf will obey Lenz's law, and oppose the change in the current. Hence the current from the right hand side as shown in Fig 3 would not be able to pass through coil B, and hence it jumps to the brush in the form of an arc. This is called rough commutation.

Remedies for rough commutation

To avoid sparks in the brush position, the following methods are used which effectively change the rough commutation to smooth commutation.

– Resistance wires are introduced between the end connection of the coil to the commutator, as shown in Fig 4. This increased resistance helps the current to change its direction smoothly, increasing the timing and reducing the statically induced emf.

Fig 4

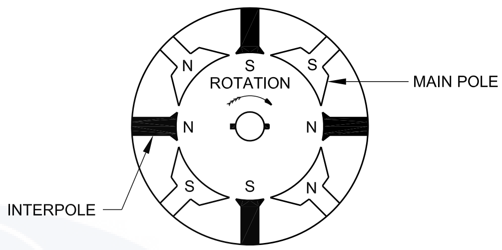


COMMUTATION WITH RESISTANCE WIRES

– High resistance brushes are used. Hence the contact resistance variation allows the current to change its direction smoothly, thereby reducing the statically induced emf.

– Small field poles called inter-poles are provided in between the main poles as shown in Fig 5. These inter-poles have their polarity the same as the next pole ahead in the direction of rotation of the, generators. Further, their winding is connected in series with the armature so that they carry the same current as that of the armature.

Fig 5

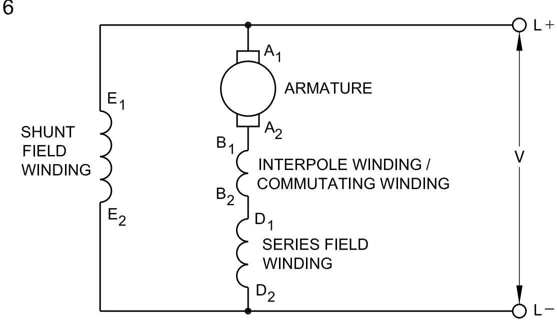


COMMUTATION WITH INTERPOLES

These inter-poles produce an emf opposite in direction to the statically induced emf, and have a magnitude depending upon the current. Thereby, the effect of statically induced emf is nullified.

These inter-poles are wound with less number of turns having thick gauge wire. Fig 6 shows the connection of inter-pole winding in a DC compound machine.

Fig 6



CONNECTION OF INTERPOLE WINDING IN A DC MACHINE

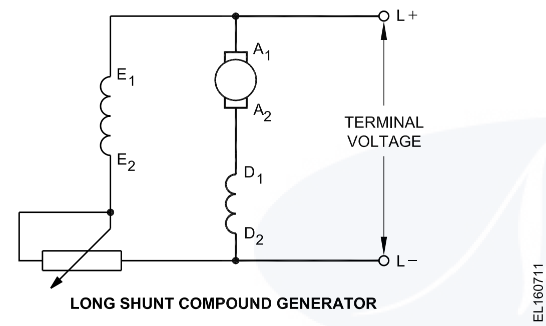
DC compound generator - Types and their external characteristics

objectives: At the end of this lesson you shall be able to
- **distinguish the type of connection of a DC compound generator as cumulative or differential**
- **explain the external characteristics of DC compound generators (cumulative and differential) and their applications**
- **solve numerical problems pertaining to the DC generator.**

Compound generator: Combination of shunt field and series field within one generator provides two sources of excitation, and such a generator is called a compound generator.

Long shunt compound generator: When the shunt field is connected in parallel with the series combination of the armature and the series field, the generator is said to be connected as a long shunt compound generator which is shown in Fig 1.

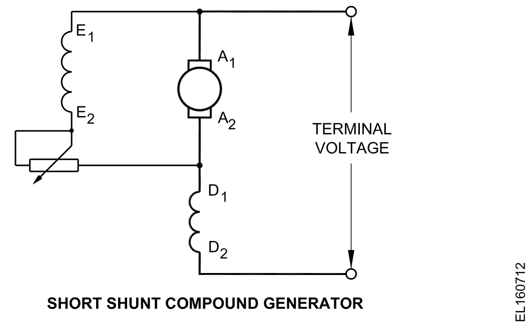
Fig 1



LONG SHUNT COMPOUND GENERATOR

Short shunt compound generator: When the shunt field is connected in parallel with only the armature, the generator is said to be connected as a short shunt compound generator which is shown in Fig 2.

Fig 2



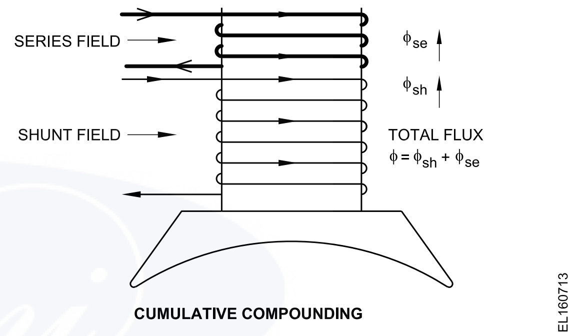
SHORT SHUNT COMPOUND GENERATOR

Cumulative compound generator: The shunt field excitation flux is usually more or less steady, and is affected only slightly as the terminal voltage fluctuates. The flux of the series field is quite variable because its ampere-turns depend upon the load current.

When the load current is zero, it produces less flux (long shunt) or no flux (short shunt) and when the load current is high, it creates a good amount of flux. How much flux it must develop depends upon the extent to which it must compensate for the voltage drop. In a compound machine, the series field is wound directly over the shunt field with proper separation by insulations.

The series field coils may be connected to `assist' or `aid' the shunt field, as shown in Fig 3. Then this machine is said to be a cumulative (increasing by successive additions) compound generator. The ampere turns of the series field determines the amount of compounding.

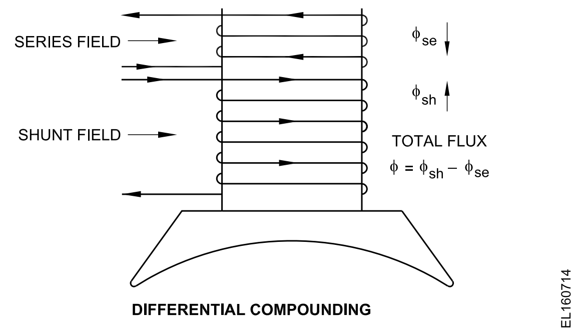
Fig 3



CUMULATIVE COMPOUNDING

Differentially compounded generator: If the flux produced by the series field opposes the shunt field flux as shown in Fig 4, then the action is called `bucking' and the machine is said to be a differential (decreasing by successive subtractions) compound generator.

Fig 4



DIFFERENTIAL COMPOUNDING

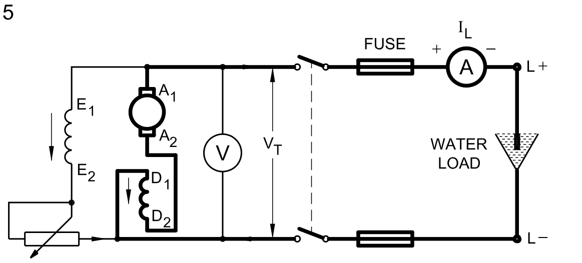
External characteristics of DC compound generator

Cumulative compound generator: Fig 5 shows the connection diagram for a long shunt cumulative compound generator. In such a connection, the series field aids the shunt field and the total flux is equal to the sum of both the fluxes. By taking a set of readings for different load currents I_L and the corresponding terminal voltage V_T, we can draw a graph showing the relation between V_T and I_L. This curve is called the external characteristic curve.

If the shape of the curve is as shown in curve `C' of Figure 6, then it will be the same as the curve shown for the shunt generator, and this generator could be used for constant voltage loads. If the shape of the curve is as shown in curve `a' of Fig 6, it shows that the terminal voltage goes on increasing with an increase of the load current. It is due to the reason that the series ampere-turns produce more flux than the flux required to over come the I_aR_a drop and the armature reaction.

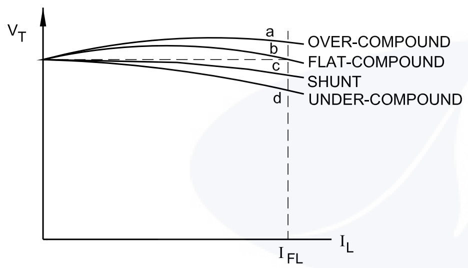
Such a machine is called an over-compounded generator, and this generator could be used for supplying load to long distance distribution lines so that the voltage drop in the line could be compensated by increased voltage.

Fig 5



LONG SHUNT CUMULATIVE COMPOUND GENERATOR CONNECTION DIAGRAM

Fig 6



EXTERNAL CHARACTERISTICS OF COMULATIVE COMPOUND DC GENERATORS

If the shape of the curve is as shown in curve `b' of Fig 6, it shows that the series ampere-turns at light load are producing more flux than required to overcome the I_aR_a drop but at full load the series field flux is just sufficient to overcome the I_aR_a drop and armature reaction. Such a machine is called a flat (level) compounded generator, and this generator could be used for supplying power to constant loads requiring specified terminal voltage.

If the shape of the curve is as shown in curve `D', it shows that the series ampere-turns are not sufficient to overcome the drop in the terminal voltage due to the I_aR_a drop and the armature reaction but still they are aiding the shunt field. Such a machine is called an under-compounded generator, and this generator may be used for electroplating or lighting.

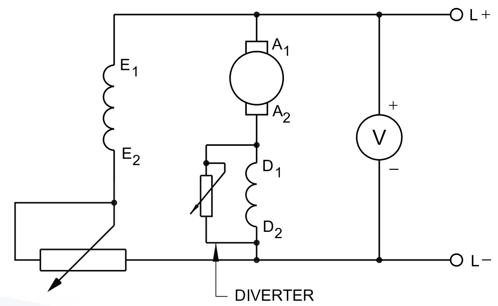
Degree of compoundings in a cumulative compound generator:

The level of compounding in a generator can be altered by the amount of the series field current. Hence to adjust the series field current, a diverter may be connected as shown in Fig 7.

Differential compound generator: If the series field terminals are interchanged as shown in Fig 8, then the curve obtained may be as shown in Fig 9. In such a connection, the series field opposes the shunt field, and the generator becomes a differential compound generator. The total flux produced will be equal to the shunt field flux minus the series field flux.

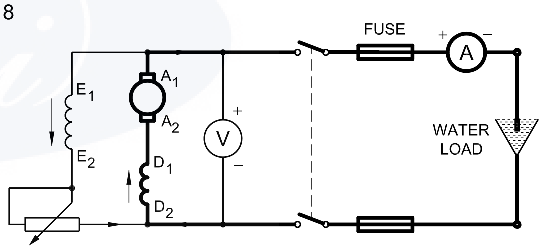
From the curve, it is clear that the terminal voltage drastically reduces with increase in the load current. It is due to the reason that series ampere-turns produce flux which are opposing or bucking the shunt field flux. This characteristic may be used in welding work, where the potential difference between the electrode and the job before striking an arc is in the order of, say 100V, and when the arc strikes it falls to, say 40 to 50 V, to maintain the flow of current.

Fig 7



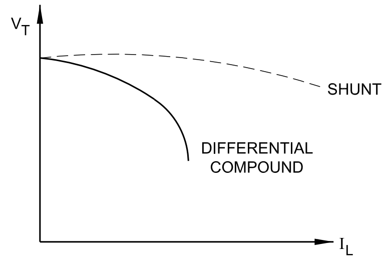
SERIES FIELD DIVERTER IN COMPOUND GENERATOR

Fig 8



CUMULATIVE COMPOUND GENERATOR CIRCUIT

Fig 9



EXTERNAL CHARACTERISTIC OF DIFFERENTIAL COMPOUND DC GENERATOR

Application of a compound generator: Table 1 gives the different types of compound generators and their application in industry.

Numerical problems pertaining to DC generator: When the generator is loaded, there will be voltage drops in the armature resistance and series field resistance. To calculate the induced emf from the available data, the following steps should be adopted.

$E_g = V + I_aR_a + I_{se}R_{se}$

In the case of a short shunt compound generator shown in Fig 10, $I_{se} = I_L$ and $I_a = I_L + I_{sh}$.

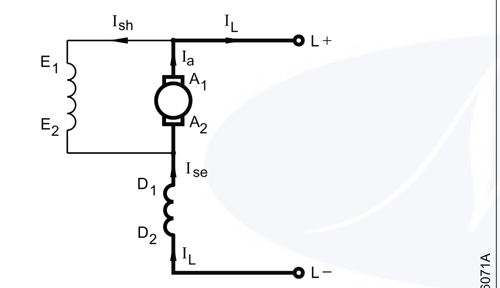
In the case of a long shunt compound generator shown in Fig 11 $I_{se} = I_a$ and $I_a = I_L + I_{sh} = I_{se}$

where I_a = armature current in amps
I_{sh} = shunt field current in amps
I_{se} = series field current in amps
I_L = load current in amps.

TABLE 1

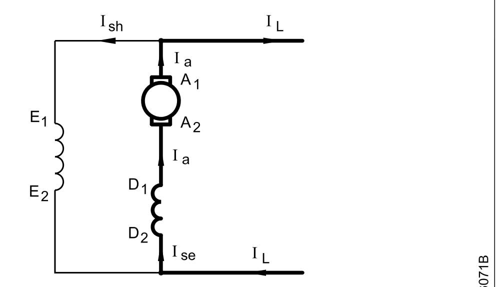
Sl.No.	Type of compound generator	Uses
1	Cumulative compound generator a.Over-compounded	Used where the load is at a considrable distance from the generator as in railways, street lights etc.
	b. Flat or level compound	Used where the load is nearby, such as lighting loads and power loads of small buildings or lathes which require constant voltage.
	c. Under-compounded	Used for electroplating, lighting, etc.
2	Differential compound generator	Used for arc welding generators.

Fig 10



SHORT SHUNT COMPOUND GENERATOR

Fig 11



LONG SHUNT COMPOUND GENERATOR

Example: A long-shunt compound generator delivers a load current of 100 A at 400 V, and has armature, series field and shunt field resistances of 0.1 ohm, 0.03 ohm and 200 ohm respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.

Solution

Generator circuit is shown in Fig 12.

I_{sh} = 400/200 = 2 A

Current through armature and series winding is the same.

Hence $I_a = I_{se}$ = 100 + 2 = 102 A.

Voltage drop in series field winding=$I_{se}R_{se}$ =102 x 0.03 = 3.06 V

Armature voltage drop I_aR_a = 102 x 0.1 = 10.2 V.

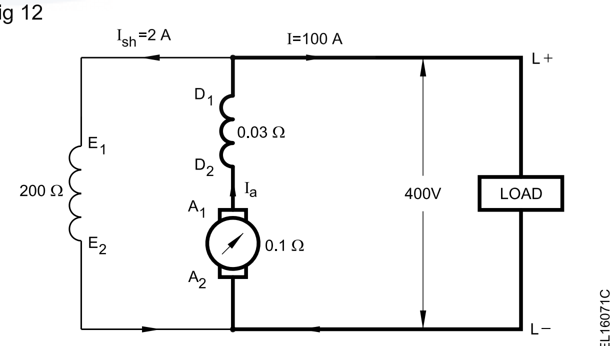
Assuming 2 brushes,

drop at brushes = 2 x 1 = 2 V.

Now, $E_g = V + I_aR_a$ + series drop + brush drop

= 400 + 10.2 + 3.06 + 2 = 415.26 V

Fig 12



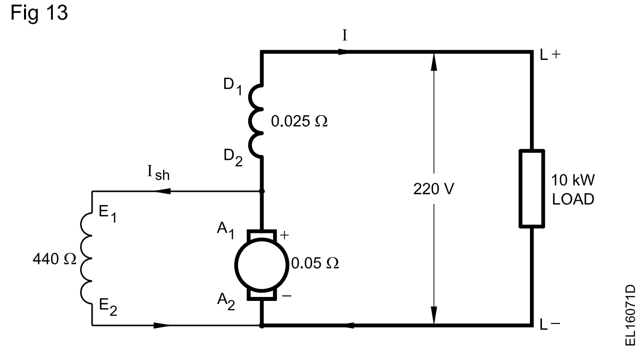
Example: A 10 kW compound generator works on full load with a terminal voltage of 220 V. The armature, series and shunt windings have resistances of 0.05 ohm, 0.025 ohm and 440 ohms respectively. Calculate the total emf generated in the armature when the machine is connected as short shunt.

Solution: Generator circuit is shown in Fig 13.

$$\text{Load current} = \frac{\text{Load in watts}}{\text{Ter min a voltage}} = \frac{10{,}000}{220} = 45.45\text{A}.$$

Voltage drop in series windings = 45.45 x 0.025 = 1.14 V.

Fig 13



Voltage across shunt winding = 220 + 1.14 = 221.14 V

I_{sh} = 221.14/440 = 0.503 A

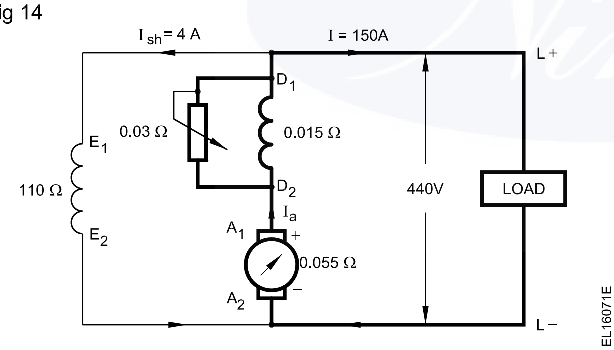
I_a = 45.45 + 0.503 = 45.953 A

I_aR_a = 45.953 x 0.05 = 2.297 V.

Generator emf = Terminal voltage + voltage drop in armature + voltage drop in series field = 220 + 2.297 + 1.14 = 223.44 V.

Example: In a long-shunt compound generator, as shown in Fig 14, the terminal voltage is 440 V when the generator delivers 150 A. Determine (i) induced emf (ii) total power generated and (iii) distribution of this power given that shunt field, series field, divertor and armature resistances are 110 ohms, 0.015 ohm, 0.03 ohm and 0.055 ohm respectively.

Fig 14



Solution

I_{sh} = 440/110 = 4A;

I_a = 150 + 4 = 154 A

Since the series field resistance and divertor resistance are in parallel (Fig 14), their combined resistance is = 0.03 x 0.015/0.045 = 0.01 ohm.

Total armature circuit resistance is = 0.055 + 0.01 = 0.065 ohm.

voltage drop across the series field and armature = 154 x 0.065 = 10.01V.

(i) Voltage generated by armature E_g = 440 + 10.01 = 450.01 V, say 450 V

(ii) Total power generated by armature = E_gI_a = 450 x 154 = 69,300 W.

(iii) Power lost in armature = $I_a^2R_a$ = 154^2 x 0.055 = 1304.4 W.

Power lost in the series field and divertor = 154^2 x 0.01 = 237.2 W

Power dissipated in shunt winding = VI_{sh} = 440 x 4 = 1760 W

Power delivered to load = 440 x 150 = 66000 W.

DC motor – Principle and Types - Starters

Objectives : At the end of this lesson you shall be able to
- **explain the working principle of a DC motor - action of current carrying conductor in the magnetic field and Fleming's left hand rule**
- **state the types of DC motors.**

INTRODUCTION

A DC motor is a machine which converts DC electrical energy into mechanical energy. It is similar to a DC generator in construction. Therefore, a DC machine can be used as a generator or as a motor.

Even today, because of the excellent torque, speed, load characteristic of DC motors, 90% of the motors used in precision machines, wire drawing industry and traction are of this type. DC motor needs frequent care and maintenance by qualified wiremen; hence more job opportunities exist in this area for a wireman.

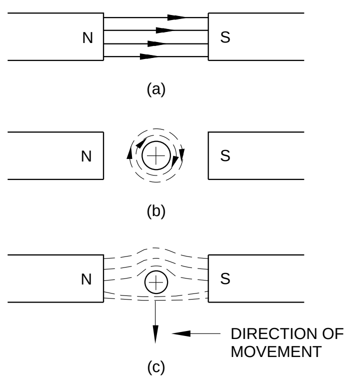
Principle's of a DC motor

It works on the principle that whenever a current carrying conductor is kept in a uniform magnetic field a force will be set up on the conductor so as to move it at right angles to the magnetic field. It can be explained as stated below.

Fig 1(a) shows the uniform magnetic field produced by a magnet whereas Fig 1(b) shows the magnetic field produced around the current carrying conductor. Combining these effects of Fig 1a and Fig 1b in one figure, Fig 1c shows the resultant field produced by the flux of the magnet and the flux of the current carrying conductor.

Due to the interactions of these two fields, the flux above the conductor will be increased and the flux below the conductor is decreased as represented in Fig 1(c). The increased flux above the conductor takes a curved path thus producing a force on the conductor to move it downwards.

Fig 1

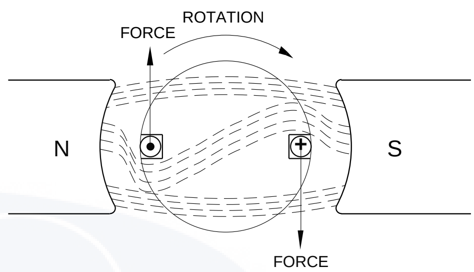


REACTION OVER A CURRENT CARRYING CONDUCTOR BY THE MAGNETIC FIELD

If the conductor in Fig 1 is replaced by a loop of wire as shown in Fig 2 the resultant field makes one side of the conductor to move upwards and the other side to move downwards. It forms a twisting torque over the conductors and they tend to rotate if they are free. This principle is applied in motors to get a rotational motion. But in practice there are a number of such conductors/coils in a motor.

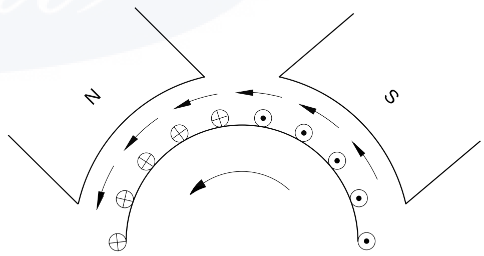
Fig 3 shows the part of a motor when its armature and field are supplied with current, the armature experiences a force tending to rotate in anticlockwise direction as shown in Fig 3.

Fig 2



REACTION OVER A CURRENT CARRYING LOOP BY THE MAGNETIC FIELD

Fig 3



REACTION OVER THE ARMATURE CURRENT CARRYING CONDUCTORS BY THE MAGNETIC FIELD

The direction of rotation or movement can be determined by Fleming's left hand rule. Accordingly the direction of rotation of the armature could be changed either by changing the direction of the armature current or the polarity of the field.

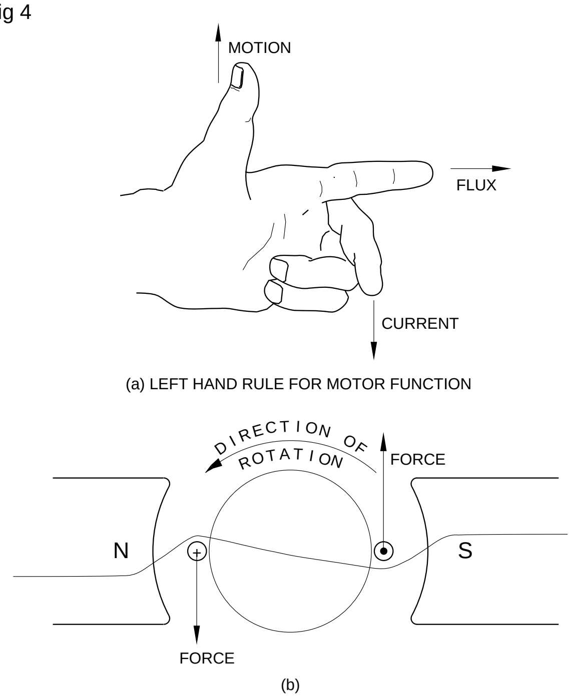
Fleming's Left Hand Rule

The direction of force produced on a current carrying conductor placed in a magnetic field can be determined by this rule.

As shown in Fig 4a, hold the thumb, forefinger and middle finger of left hand mutually at right angles to each other, such that the fore finger is in the direction of flux, and the middle finger is in the direction of current flow in the conductor; then the thumb indicates the direction of motion of the conductor.

For example, a loop of coil carrying current when placed under north and south poles as shown in Fig 4b rotates in the anticlockwise direction.

Fig 4



FLEMING'S LEFT HAND RULE

Types of DC motors

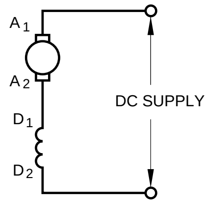
As the DC motors are identical in construction to that of DC generators, they are also classified as series, shunt and compounded motors depending upon their connection of field winding with the armature and supply.

When the armature and field are connected in series as shown in Fig 5a, it is called a **series motor**.

When the armature and field are connected in parallel across the supply as shown in Fig 5b it is called a **shunt motor.**

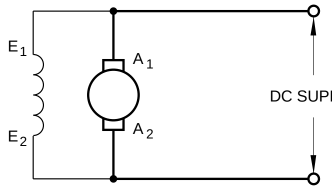
When the motor has two field coils, one in series with armature and the other in the parallel with the armature as shown in Fig 5c, it is called a **compounded motor.**

Fig 5a



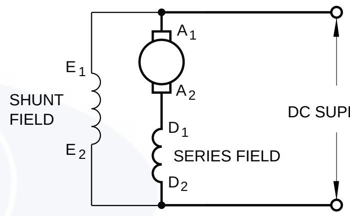
SERIES MOTOR

Fig 5b



SHUNT MOTOR

Fig 5c



COMPOUND MOTOR

Characteristics of DC motor and method of changing direction of rotation

Objectives

At the end of this lesson you shall be able to

- **explain the relation between applied voltage, back emf, armature voltage drop, speed, flux etc.**
- **describe the method of changing the direction of rotation of a DC motor.**

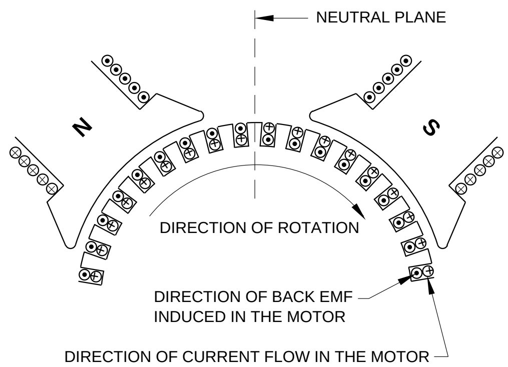
Back emf

As the armature of a DC motor starts rotating, the armature conductors also cut the magnetic flux produced by the field poles. Due to this action an emf will be produced in these conductors. The induced emf is in such a direction so as to oppose the flow of current in the armature conductor as shown in Fig 1. As it opposes the supply voltage it is called 'BACK emf' and denoted by E_b. Its value is the same as that found in the generator. It could be written as

$$E_b = \frac{\phi ZNP}{60A} \text{volta}$$

where ø is the flux per pole, 'Z' is the No. of conductors in the armature, 'N' is the r.p.m. of the machine, 'P' is the No. of poles and 'A' is the No. of parallel paths.

Fig 1



The direction of the induced (back) emf could be determined by Fleming's right hand rule.

Applied voltage

The voltage applied across the motor terminals is denoted by 'V'.

Armature voltage drop

Since armature conductors have some resistance, whenever they carry current, a voltage drop occurs. It is called I_aR_a drop because it is proportional to the product of armature current I_a and armature resistance R_a.

It has definite relation with applied voltage and back emf as shown in the formula.

$V = E_b + I_aR_a$ i.e. $I_aR_a = V - E_b$.

Further the back or counter emf E_b is depending upon flux per pole 'ø' and speed 'N'. Therefore applied voltage, back emf, armature drop, flux and speed are related to one another as follows.

$E_b = V - I_aR_a$.

Therefore $N = \dfrac{\left(V - I_aR_a\right) \times 60A}{\phi\, ZP}$ r.p.m.

For a given motor the value Z, P, A and 60 are constants and can be denoted by a single letter K

where $K = \dfrac{60A}{ZP}$

Therefore $N = K\, E_b/ø$ i.e. $N \propto E_b/ø$.

This shows that the speed of a DC motor is directly proportional to E_b and inversely proportional to the flux ø.

Reversing the direction of rotation of DC motors

The direction of rotation of a DC motor can be changed either by changing the direction of the armature current or by changing the direction of the field current.

The direction of rotation of a DC rotor cannot be changed by interchanging the supply connection, since its effect is the same while changing the supply terminal as shown in Fig 2 (a & b).

But when the field current direction alone is changed, the direction of rotation changes as shown in Fig 3. When the armature current direction alone is changed, the direction of rotation changes from counter clockwise direction shown in Fig 2a to clockwise direction as shown in Fig 4.

To reverse the direction of rotation of a compound motor without changing its characteristics, the best method is to change only the armature current direction.

In the case of changing the direction of rotation by changing the field terminals, it is essential to change the current direction in both shunt and series windings. Otherwise the machine which was running as cumulatively compounded will change its characteristic as differentially compounded or vice versa.

Fig 2a

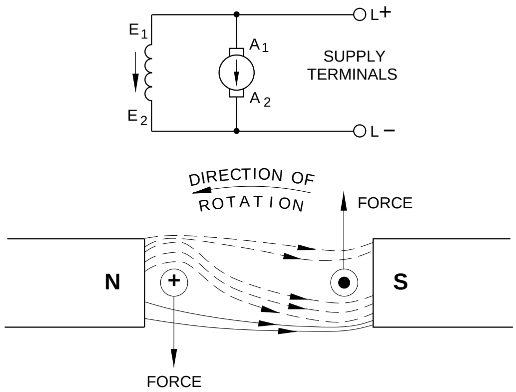
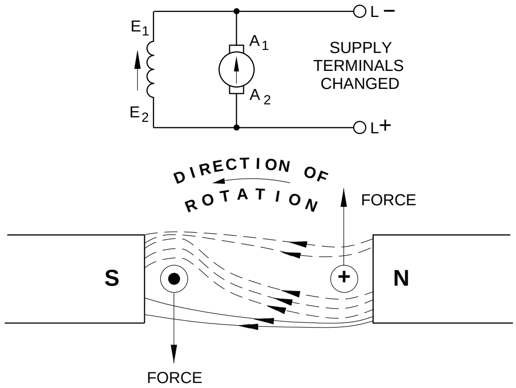
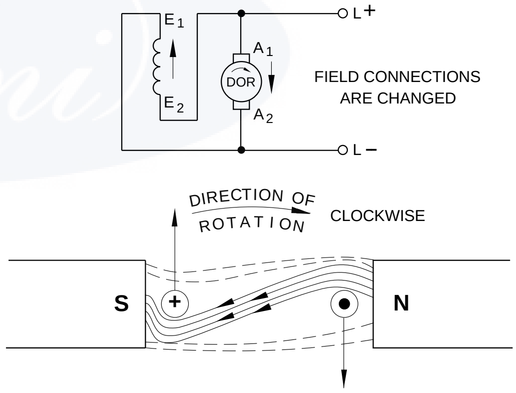


Fig 2b



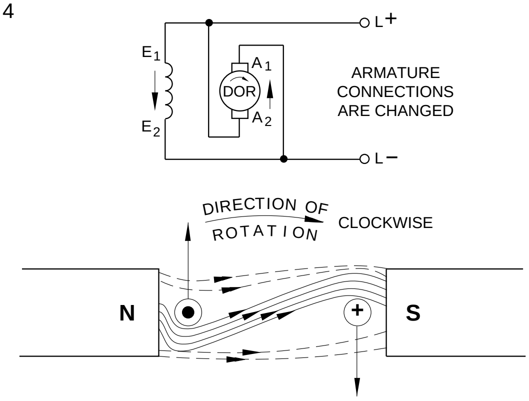
EFFECT OF CHANGING SUPPLY TERMINALS

Fig 3



EFFECT OF CHANGING THE FIELD CURRENT DIRECTION

Fig 4



EFFECT OF CHANGING THE ARMATURE CURRENT DIRECTION

DC motor starters

objectives : At the end of this lesson you shall be able to
- **state the necessity of a starter for a DC motor**
- **state the types of starters – construction and working principle of 2-point, 3-point and 4-point starters.**

Necessity of starters

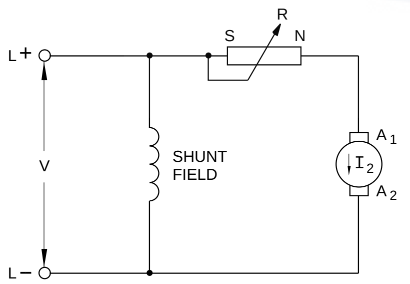
Since the armature is stationary before starting, the back emf which is proportional to speed is zero. As armature resistance is very small, if the rated voltage is applied to the armature, it will draw many times the full load current, and thereby, there is every possibility of damaging the armature due to heavy starting current.

Therefore, the starting current should be limited to a safe value. This is done by inserting a resistance in series with the armature at the time of starting for a period of 5 to 10 seconds. As the motor gains its speed, back emf is built up and then the starting resistance could be gradually cut off.

Fig 1 shows such an arrangement. Resistance R is fully included in the armature circuit by keeping the moving arm in position 'S' at the time of starting and then it is moved towards position 'N' to exclude the resistance 'R' when the motor has picked up its speed. But such an arrangement will be purely manual and needs constant monitoring.

For example, in case supply fails, the motor will stop but the moving arm will still be in position 'N'. When supply returns, as there is no resistance included in the armature circuit through 'R', the armature may draw heavy current and may get damaged. To prevent such a happening a device with sufficient protection for the machine called starter is used in a motor circuit.

Fig 1



In addition to the automatic inclusion of the resistance at the time of starting the starters may protect the motor from overload and will switch 'off' the motor when supply fails. These starters are named according to the number of connecting terminals as explained below.

TYPES OF STARTERS

Starters used to start the DC motors are generally of three types.

– Two-point starter
– Three-point starter
– Four-point starter

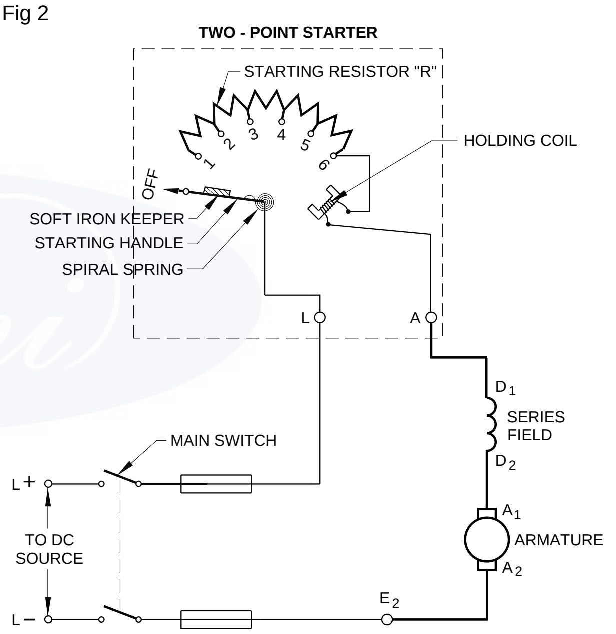
Two-point starter

This contains the following components.

1 The series resistor required for starting a motor.
2 The contacts (Brass studs) and switching arm required to include or exclude the resistor in the armature circuit.
3 A spring on the handle to bring the handle to 'off' position when supply fails.
4 An electromagnet to hold the handle in 'ON' position.

The two-point starter is frequently used with DC series motor. The starting resistance, electromagnet armature and series field all are connected in series as shown in Fig 2.

Fig 2



When the arm is moved to the first contact point the circuit is completed and the armature begins to rotate. As the armature speed increases the arm is slowly moved towards the right side of the electromagnet. Thereby, the starter resistance is reduced. When the arm is against the electromagnet , complete starter resistance is cut off from the circuit.

The electromagnet is wound with a thick gauge of wire to carry the rated armature current of the motor. This holds the handle in the 'ON' position when the motor is working. The handle comes back to 'OFF' position due to spring action when the electromagnet demagnetises due to failure of supply. This starter, in general, will not have protection against overloads.

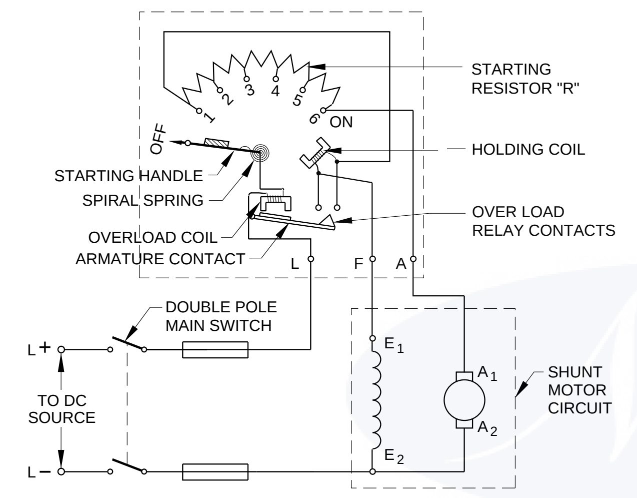
Three-point starter

Figure 3 shows the internal diagram of a three-(terminal) point starter connected to a DC shunt motor. The direct current supply is connected to the starter and the motor circuit through a double pole switch and suitable fuses.

The starter has an insulated handle or knob for the operator's use. By moving the starter handle from the 'OFF' position to the first brass contact (1) of the starter, the armature is connected across the line through the starting resistance. Note that the armature is in series with the total starting resistance.

The shunt field, in series with the holding coil, is also connected across the line. In this mode of operation, the initial current to the armature is limited by the resistance. At the same time, the field current is at the maximum value to provide a good starting torque.

Fig 3



As the handle arm is moved to the right, the starting resistance is reduced and the motor gradually accelerates. When the last contact is reached, the armature is connected directly across the supply; thus, the motor is at full speed. In this position the holding coil magnetic attraction will hold the handle arm in 'ON' position, thereby, allowing the motor to run.

The holding coil is connected in series with the shunt field to provide a 'no field release'. If the field circuit opens by accident, the motor speed will become excessive in case the armature remains connected across the line.

To prevent this excessive speed, the holding coil is connected in series with the field. In case of an open circuit in the field, there will be no current through the holding coil, and hence, it will be demagnetized and spring action returns the arm to the 'off' position.

An overload low resistance coil is provided to prevent damage to motor from overload. Under normal load condition the flux produced by the O/L coil will not be in a position to attract the armature contact.

When the load current increases beyond a certain specified value, the flux of O/L coil will attract the armature. The contact point of the armature then short circuits the holding coil and demagnetize it. This enables the handle to come to 'OFF' position due to tension of the spiral spring.

This type of starter can be used to start both shunt and compound motors.

However, a 3-point starter is found to be tripping when the motor speed is controlled through the field regulator. The reason could be explained as stated below. When the speed of a shunt or compound motor is to be increased beyond its rated speed, the resistance is increased in the field regulator to reduce the field current, consequently the field flux.

While doing so, the holding coil which is in series with the field gets very low current and produces less holding force on the handle armature against the tension of the spiral spring. When the current reduces below a certain value, the handle is pulled out from the 'ON' position to the 'OFF' position.

This is an undesirable effect. To avoid this, the 3-point starter circuit is modified and the holding coil circuit is made independent of the field circuit. Such a starter is called a 4-point starter.

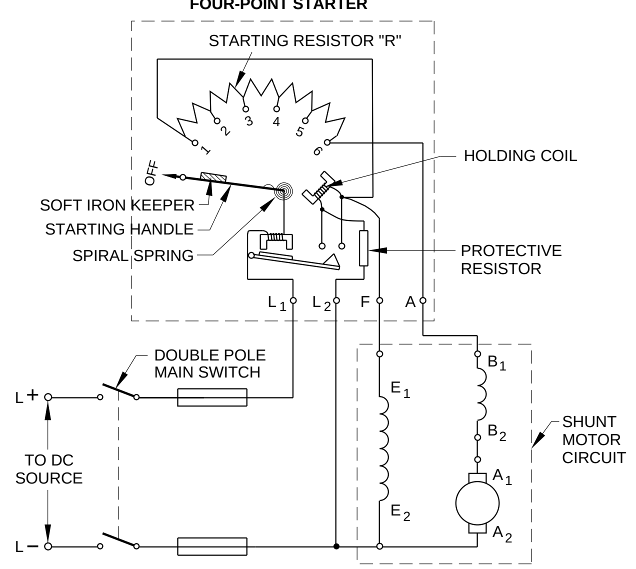
Four-point DC starter

In applications where many motor speeds are to be increased beyond the rated value, a four-terminal face-plate starter is used with the motor.

The four-(terminal) point starter, shown in Fig 4, differs from the three-point starter in such a way that the holding coil is not connected in series with the shunt field. Instead, it is connected across the supply in series with a resistor. This resistor limits the current in the holding coil to the desired value. The holding coil serves as a no-voltage release rather than as a no-field release.

If the line voltage drops below the desired value, the magnetic attraction of the holding coil is decreased, and then the spring pulls the starter handle back to the off position.

Fig 4



Relation between torque, flux and armature current in a DC motor

Objectives: At the end of this lesson you shall be able to
- **explain the relation between torque, flux and armature current**
- **solve problems pertaining to metric HP, load current, rated voltage, torque and speed of DC motor.**

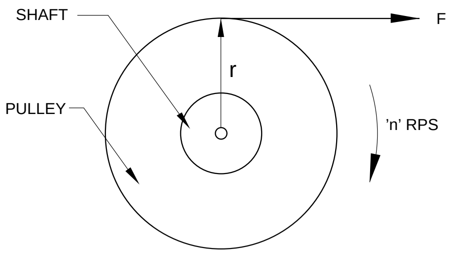
Relation between armature current, flux and torque

Torque

The turning or twisting moment of a force about an axis is called torque. It is equal to the product of force and the radius of the pulley.

Consider a pulley of radius 'r' metre acted upon by a circumferential force 'F' newton and rotating at a speed of 'n' RPS as shown in Fig 1.

Fig 1



TORQUE PRODUCTION IN A MOTOR

Then torque T = F X r newton-metres(N m).

Work done by this force in one revolution

= Force X distance covered in one revolution

= F X 2πr joules.

Power developed in one second

= F X 2πr X n joule/second or watts.

= (F X r)2πn watts.

where Joules/second = Watts,

n = revolutions/second.

As 2πn is the angular velocity 'ω' in radian/second and

(F X r) = Torque T.

Substituting the above

Power developed = (F x r) X (2 π n) = Tω x watts

so P = Tω watts.

Torque of a motor

Let T_a be the torque developed by the armature of a motor in newton-metre and 'n' be the speed of armature in rps.

Then the power developed in the armature = T_a X 2πn watts.

As we know electrical power is converted into mechanical power in a motor.

Electrical power supplied to the armature = $E_b I_a$ where

E_b is the back emf and I_a is the armature current.

Electrical power supplied to the armature = Mechanical power developed in the armature.

We get $E_b I_a = T_a 2\pi n$.

Since, $E_b = \frac{øZnP}{A}$ Volts (By taking 'n' in rps)

$$T_a \text{ x } 2\,\pi\, n = \frac{øZnP}{A} \text{ x } I_a$$

By cross multiplication we get

$$T_a = \frac{øZP \text{ x } I_a}{2\pi A} \text{ Nm}$$

or

$$T_a = \frac{0.159 \text{ x } øZP \text{ x } I_a}{A} \text{ Nm}$$

For a given motor Z, P and A are constants as they depend upon the design.

So $\frac{0.159\ ZP}{A}$ can be regarded as constant 'K'

Then $T_a = K\phi I_a$

Where ϕ is the flux/pole in weber

I_a is the amature current

T_a is the armature torque in newton metres.

$$K = \frac{0.159ZP}{A}$$

Therefore, we can say the torque of a DC motor is directly proportional to the field flux and the armature current.

The other formula which gives torque is

$$T_a = \frac{9.55\ E_b I_a}{N} \text{ Nm}$$

where 'N' is the speed in rpm.

Shaft torque

The complete armature torque calculated above is not available for doing useful work because of losses in the motor.

The torque which is available for doing work is known as shaft or output torque and it is denoted as T_{sh}.

The difference ($T_a - T_{sh}$) is known as loss of torque due to iron friction and windage losses of the motor.

$$\text{One H.P. metric} = \frac{2\,\pi\,n\,T_{sh}}{735.6}$$
$$= \frac{2\,\pi\,N\,T_{sh}}{60 \times 735.6}\ \text{HP}$$

where n is speed in rps and N is the speed in rpm. and T_{sh} is the shaft torque in Newton metre.

If the torque is given in kg. metre, it can be converted into newton metre as given below.

newton metre = kg. metre X 9.81

Example : A 250 V, 4-pole, wave-wound DC series motor has 782 conductors on its armature. It has combined armature and series field resistance of 0.75 ohms. The motor takes a current of 40 A. Estimate its speed, armature torque and HP if flux per pole is 25 milli-weber.

$E_b = V - I_a R_a$ (known formula)

= 250 – (40 x 0.75)

= 250 – 30 = 220 V.

$$\text{We have, } E_b = \frac{øZnP}{A}\ \text{Volts}$$

$$N = \frac{E_b \times 60 \times A}{ø\,Z\,P}$$

$$= \frac{220 \times 60 \times 2}{25 \times 10^{-3} \times 782 \times 4}$$

(Given that Z = 782, P = 4, ø = 25×10^{-3} Weber)

$$= \frac{220 \times 60 \times 2 \times 10^{-3}}{25 \times 782 \times 4} = 338\ \text{rpm}$$

$$T_a = \frac{9.55\ E_b I_a}{N}\ \text{Nm}$$

Substituting the values we get,

$$T_a = \frac{9.55 \times 220 \times 40}{338} = 248\ \text{Nm}$$

Assuming armature Torque T_a = shaft torque T_{sh}

$$\text{We know Metric HP} = \frac{2\pi\,N\,T_{sh}}{60 \times 735.6}$$

$$= \frac{2 \times 22 \times 338 \times 248.64}{7 \times 60 \times 735.6}$$

= 11.97 HP metric

Example 2 A 220 V DC shunt motor runs at 500 rpm when the armature current is 50A. It has an armature resistance of 0.2 ohms. Calculate the speed if the torque is doubled.

The torque is proportional to I_a and ø. But ø is constant for shunt motor. Therefore 'T' is proportional to I_a.

Therefore, $T_{a1} \propto I_{a1}$ and $T_{a2} \propto I_{a2}$

where a_1 indicates the condition when torque is normal and a_2 indicates the condition when torque is doubled.

$$\text{Therefore,}\quad \frac{T_{a2}}{T_{a1}} = \frac{I_{a2}}{I_{a1}}$$

As T_{a2} is doubled of T_{a1} we have $(T_{a2}/T_{a1}) = 2$

$2 = (I_{a2}/I_{a1}) = (T_{a2}/50)$

Therefore I_{a2} = 50 x 2 100 amps

we know,

$E_{b1} = V - I_a R_a$

= 220 - (50 x 0.2)

= 220 - 10 =210 Volts

$E_{b2} = V - I_a R_a$

E_{b2} = 220 - (100 x 0.2)

= 220 - 20 = 200 Volts

$$\text{Now,}\quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{N_2}{500} = \frac{200}{210}$$

$$\text{Therefore, } N_2 = \frac{200 \times 500}{210} = 476\ \text{rpm}$$

Maintain, service & trouble shoot the 3 point abd 4 point starters for DC motor

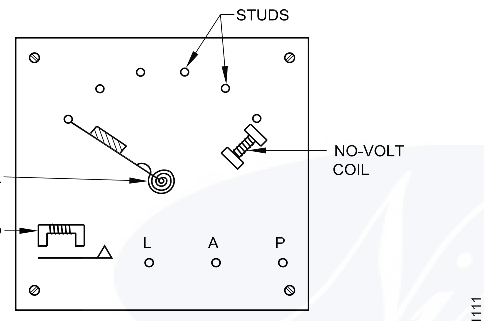
Objectives: At the end of this lesson you shall be able to
- **maintain, service and troubleshoot the DC starter**
- **check the handle for its spring tension and contact pressure against the studs**
- **check the no-volt coil assembly**
- **adjust the overload relay for the desired current rating.**

Servicing the starter: The starting resistance of the 3-point and 4-point starters is made up of coiled Eureka wire and it is fixed between the studs of the starter. The brass studs are arranged on the face plate of the starter in a semi circular form as shown in Fig 1.

The studs are firmly fixed on the insulated face plate. During maintenance the studs should be dressed with zero number sandpaper if the burrs are small and a smooth file should be used for pittings and big burrs, and then cleaned properly with a contact cleaner.

In case the starter resistance is found open, replace it with a new resistance coil as per the original specification of the manufacturer.

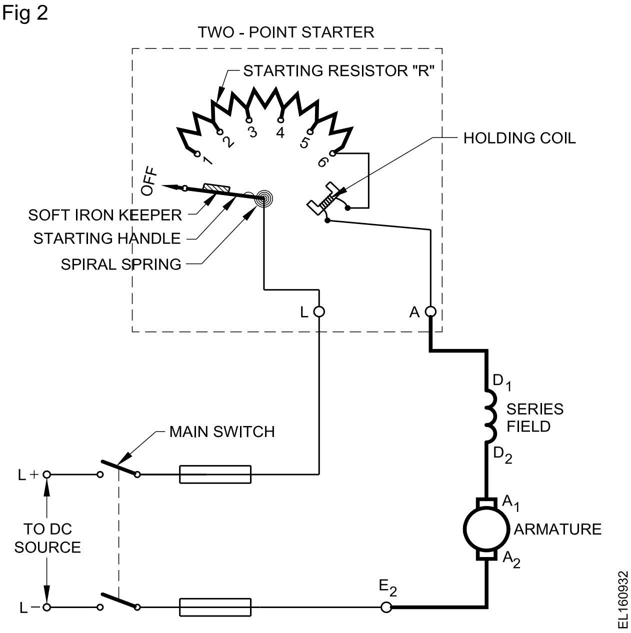
Fig 1



FACE PLATE ARRANGEMENT

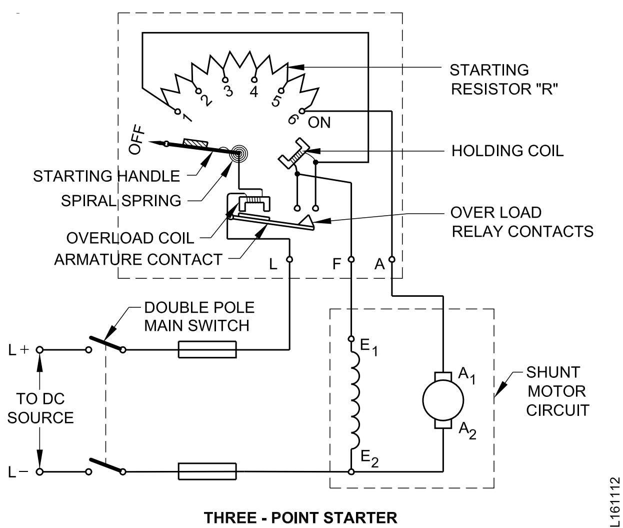
Figs 2, 3 and 4 show the schematic diagrams of 2, 3 and 4 point starters respectively.

Fig 2



Handle: The handle of the face plate starter consists of a movable arm attached with a spiral spring which acts against the magnetic action of the no volt coil. In case the spring becomes weak, the arm will not come to the off position even though the supply fails.

Fig 3

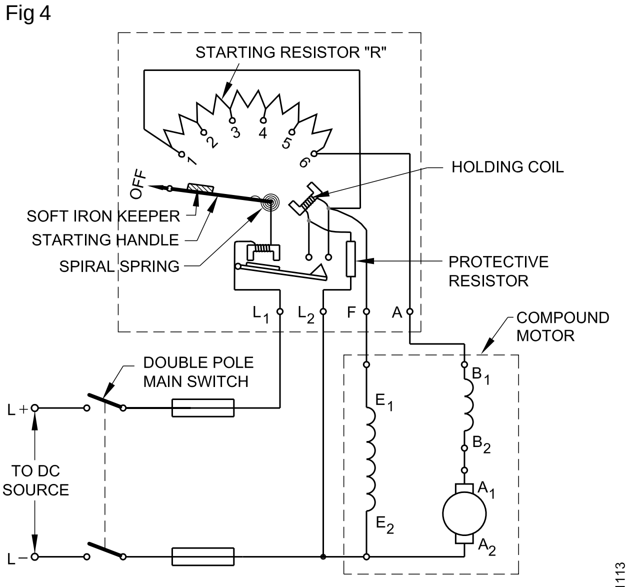


THREE - POINT STARTER

During the course of maintenance these points have to be checked. If the starter handle does not come to the off position in case of power failure, it is necessary to replace the spring as per the manufacturer specification. Also ensure during maintenance, proper pressure of the movable contact of the arm is available against the brass studs of the face place.

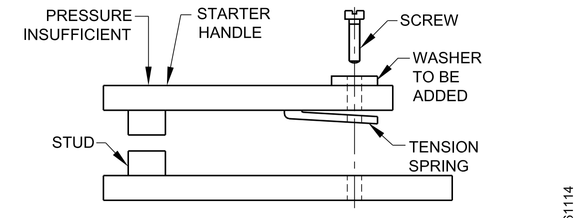
If proper tension is not found then the starter handle is to be tightened with the help of fixing screw by adding one or two flat washers on the top of the handle as shown in Fig 5.

Fig 4



FOUR – POINT STARTER

Fig 5



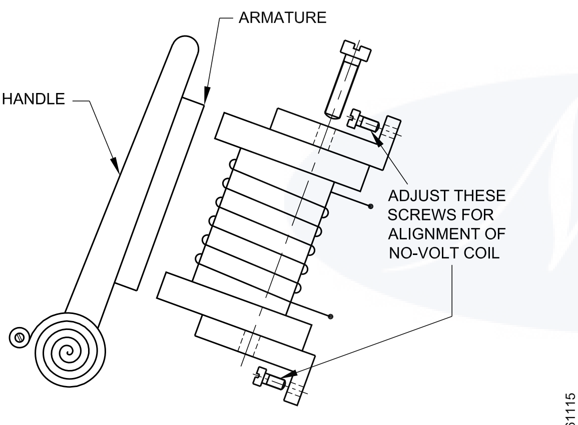
ADJUSTING THE STUD PRESSURE

Maintenance and servicing of no-volt coil assembly: The no-volt coil is connected in series with the field winding in the case of 3-point starter and in parallel with the supply through a limiting resistance in the case of 4 point starter. The no-volt coil is wound with a thin insulated wire and has a number of turns.

When the handle of the starter is moved to the running position, the armature of the handle should be touching the core assembly of the no-volt coil.

In case the core assembly is not touching properly, loosen the mounting screws of the core/coil assembly, align the core and tighten the screws. (Fig 6).

Fig 6



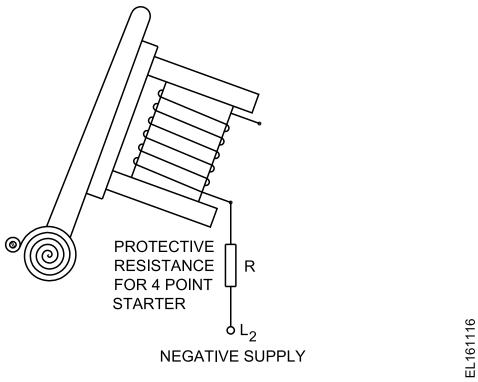
SETTING OF NO-VOLT COIL

If the NVC is not energised check visually the condition of the NVC. Measure the value and resistance of the coil as well as the insulation value and make a note of these readings. Periodically check these values and compare these with original manufacturer's data.

In any case, at any time if the value falls below 80% of the normal value, then replace it with a new no-volt coil of the same specification.

In the case of 4-point starter, the no-volt coil should be checked as mentioned above. If found OK, then the protective resistance should be checked with a multimeter. If found defective it has to be replaced with a resistance of same specification. (Fig 7.)

Fig 7

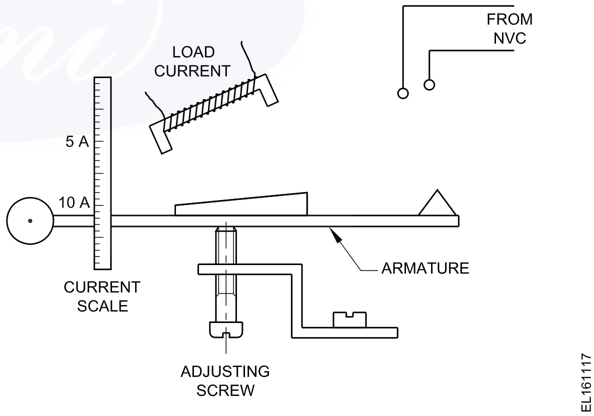


The overload relay coil is wound with thick gauge insulated wire suitable to carry the load current and has less turns. When the load current exceeds the set current, the magnetic strength of the overload coil assembly will be sufficient to attract the armature.

The upward movement of the armature short-circuits the tapped contacts of the no-volt coil, thereby bypasses the current in the no-volt coil resulting in the demagnetisation of the no volt coil and releasing the handle to off position.

Maintenance of overload relay: A magnetic overload relay is provided near the handle on the left side of the starter face plate; underneath the overload relay an armature is provided and it is adjusted as per the load current of the motor.

Fig 8



To test the overload relay the motor has to be loaded and the tripping of the overload relay to be observed. In case the overload relay trips at a lower current or higher current value when compared to set current value the current scale has to be recalibrated.

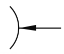
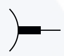
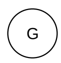
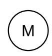
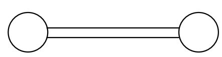
In the case of chattering noise observed at the no-volt coil the surfaces of the core assembly and armature need to be cleaned.

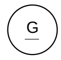
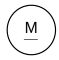
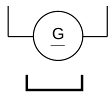
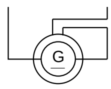
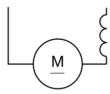
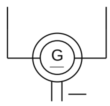
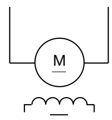
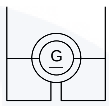
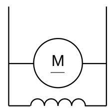
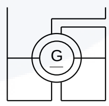
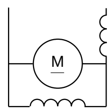
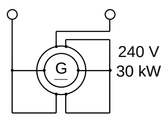
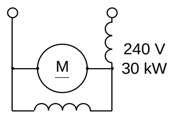
For the troubleshooting procedure follow the chart given in the trade practical exercise.

BIS Symbols related to DC machines

NOTE: In the standard BIS: 2032 (Part IV) - 1964 more than one symbol have been used to designate the same type of rotating machine depending on the type and class of drawing involved. For the same type of rotating machines in simplified as well as in the complete, multi-line symbols have been specified.

Wherever single line representation is required for rotating machines, reference may be made to IS: 2032 (Part II) - 1962.

Sl.No.	BIS Code No.	Description	Symbol	Remarks
1	3.14	Winding NOTE: The number of half-circles is not fixed, but if desired, a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4.		
2	3.24	Commutating or compensating winding		
3	3.34	Series winding		
4	3.44	Shunt winding or separate winding		
5	3.54	Brush on slip-ring		
6	3.64	Brush on commutator		
7	3.74	Supplementary indications, Numerical data. Supplementary indications (method of connecting windings, letter M, G or C and numerical data) are shown only on one symbol for each class of machine, as an example.		
	4	ROTATING MACHINES		
	4.1	General symbols		
8	4.1.1	Generator		
9	4.1.2	Motor		
10	4.1.3	Machine capable of being used as generator or motor.		
11	4.1.4	Mechanically coupled machines NOTE Other special types of coupling, that is, mono-bloc construction shall be suitably indicated wherever necessary.		
	4.2	Direct current machines		

Sl.No.	BIS Code No.	Description	Symbol	Remarks
12	4.2.1	Direct current generator, general symbol.		
13	4.2.2	Direct current motor, general symbol		
14	4.2.3	DC 2-wire permanent magnet generator (G) or motor (M)		
			Simplified multi-line representation	Complete multi-line representation
15	4.2.4	DC 2-wire series generator (G) or motor (M).		
16	4.2.5	DC 2-wire generator (G) or motor (M) specially excited.		
17	4.2.6	DC 2-wire shunt generator(G) or motor (M).		
18	4.2.7	DC 2-wire generator (G) or motor (M), compound excited, short shunt.		
19	4.2.8	Symbol showing terminals, brushes and numerical data. *Example:* DC 2-wire generator compound excited short shunt, 240 V, 30 kW.		

Characteristics and applications of a DC shunt motor

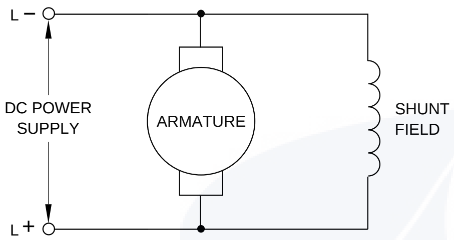
Objectives: At the end of this lesson you shall be able to
- **describe the characteristics of a DC shunt motor**
  - **– speed Vs load characteristics**
  - **– torque Vs load characteristics**
  - **– torque Vs speed characteristics**
- **state the applications of the DC shunt motor.**

Shunt motor

As shown in Fig 1, in a shunt motor the field is connected directly across the armature and the supply. Hence the field current and the field flux are constant. When operating without a load, the torque requirement is small since it is only needed to overcome windage and friction losses.

Because of the constant field flux, the armature will develop a back emf that will limit the current to the value needed to develop only the required torque.

Fig 1



DC SHUNT MOTOR

Speed load characteristic of the DC shunt motor

Shunt motors are classified as constant speed motors. In other words, there is very little variation in the speed of the shunt motor from no load to full load. Equation 1 may be used to determine the speed of the DC motor at various loads.

$$N = \frac{V - I_a R_a}{K_1 ø} = \frac{E_b}{K_1 ø} \text{ ...... Equation 1}$$

where N – speed of the armature, in (rpm)

V – applied voltage

I_a – armature current at a specific load

R_a – armature resistance

ø – flux per pole

K_1 – a constant value for the specific motor

E_b – the back emf.

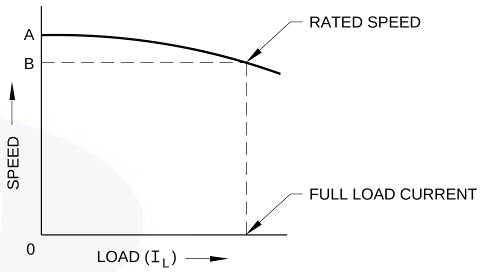
In a shunt motor, V, R_a, K_1 and ø are practically constant values and armature current is the only variable. At no load the value of 'I_a' is small leading to maximum speed.

At full load, $I_a R_a$ is generally about 5 percent of V. The actual value depends upon the size and design of the motor. Consequently, at full load the speed is reduced to 95 percent of the no-load value.

However, the speed will drop slightly to reduce the back emf such that armature can draw more current to develop increased torque from no load to full load.

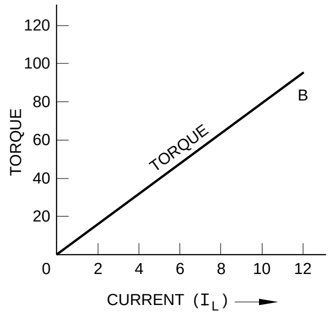
Fig 2a shows the speed load characteristic of a DC shunt motor. From the curve it is observed that the speed slightly drops from its no-load speed OA to OB when motor delivers full load. This is due to increased $I_a R_a$ drop in armature. As the drop is small the DC shunt motor is regarded as practically a constant speed motor.

Fig 2a



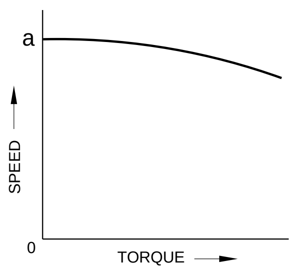
LOAD VERSUS SPEED CHARACTERISTIC OF DC SHUNT MOTOR

Fig 2b



TORQUE VERSUS LOAD CHARACTERISTIC CURVE

Fig 2c



SPEED VERSUS TORQUE CHARACTERISTIC OF DC SHUNT MOTOR

Torque Vs load characteristics of the DC shunt motor

Motor torque is proportional to the product of the field flux and the armature current. As the field flux is constant, the torque varies as the load current varies.

Fig 2(b) shows the torque Vs load curve of a DC shunt motor. From this it is clear that the torque is directly proportional to the load current.

The starting torque of a shunt motor is about 1.5 times the full load torque indicating that the shunt motor does not have as high a starting torque as the series motor, but it has much better speed regulation.

Torque Vs speed characteristics

Fig 2c shows the torque characteristic of a DC shunt motor. From the curve it is observed that the increase in torque has negligible effect on speed. The speed drops slightly as torque increases.

Application of DC shunt motor

A DC shunt motor is best suited for constant speed drives. It meets the requirements of many industrial applications.

Some specific applications are

Machine tools

Wood planers

Circular saws

Grinders

Polishers

Printing process

Blowers and

Motor generator sets.

When working with a shunt motor, never open the field circuit when it is in operation. If this happens, as the flux is only due to the residual field, the motor speed increases to a dangerous magnitude.

At light loads with open shunt field the speed could become dangerously high and the armature may fly off.

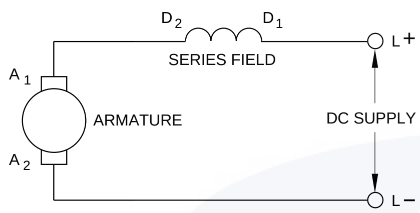
Characteristics and applications of a DC series motor

Objectives: At the end of this lesson you shall be able to
- **explain the characteristics of a series motor, such as**
  - **torque versus load**
  - **speed versus load**
  - **speed versus torque**
- **state the uses of a DC series motor**
- **explain the method of changing direction of rotation of the DC series motor**
- **state the method of loading the motor and explain the brake test.**

DC series motors

The DC series motor, like the DC series generator, has its field connected in series with the armature as shown in Fig 1. Due to this mode of connection all the current that flows through the armature must also flow through the field, and hence, the field strength varies with a change in the load.

Fig 1



DC SERIES MOTOR CONNECTION

A DC series motor has a very high starting torque. In some motors it may be as high as 5 times the full load torque. Further, the speed of the DC series motor also varies with the load.

Characteristics of DC series motors

The torque 'T' in DC motor is proportional to flux `ø' and armature current 'I_a'. The speed is inversely proportional to the flux.

The relation between these factors i.e. torque Vs load, speed Vs load and torque Vs speed are plotted on a graph and are known as characteristic curves of motors. A study of these characteristics curves enable us to understand the behaviour of motors under different conditions.

Torque load characteristics of the DC series motor

Fig 2 shows the torque load curve of a DC series motor. At light load the torque is low due to low armature current and low field flux.

But as the load increases, the torque increases proportional to the square of the armature current up to the point 'P' of the curve. This could be illustrated by the formula

Torque 'T' is proportional to the armature current and series field flux

i.e. $T \ \alpha I_a \text{ø}_{se}$

where ø_{se} is the series field flux.

As ø_{se} is proportional to I_{se} and further I_{se} is proportional to the armature current,

we have

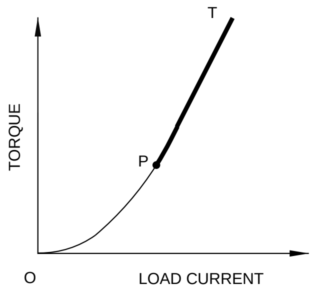
$T \ \alpha \ I_a I_{se}$

i.e. $T \ \alpha \ I_a I_a$ (since $I_a = I_{se}$)

$T \ \alpha \ I_a^2$.

Beyond this point 'P' the curve becomes a straight line and indicates torque is proportional to the armature current only as field cores are saturated. This curve shows that the torque is low at light loads and increases at heavy loads. Further the starting current of a DC series motor is about 1.5 times the full load current, the torque is about 2.25 times (1.5^2) the full load torque assuming the poles are not saturated.

Fig 2



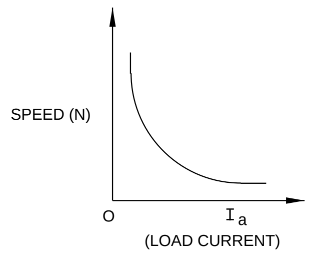
TORQUE-LOAD CHARACTERISTIC

Speed Vs Load characteristics

Fig 3 shows the speed load characteristic curve of a DC series motor. From the curve it is clear that when the load is small the speed is high and as the load increases the speed decreases. As the curve shown is parallel to the 'Y' axis at low load currents, it can be inferred that the speed attains a dangerous value. Therefore, the DC series motors are seldom used without load at the starting time.

Care should be taken while using belt drives where the load can be 'OFF' if the belt breaks or slips out. To avoid this, usually, the load is connected directly or through gears to a DC series motor.

Fig 3

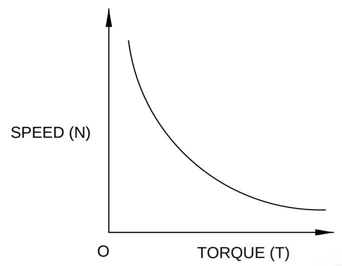


SPEED-LOAD CHARACTERISTIC

Speed-torque characteristics

Fig 4 shows speed-torque characteristics of this motor. It shows that when the torque is low the speed is high. This is due to low field flux (N α 1/ø). As the torque increases the motor draws more current and causes the speed to reduce. This is due to the increased field flux by the increased load current in the DC series field.

Fig 4



SPEED-TORQUE CHARACTERISTIC

Uses of a DC series motor

The DC series motor is used in applications where torque and speed requirements vary substantially. Jobs that require a heavy starting torque and a high rate of acceleration as in traction, hoists, cranes, and heavy construction trucks make use of this motor.

Method of changing the direction of rotation of a DC series motor

We know that by applying Fleming's left hand rule, the direction of rotation of the armature in a DC motor could be determined. According to Fleming's left hand rule, either by changing the polarity of field or by changing the direction of current in the armature, the direction of rotation could be changed.

However, if the polarity of the supply is changed, as both the polarity of the field and the direction of current in the armature change, the direction of rotation will remain unchanged. Therefore, the direction of rotation of DC series motor can be changed by changing either the field or the armature connection.

Method of loading a DC series motor

A DC series motor should never be operated without load. To keep the speed of the DC series motor within safe limits we have to maintain a certain load on the shaft.

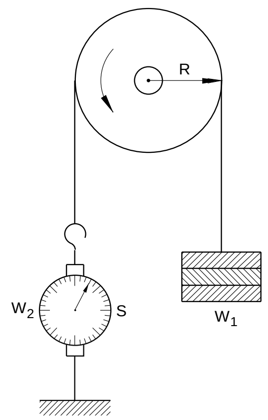
This could be done by connecting the DC series motor to directly coupled load or by mounting gear coupled load.

The method of loading a DC series motor of small capacity for testing in a laboratory is by brake test which is explained below.

Brake test (Method 1)

It is a direct method and consists of applying a brake through a special (camel hair) belt to a water-cooled drum mounted on the motor shaft as shown in Fig 5. One end of the belt is fixed to the base through a spring balance 'S' and the other end is connected to a suspended weight 'W_1'. The motor is run and the load on the motor is adjusted till it carries its full load current.

Fig 5



BRAKE TEST

Let W_1 – suspended weight in kg.

W_2 – reading on spring balance in kg.wt.

The net pull on the belt due to friction at the pulley is

$(W_1 - W_2)$ kg. wt. or

$9.81 (W_1 - W_2)$ Newton.

The radius of the pulley 'R' in metre then, shaft torque T_{sh} developed by the motor $= (W_1 - W_2)R$ kg.m

$= 9.81(W_1 - W_2)R$ Nm

If n is the speed of the motor or drum in rps

then motor output power $= T_{sh} \times 2\pi n$ Watt

$= 2\pi \times 9.81\, n\, (W_1 - W_2)R$ Watt

$= 61.68\, n\, (W_1 - W_2)R$ Watt.

Let, V = supply voltage;

I = load current taken by the motor.

Then, input power = VI Watt

Therefore, efficiency of the motor is

$$= \frac{\text{Output}}{\text{Input}} = \frac{61.68\, n\,(W_1 - W_2)R}{VI}$$

Further metric horsepower developed by the motor can be calculated by the formula

$$\text{HP Metric} = \frac{2\pi\, n\, T_{sh}}{735.6}$$

where 'n' is the speed in rps

T_{sh} is the shaft torque in newton metres.

The power rating given in the name-plate of the motor indicates the horsepower which is developed at the shaft.

The simple brake test described above can be used for small motors only, because in the case of large motors, it is difficult to dissipate the large amount of heat generated at the brake.

It is most important to remember that a series motor should never be operated without a load.

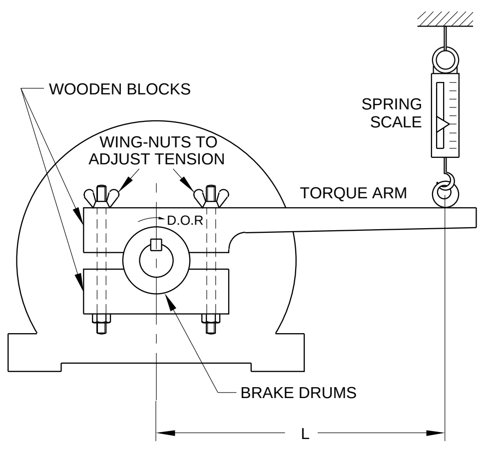
Since the field is very weak at no load, operating the motor without a load will allow the rotor to reach such high speeds that the centrifugal force will cause the windings to tear free.

Brake test (Method 2)

The torque developed by a motor may be measured alternatively by a device called a prony brake as shown in Fig 6.

There are various types of prony brake designs available. In Fig 6, the brake drum is encased in split wooden blocks. By tightening the wing-nuts, the pressure of the wooden blocks on the brake-drum can be varied and thereby, the load can be adjusted to the desired value. The brake drum has an extension torque arm that is fastened to a spring scale which measures the force developed on the brake drum in newton. The torque developed is the product of the net force on the scale (in newtons) and the effective length (L) of the torque arm in metres.

Fig 6



PRONY BRAKE USED FOR MEASURING TORQUE DEVELOPED BY A MOTOR

Therefore,

Torque = force X distance

= spring balance reading in kg.wt X 'L' in metres.

The efficiency and the output of the motor in metric horsepower could be calculated as explained in Method 1.

Example 1

A prony brake arm in 0.4 m in length. The wing-nuts on the brake are tightened on the motor pulley, creating a force of 50 kg.wt. What is the torque that is being developed by the motor?

Torque = force X length(distance)

1 kg.wt = 9.81 newtons

= 50 X 9.81 X 0.4

= 196.2 newton metres.

Example 2

In the above case calculate the metric horsepower developed by the motor when the shaft speed is 1500 rpm.

$$\text{HP Metric} = \frac{2\pi\ n\ T_{sh}}{735.6}$$

Given N = 1500

rps = 1500/60 = 25 rps

T_{sh} = 196.2 N.m

$$\text{i. e. HP Metric} = \frac{2\pi \times 25 \times 196.2}{735.6}$$

= 41.9 HP metric.

DC compound motor – Types, Characteristics and Applications

Objectives: At the end of this exercise you shall be able to
- **state the types, applications of DC compound motors**
- **state the characteristic of a DC compound motor**
- **state the precautions to be observed while starting a differential compound motor.**

DC compound motor

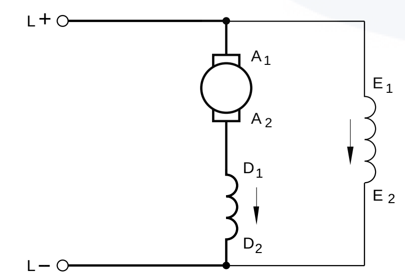
A DC compound motor has both shunt and series field for producing the required main flux in the poles. A DC compounded machine can be used as a motor or generator. A DC compound motor can be classified as below.

DC Compound motor
- Cumulative compound
  - Long shunt
  - Short shunt
- Differential compound
  - Long shunt
  - Short shunt

Cumulative compound motor

When the series field of the DC compound motor is connected in such a way that its flux aids the flux produced by the shunt field, as shown in Fig 1 then it is called a **cumulative compound motor**.

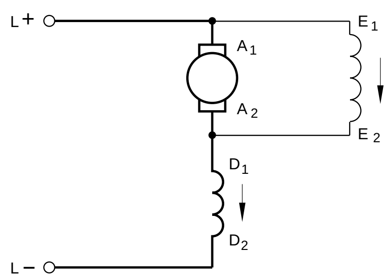
Fig 1



CUMULATIVE COMPOUND MOTOR (LONG SHUNT)

Depending on the shunt field connection it is further subdivided as long shunt (Fig 1) and the short shunt (Fig 2) cumulative compound motor.

Fig 2



CUMULATIVE COMPOUND MOTOR (SHORT SHUNT)

As this motor has both shunt and series fields it has the combined behaviour of shunt and series motors depending on the magnitude of the fluxes due to these two fields. If the series ampere turns are more predominant than the shunt ampere-turns at full load then it has a higher starting torque than the shunt motor and its speed falls more than that of the shunt motor.

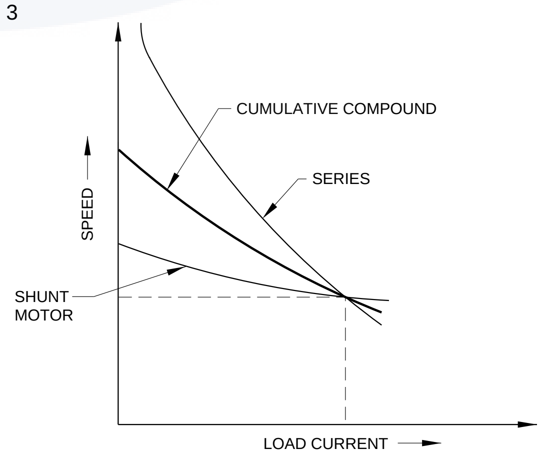
If the shunt ampere turns are more predominant than the series ampere-turns at full load the motor acts almost like a shunt motor but its speed drops a little more than that of the shunt motor.

Speed-load characteristic

Fig 3 shows the speed-load characteristic of the cumulative compound motor and also series and shunt motor characteristics for comparison. The speed of this motor falls more than the shunt motor but falls less than that of the series motor.

As the speed-load curve 'C' starts from the 'Y' axis, unlike a DC series motor, the cumulative compound motor can also run on no load at a specified speed.

Fig 3



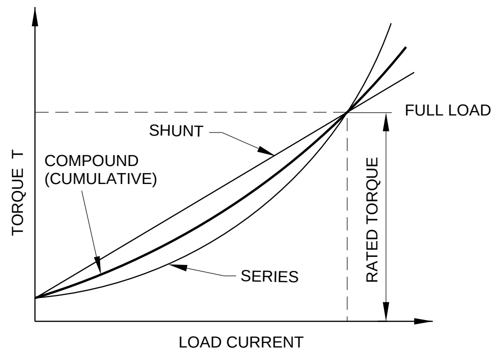
SPEED-LOAD CHARACTERISTIC OF CUMULATIVE COMPOUND MOTOR

Increased drop in speed at load is due to the combined drop of the voltage due to the armature and series field resistances.

Torque-load characteristic

Fig 4 shows the torque-load characteristic of the cumulative compound motor and also the series and shunt motors for comparison. Up to full load the torque developed in a cumulative compound motor is less than that in the shunt motor but more than in the series motor.

Fig 4



TORQUE-LOAD CHARACTERISTIC OF COMPOUND MOTOR (CUMULATIVE)

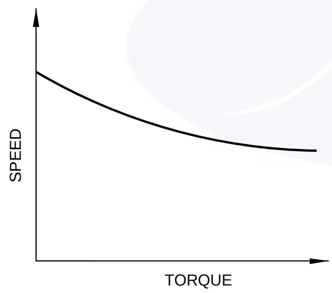
However, at the time of starting, the starting current is about 1.5 times the full load current, and hence, the cumulative compound motor produces high torque which is better than the shunt motor during starting.

Torque-speed characteristic

Fig 5 shows the torque-speed characteristic of a cumulative compound motor. As the total flux of the motor increases with load, the speed decreases but the torque increases.

As the output power is proportional to the product of speed and torque, the cumulative compound motor will not be overloaded in case of sudden appearance of load as in rolling mills.

Fig 5



TORQUE SPEED CHARACTERISTIC OF A CUMULATIVE COMPOUND MOTOR

Application of cumulative compound motors

Compound motors are used to drive machines that require a relatively constant speed under varying loads. They are frequently used in machines that require sudden application of heavy loads, such as presses, shears, compressors, reciprocating tools, steel rolling machinery and elevators.

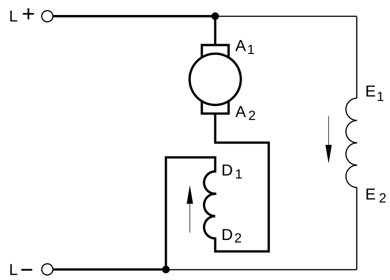
Compound motors are also used when it is desired to protect the motor by causing it to reduce the speed under heavy loads. Under sudden application of heavy loads, using a flywheel along the motor facilitates almost constant speed by converting the stored energy in the flywheel to be utilised during heavy loads. Alternatively the kinetic energy is stored in the flywheel during the light load period.

Never open the shunt field of a compound motor when the motor is operating at high load.

Differential compound motor

When the series field of the DC compound motor is connected in such a way that its flux opposes (bucks) the flux produced by the shunt field as shown in Fig 6, it is called a differential compound motor.

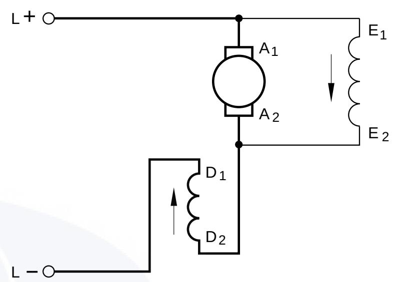
Fig 6



DIFFERENTIAL COMPOUND MOTOR (LONG SHUNT)

Depending upon the shunt field connection it is further subdivided as long shunt (Fig 6) and short shunt (Fig 7) differential compound motors.

Fig 7



DIFFERENTIAL COMPOUND MOTOR (SHORT SHUNT)

As the series field flux is in the opposite direction to the shunt field flux there is some inherent problem at the time of starting. At this time, the shunt field takes some time to build up, whereas heavy rush of current will be through the series field and armature.

The motor will, therefore, tend to start up the wrong way. When the shunt field is fully established the total flux which is the difference of series and shunt field fluxes may be so small that the motor may not produce sufficient torque to run the motor.

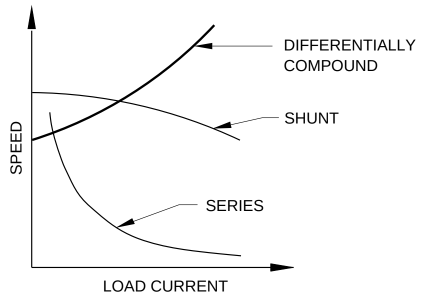
Hence, it is advisable to short circuit the series field of the differential compound motor at the time of starting and then putting the series field in the circuit when the motor is running.

Characteristics of differential compound motor

Fig 8 shows the characteristic of the differential compound motor and also series and shunt motor characteristic for comparison. This type of motor indicates that the motor speed increases with increase in load due to the fact that the total flux decreases at the increased load.

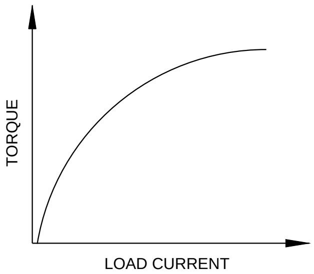
Torque load characteristic of the DC differential compound motor shown in Fig 9 indicates that the torque increases with the increased load.

Fig 8



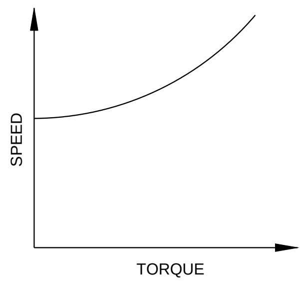
SPEED - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 9



TORQUE - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 10



TORQUE-SPEED CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 10 shows the torque-speed characteristic indicating that both speed and torque increase in the machine resulting in overloading of the machine initially and, thereby, reaching an unstable state.

Application of DC differential compound motor

This motor is not in common use due to its unstable behaviour at overloads. This motor is dangerous to use unless there is no possibility of the load exceeding the normal full load value or designed to work within full load limits.

Speed control methods of DC motors and their application

Objective: At the end of this lesson you will be able to
- **explain the principle and the methods of controlling the speed of a DC motor.**

Principle of speed control in DC motors

In certain industrial applications the variation of speed is a necessity. In DC motors the speed can be changed to any specified value easily. This is the main reason for certain industries to prefer DC motors for drives rather than AC motors. The speed of a DC motor can be varied based on the following simple relation.

We know the equation

$$N = \frac{V - I_a R_a}{K\text{ø}} = \frac{E_b}{K\text{ø}}$$

(Refer to Related Theory of Exercise 3.3.11)

From the above equation, it is clear that the speed of a DC motor is directly proportional to the back emf E_b and inversely proportional to flux (ø). Thus the speed of the DC motor can be varied by changing either the back emf E_b or the flux ø or both.

In fact if the back emf is decreased across the armature, the speed decreases and if the flux is decreased the speed increases. Accordingly the following are the most common methods of controlling speed of the DC motors based on the above principle.

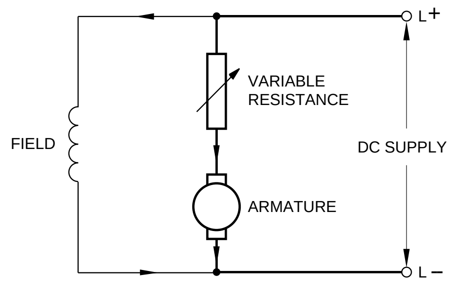
Methods of speed control in DC shunt motors and compound motors

Armature control method

This method works on the principle that the speed of the DC motor could be varied by varying the back emf.

As we know, the back emf = $V - I_aR_a$, and so by varying the armature resistance we can obtain various speeds. A variable resistance called controller is connected in series with the armature as shown in Fig 1. The controller should be selected to carry the armature current for a longer period.

Fig 1



SPEED CONTROL BY ARMATURE RESISTANCE METHOD

Let the initial and final speeds of the motor be N_1 and N_2 and the back emf be Eb_1 and Eb_2 respectively.

$$N_1 = \frac{Eb_1}{K} \text{ ... ... Eq. 1}$$

$$N_2 = \frac{Eb_2}{K} \text{ ... ... Eq. 2}$$

By dividing Eqn. 1 by Eqn. 2

$$N_2 = \frac{Eb_2 N_1}{Eb_2}$$

By varying the controller resistance value in the armature circuit, the back emf can be varied from Eb_1 to Eb_2, thereby, the speed can be varied from N_1 to N_2.

Advantages of armature control method

This method is suitable for constant load drives where speed variations from low speed up to normal speed only are required.

Disadvantages of armature control method

1 Speeds below normal only could be obtained.
2 After setting the required speed it changes with the change in load. Hence, stable speed cannot be maintained when load changes.
3 Power loss in the control resistance is high due to higher current rating leading to low efficiency of the motor.
4 Cost of control resistance is high due to the fact it has to be designed to carry the armature current.
5 Requires expensive arrangement to dissipate the heat developed in the control resistance.

Application of armature resistance method of speed control

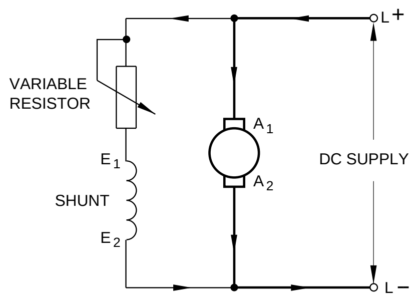
This method is suitable for DC shunt and compounded motors used in printing machines, cranes and hoists where duration of low speed operation is minimum.

Shunt field resistance method of speed control

This method works on the principle that the speed of the DC motor could be varied by varying the field flux. For this, a variable resistance (Rheostat) is connected in series with the shunt winding as shown in Fig 2.

When the resistance is increased, the field current and the flux are reduced. Due to the reduction of flux, the speed is increased.

Fig 2



SHUNT FIELD CONTROL CIRCUIT

Advantages

1 Higher speeds above normal only could be obtained which will be stable from no load to full load.

2 As the magnitude of field current is low, power loss in the field rheostat is minimum.

3 Control is easy, economical and efficient.

Disadvantages

1 Owing to the very weak field, a reduced torque is obtained at top speeds.

2 The operation at high speeds with weak field renders commutation difficulties unless interpoles are used.

Application of shunt field control

This method is the most widely used speed control method where speeds above normal are required and at the same time the load applied to the motor changes often. Eg: Traction motors.

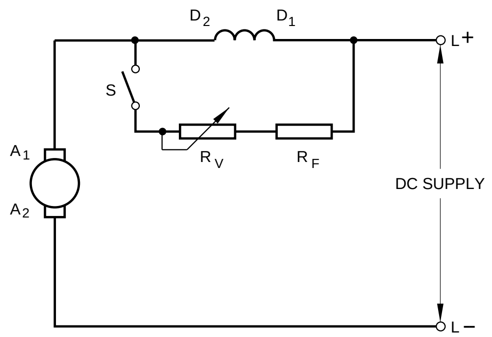
Method of speed control in DC series motors

Field diverter method

A variable resistance called diverter, is connected in parallel with the field winding as shown in Fig 3. R_V represents the variable portion of the diverter and R_F the fixed portion. The function of R_F is to prevent the series winding from being short-circuited, when the diverter is operated.

The smaller the value of $R_V + R_F$ the greater is the current diverted from the series winding and higher is the speed of the motor. Minimum speed for a given input current is obtained by opening the switch 'S', thereby, breaking the circuit through the diverter.

Fig 3



FIELD DIVERTER CONTROL CIRCUIT

Application of the series field diverter method

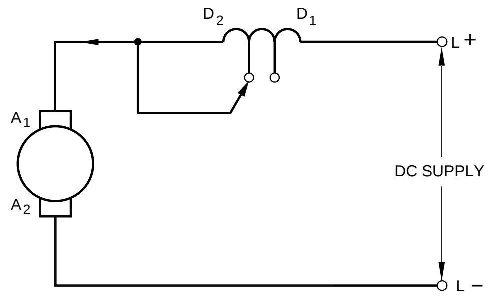
This method is mainly used in the speed control of electric trains. By this method, speed above normal can only be obtained and the power loss in the diverter is quite considerable.

Field tapping method

A tap changing arrangement is made on the series field winding as shown in Fig 4. By varying the number of effective turns of the field winding, the speed can be controlled. The motor circuit should be started with all the winding included and the speed can be changed then, by setting at suitable tapping.

This provision should be incorporated in the switch gear. Otherwise, if the tapping is kept at lower setting and the motor started, it races to high speed at the time of starting itself which is undesirable.

Fig 4



FIELD TAPPING CONTROL CIRCUIT

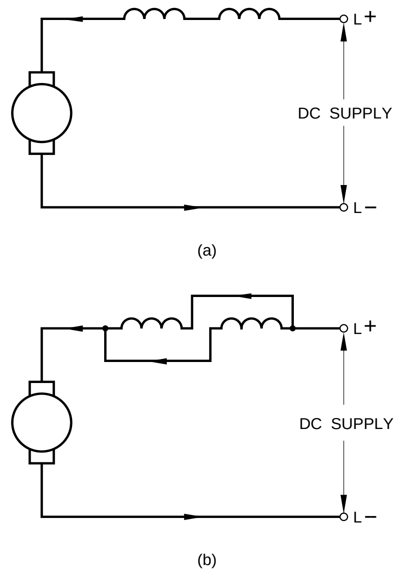
Application of series field diverter method

This method is used in small motors like food mixers, fans etc.

Series-parallel method

Fig 5(a) shows a series motor with two halves of the field winding connected in series. If the two halves of the field winding are connected in parallel as in Fig 5(b) then for a given current 'I' taken from the supply, the current in each field coil is reduced to 1/2 and the flux is, therefore, reduced and thus the speed increases.

Fig 5



SERIES-PARALLEL METHOD OF CONTROL

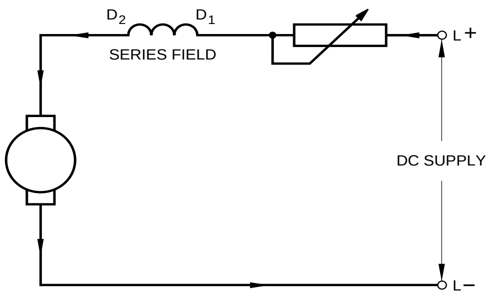
Application of series-parallel method

This is the simplest method though only two speeds are possible. This method is often used for controlling the speed of fan motors in various applications.

Supply voltage control method

A controller (variable resistance) is connected in series with the motor as shown in Fig 6. This method can be used to control the speed from very low speed up to full normal speed.

Fig 6



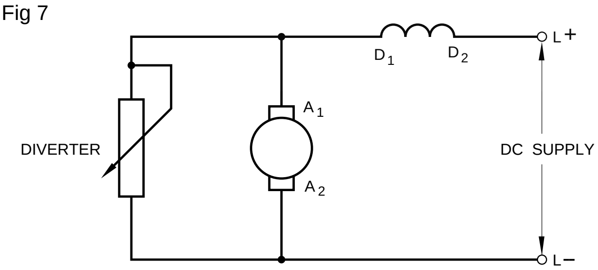
VOLTAGE CONTROL CIRCUIT

The disadvantage in this method is loss of energy in the control resistance in the form of heat. But with the introduction of SCR based control circuit, obtaining variable supply voltage to motor is achieved with minimum power loss. This method is widely used in larger modern machines where power loss is a major concern.

Armature diverter method

In this method, a variable resistor called diverter is connected across the armature as shown in Fig 7. By this method armature current is controlled to vary the speed below the rated value for a series motor.

Fig 7



ARMATURE DIVERTER CONTROL CIRCUIT

For a motor running at constant load-torque, if the armature current is reduced by the armature diverter, the line current increases to meet the torque, thereby, the series field current increases. This increased field current reduces the speed.

This method is wasteful, costly and unsuitable for changing loads.

The speed control methods illustrated for DC series motor cannot be used for compounded motors as these adjustments would radically change the performance characteristics of the compounded motor.

Ward - Leonard system of speed control

In all the methods explained in the preceding paras, it is clear that the speed cannot be varied from zero to above normal by any one method. Two methods are to be combined to do so. Further the efficiency of the pre-mentioned controls is much less due to power loss and instability due to load variation.

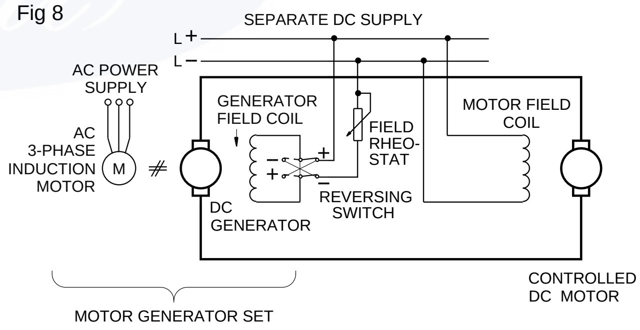
A smooth variation of speed from zero to above normal with inherent stability of speed at all loads is achieved through an adjustable voltage system of speed control called **'Ward-Leonard system**'.

In this system a DC generator is mechanically coupled to a constant speed DC motor or an AC 3-phase induction motor as shown in Fig 8. The generated supply from the DC generator is fed directly to the armature of the controlled DC motor.

The fields of both the DC generator and the controlled DC motor are separately excited from a suitable DC supply. The field of the DC generator is controlled through a field rheostat and a change over switch to vary the generated voltage and to change the polarity respectively. This enables the supply to the controlled DC motor to vary at a wide range, and also it is possible to reverse the supply voltage polarity.

This in turn changes the speed of the controlled DC motor to vary from zero to above normal speed as well as change the direction of rotation, if necessary. Controlled DC motor speed can be brought down to zero by reducing the supply voltage of the generator to a suitable level.

Fig 8



WARD-LEONARD SYSTEM OF SPEED CONTROL

Advantages

1 By this system, speed as low as zero and as high as two times the normal speed could be achieved.

2 Direction of rotation of the controlled DC motor cannot be changed simply by reversing the controller in the field circuit of the generator.

3 As there is not much power loss in the field rheostat, the speed variations are achieved at higher efficiency.

4 The speed of the controlled DC motor is independent of the load.

Disadvantage

This method requires high initial cost but has low overall efficiency due to three machines being in operation.

Application of the Ward-Leonard speed control method

This system is used in steel rolling mills and paper mill drives, hoists, elevators etc. where a precise control of speed over a wide range is required. Even today the DC motors are used in India as electrical drives for modern steel rolling mills, heavy industries like BHEL, HMT etc.

Latest developments of speed control

In the modernization process, nowadays the DC motors are incorporated with solid state control devices like transistors, diodes, thyristors and microprocessors for accurate speed control and to eliminate human errors of operation and to maintain trouble-free service.

Method of calculation of control resistance and new speed

Objective : At the end of this lesson you shall be able to

- **explain the method of calculating the value of control resistance at full load current of the motor; armature resistance and applied voltages are known.**

We know from the earlier exercises that the speed of a DC motor

$$N = \frac{V - I_a R_a}{K\phi} = \frac{E_b}{K\phi}$$

The various methods of speed control discussed in the earlier chapter are based on the above formula.

To obtain these we found that control resistance is connected either in field or in armature circuits.

An electrician/wireman should be in a position to determine the value of the control resistance to be connected in the circuit to obtain a designated speed. The value of control resistance to be used to obtain a new speed can be calculated based on the following information.

Method of calculating control resistance in series with the shunt field

Referring to Fig 1 we have,

Eb_1 = back emf at speed N_1

Eb_2 = back emf at speed N_2

N_1 = speed at which it is running

N_2 = new speed/speed to which it changes

I_{F1} = field current at N_1

I_{F2} = field current at N_2

R_t = total shunt field circuit resistance

R_{sh} = shunt field resistance

R_c = value of control resistance in series with shunt field.

Then, $$\frac{Eb_1}{Eb_2} = \frac{K\phi_1 N_1}{K\phi_2 N_2}$$

As ø is proportional to the field current I_F (k is the constant)

Therefore we have $$\frac{Eb_1}{Eb_2} = \frac{K\, I_{F1} N_1}{K\, I_{F2} N_2}$$

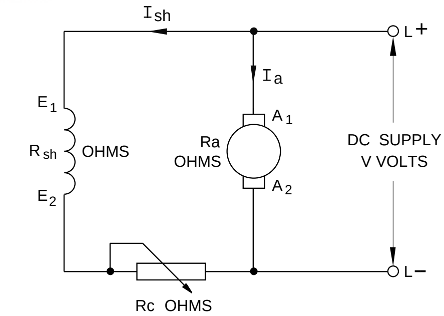
Therefore the new speed $$N_2 = \frac{Eb_2\, I_{F1} N_1}{Eb_1\, I_{F2} N_2}$$

$$\text{Further, } I_{F2} = \frac{\text{Applied Voltage}}{\text{Shunt field circuit resistance}}$$

$$= \frac{V}{R_{sh} + R_c}$$

$$R_c = \frac{V}{I_{F2}} - R_{sh} = R_t - R_{sh}$$

Fig 1



Method of calculating the control resistance in series with the armature

Referring to Fig 2, we have,

I_{a1} = armature current at N_1

I_{a2} = armature current at N_2

If I_{a1} = I_{a2}, then the load is of constant torque

N_1 = initial speed

N_2 = new or final speed

V = supply voltage

R_t = total armature circuit resistance

R_s = control resistance.

$$N_1 = \frac{Eb_1}{K\phi} \text{ and } N_2 = \frac{Eb_2}{K\phi}$$

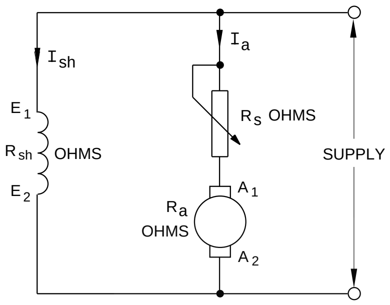
$$N_1 = \frac{N_1 Eb_2}{Eb_1} = \frac{N_1 (V - I_{a1}R_t)}{(V - I_{a2}R_a)}$$

where $R_t = R_s + R_a$

Example 1

A 230 volts DC shunt motor runs at 1000 r.p.m. and takes an armature current of 20 A. Find the resistance to be added to the field to increase the speed to 1200 r.p.m. at an armature current of 30 amps. If R_a = 0.25 ohms, R_{sh} = 230 ohms.

Fig 2



As the armature current varies from 20 to 30 amps we get two variables Eb_1 and Eb_2. Further the speed has to be increased by adding resistance in the shunt field as such field current changes from I_{F1} to I_{F2}.

$Eb_1 = V - I_{a1}R_a$ = 230 - (20 x 0.25)

= 230 - 5 = 225 Volts

$Eb_2 = V - I_{a2}R_a$ = 230 - (30 x 0.25)

= 230 - 7.5 = 222.5 Volts

I_{F1} = 230/230 = 1 amp.

$$\text{We know } \frac{Eb_1}{Eb_2} = \frac{I_{F1}N_1}{I_{F2}N_2}$$

$$I_{F2} = \frac{Eb_2 \text{ x } I_{F1} \text{ x } N_1}{Eb_1 N_2}$$

$$= \frac{222.5 \text{ x } 1 \text{ x } 1000}{225 \text{ x } 1200} = 0.824 \text{ amps}$$

$$R_t = \frac{230}{I_{F2}} = \frac{230}{0.824} = 279.2 \text{ ohms}$$

Therefore, added resistance

$R_c = R_t$ – 230 = 279.2 – 230 = 49.2 ohms.

Example 2

A DC shunt motor operates on 230 V and takes an armature current of 20A at 1000 r.p.m. Its armature resistance is 1 Ohm. Calculate the value of resistance to be added to the series with armature to reduce its speed to 800 r.p.m.

$Eb_1 = V - I_a R_a$ = 230 - (20 - 1) = 230-20 = 210 Volts

$$\text{Then,} \frac{Eb_1}{Eb_2} = \frac{N_1}{N_2}$$

$$\text{Therefore, } Eb_2 = \frac{Eb_1 N_2}{N_1}$$

$$= \frac{210 \text{ x } 800}{1000} = 168 \text{ Volts}$$

$Eb_2 = V - I_a R_t$

Therefore $I_a R_t$ = V- Eb_2 = 230 - 168 = 62 Volts

$$\text{Therefore, } R_t = \frac{62}{20} = 3.1 \text{ Ohms}$$

$R_s = R_t - R_a$ = 3.1 - 1 =2.1 Ohms

Example 3

A 240 volts series motor takes 10 amps when giving its rated output at 2000 r.p.m. Its resistance is 0.5 ohm. Find what resistance must be added to obtain the same torque at 1500 r.p.m. Calculate the power loss in control. (As torque is the same the current taken by the motor should be the same.)

$Eb_1 = V - I_a R_a$ = 240 - 10 x 0.5

= 240 - 5 = 235 Volts

$$Eb_2 = \frac{Eb_1 N_2}{N_1} = \frac{235 \text{ x } 1500}{2000}$$

$$= 176.3 \text{ Volts}$$

$I_a R_t$ = V– Eb_2 = 240 – 176.3 = 63.7 volts.

Therefore, $R_t = I_a R_t / I_a$ = 63.7/10 = 6.37 ohms.

Therefore, $R_s = R_t - R_a$ = 6.37 – 0.5.

Series control resistance = 5.87 Ohms.

Power loss in control resistance

$I_a^2 R_s = 10^2$ x 5.87 = 587 watts.

Maintenance procedure for DC machines

Objectives: At the end of this lesson you shall be able to
- **state what is meant by preventive maintenance and its importance**
- **describe the recommended maintenance schedule for DC motors**
- **explain how to maintain a record of steps taken for maintenanace**
- **describe the method of preventive maintenance on DC machines.**

Preventive maintenance

Preventive maintenance of electrical machines consists of routine scheduled periodical inspections, tests, planned minor maintenance repairs and a system of maintaining inspection records for future reference. Preventive maintenance is a combination of routine and planned operations.

Routine operations are those which follow fixed schedules to maintain electrical motors at daily, weekly or at other fixed intervals.

Planned maintenance

By contrast, planned maintenance consists of additional work which is performed at irregular frequencies, determined by inspection and previous operating experience or the details of defects found in the maintenance records.

Necessity of preventive maintenance and its importance

By carrying out an effective preventive maintenance programme on electrical machines, we can eliminate major failures of the machines, accidents, heavy repair costs and loss of production time.

Proper preventive maintenance will lead to economy of operation, less down time, dependable machine operation, longer machine life and lower overall cost of maintenance and repair.

Scheduling of preventive maintenance

Routine periodical inspection and tests may be scheduled to be carried out daily, weekly, monthly, half-yearly and annually depending upon the following factors:

a the importance of the motor/generator in the production

b the duty cycle of the machine

c the age of the machine

d the earlier history of the machine

e the environment in which the machine operates

f the recommendations of the manufacturer.

Recommended maintenance schedule for machines

While carrying out routine periodical maintenance, the maintenance man should do his best to diagnose and locate problems in electrical machines, and use the sense of smell to detect burning insulation due to excessive heating in winding or bearing; the sense of hearing to detect excessive noise, speed or vibration; the sense of sight to detect excessive sparking and many other mechanical faults.

Sensory impressions usually must be supplemented by various testing procedures to localize the trouble. A thorough understanding of electrical principles and the efficient use of test equipment are important to electricians/ wiremen in this phase of operation.

The following maintenance schedule is recommended for DC machines.

1 Daily maintenance

1.1 Examine visually earth connections and machine leads.

1.2 Check the sparking at the commutator.

1.3 Check the motor windings for overheating (the permissible maximum temperature is near about that which can be comfortably felt by hand.)

1.4 Examine control equipment.

1.5 In the case of oil ring lubricated machines:

a) examine the bearings to see that oil rings are working

b) note the temperature of bearings

c) add oil, if necessary

d) check the end play.

1.6 Check for unusual noise at the machine while running.

2 Weekly maintenance

2.1 Examine the commutator and brushes.

2.2 Check the belt tension. In cases where this is excessive it should immediately be reduced.

In the case of sleeve bearing machines the air gap between the rotor and stator should be checked.

2.3 Blow air through the windings of protected type machines situated in dusty locations.

2.4 Examine starting equipment for burnt contacts where the machine is started and stopped frequently.

2.5 Examine the oil in the case of oil ring lubricated bearings for contamination by dust, grit, etc. (This can be roughly judged from the colour of the oil.)

2.6 Check the foundation bolts and other fasteners.

3 Monthly maintenance

3.1 Overhaul the controllers.

3.2 Inspect and clean the oil circuit breakers.

3.3 Renew oil in high speed bearings which are in damp and dusty locations.

3.4 Wipe the brush-holders and check the bedding of the brushes of DC machines.

3.5 Test the insulation of the windings.

4 Half yearly maintenance

4.1 Check the brushes and replace if necessary

4.2 Check the windings of the machines subjected to corrosive and other elements. If necessary bake the windings and varnish.

4.3 Check the brush tension and adjust if necessary

4.4 Check the grease in the ball and roller bearings and make it up where necessary taking care to avoid overfilling.

4.5 Check the current input to the motor or output of generator and compare it with the normal values.

4.6 Drain all oil bearings, wash with petrol to which a few drops of oil have been added; flush with lubricating oil and refill with clean oil.

5 Annual maintenance

5.1 Check all high speed bearings and replace, if necessary.

5.2 Blow clean dry air through all the machine windings thoroughly. Make sure that the pressure is not so high as to damage the insulation.

5.3 Clean, dry and varnish the oily windings.

5.4 Overhaul the motors which have been subjected to severe operating conditions.

5.5 Renew the switch and fuse contacts, if damaged.

5.6 Check the oil in the starter and the grease/oil in the bearings.

5.7 Renew the oil in the starters subjected to damp or corrosive elements.

5.8 Check the switch condition, resistance to earth between motor/generator windings, control gear and wiring.

5.9 Check the resistance of the earth connections.

5.10 Check the air gaps in between the armature and the field.

5.11 Test the insulation of winding before and after overhauling the motors/generators.

6 Records

6.1 Maintain a register giving one or more pages for each machine and record therein all important inspections and maintenance works carried out from time to time.

These records should show past performance, normal insulation level, air gap measurements, nature of repairs and time between previous repairs and other important information which would be of help for good performance and maintenance.

While routine maintenance could be done either during working of the machine or during short interval 'down' periods, the planned maintenance requires to be done during holidays or by taking shut downs of the machine for small durations.

Planned maintenance schedule needs to be decided based on routine maintenance reports entered in the maintenance card.

Maintenance Record

Maintaining a system of inspection records is a must in preventive maintenance schedule. This system uses a register as stated above or cards as shown below which are kept in the master file. By referring to these maintenance cards the foreman can schedule the planned maintenance.

Maintenance card

The first page gives details of the name-plate, location, year of purchase, bearing details, initial test results etc pertaining to the rotating machine/equipment.

Machine Details
Manufacturer, Trade mark ....
Type, Model or List number ....
Type of current ....
Function ....Generator/Motor ....
Fabrication or serial number ....
Type of connection...........Sep/Shunt/Series/Compound
Rated voltage ....volts Rated current .... amps
Rated power ....k.w. Rated speed ....rpm.
Rated Exc. voltage .....volts Rated Exc. current .....amps
Rating class .... Direction of rotation ....
Insulation class .... Protection class ....

Details of Inner parts

Bearing
Sleeve Ball Roller
Front end No. ....
Pulley end No. ....
Grease type ....
Coupling type..
Brush grade ....
Brush No. as per manufacturer....................................

Particulars of supply order

Supply order No: ....

Year of purchase ....

Date of first inspection and test ....

Date of installation ....

Location ....

Intial test results

Resistance value of shunt winding ....

Resistance value of series winding...............................

Resistance value of armature ....

Insulation resistance value between

Armature and shunt field ....

Armature and series field ....

Series field and shunt field ....

Armature and frame ....

Shunt field and frame ....

Series field and frame ....

Maintenance Card

Report on routine maintenance

Date of maintenance	Scheduled maintenance carried out	Defects noted	Attended by (signature)	Reported to (signature)	Remarks

The third page gives details of the tests carried out in the motor at intervals with the corresponding reading

Maintenance Card

Report on routine maintenance

Date of test	Scheduled	Test Particulars	Test results	Tested by (signature)	Reported to (signature)	Remarks

The fourth page gives details of the defects, causes and the repair carried out.

Motor Service Card

Date of repair	Repair and parts replaced	Cause	Repaired by	Supervised by (signature)	Remarks (signature)

A careful study of the maintenance card helps the foreman to plan the shut down date to facilitate early overhauling or planned maintenance schedule to avoid major breakdowns.

Method of maintenance

Investigations and adjustment to be carried out in parts and accessories of the motors/generators during the routine maintenance inspection, are given below to improve the efficiency of preventive maintenance.

1 Clean the motor/generator, switch gear and associated cables free from dirt, dust and grease daily. Use dry compressed air to drive away the dust from the machines.

2 Check the bearing for excessive noise and temperature daily. If required re-grease or re-oil the bearing with the same grade of grease/oil as in the original. Do not mix different grades of grease together as it may result in forming a sludge or acids and spoil the bearings.

3 Check daily the machine against strains of water or oil or grease which may leak from the surroundings. Take necessary protective steps to prevent the leakage.

4 Check daily the belts, gears and coupling for looseness, vibration and noise. Readjust if found defective.

5 Check brushes and commutator for sparking and wear weekly.

6 Check weekly the bearing for proper lubrication weekly.

7 Check weekly the terminal and switch contacts.

8 Inspect brushes and commutator once in a month for excessive wear, chatter and sparking. Worn out brushes need to be replaced with the same grade brushes. Check the spring tension on the brushes and adjust if necessary. A badly worn out commutator needs to be turned in a lathe or replaced.

9 Check the brushes monthly for proper seating. If necessary, reshape the brushes to proper curvature to suit the commutator surface.

10 Check the end plates and the shaft montly for excessive end play.

11 Monthly check the main and auxiliary contact points of the switch gear for wear, pitting and burns. Badly worn out contact point needs replacement. Check the connection terminals for loose connection and scales or burning. Rectify the defects.

12 Monthly once, test the field windings and armature for insulation and ground faults. Low reading of insulation below 1 megohm indicates weak insulation. Dry out the winding and revarnish if necessary.

13 Monthly once, check the foundation bolt and other fasteners for tightness.

14 Once a year undercut the mica in between the commutator bars, test the commutator and armature for shorts, open and ground faults.

From the above discussions it is clear that atleast once in a year, the motor/generator needs a thorough overhauling in addition to frequent routine maintenance.

Method of testing and repairing a DC machine

Objective: At the end of this lesson you shall be able to
- **describe the methods of testing and repairing a DC machine.**

Though overhauling is done on the DC machines as one of the operations of routine preventive maintenance, generally repairs are also done during this process as a part of planned preventive maintenance.

A thorough check of the maintenance card of the particular machine will reveal the problem area leading to preventive repairs in the machine during overhauling.

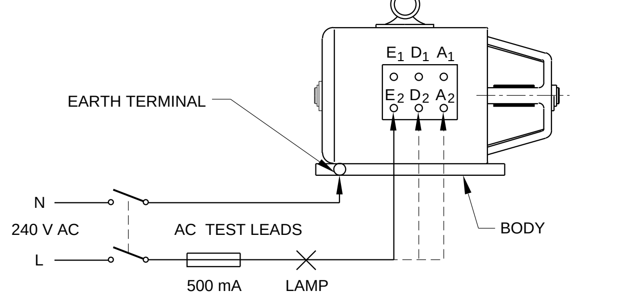
Apart from conducting an insulation test as explained in Exercise No.6.09, the technician will resort to certain other testing methods on the DC machine to identify the faults and repair it to keep the machine in top condition. General tests conducted during overhauling operation and the connected repairing methods are explained in the following paras.

Ground test

Method of testing a DC compound motor for suspected ground is shown in Fig 1. Though the method of testing for ground by a Megger is the most appropriate one, this method shown in the figure is as a substitute by the technician to locate the well established ground faults in a DC machine quickly.

One prod of the test lamp which is in the neutral line is connected to the earth terminal stud of the machine and the other prod which is in the phase line and connected through a test lamp is touched with each terminal of the DC machine in succession. In a sound machine, the lamp should not light. If the lamp lights, a ground is indicated.

Fig 1

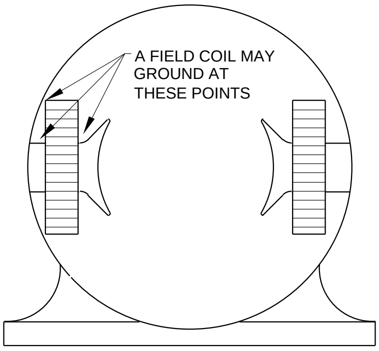


TESTING A DC COMPOUND MOTOR FOR GROUNDING

From the terminal marking determine the grounded winding. If a ground is indicated in the field winding, it will be necessary to remove the field coils from the poles and re-insulate them with varnish and tape.

Fig 2 shows the places in the field coils where ground is most likely to occur.

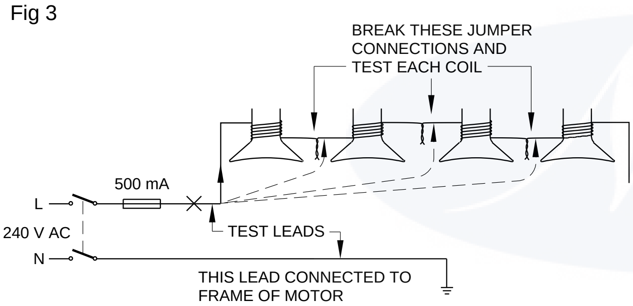
Fig 2



A grounded field coil might have been either completely burnt out or partially lost its insulation and touching the body. A completely burnt out field coil could be identified by the surface decolourisation or smell. However, grounds due to poor insulation need a thorough checking.

As it is not necessary that all coils in the field chain need to have been grounded, the defect may be located in one coil. To locate the defective coil, the jumpers used in between the coil connections need to be broken and tests should be carried in individual coils as shown in Fig 3.

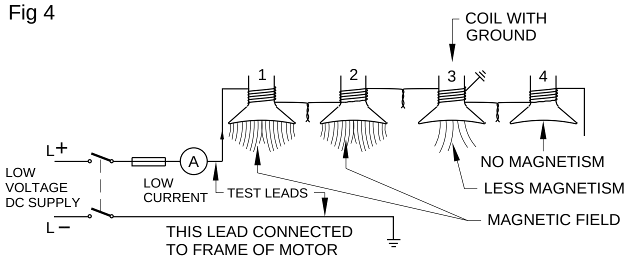
Fig 3



TEST FOR GROUND IN INDIVIDUAL FIELD COILS

Alternatively using a low voltage DC supply and a screw-driver, the grounded coil could be identified as shown in Fig 4. The coils which are in series with the line and ground will produce magnetism and could be determined by the attraction of the screwdriver blade to the poles.

Fig 4

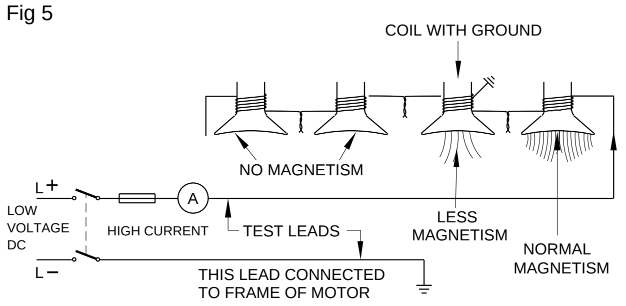


TEST ON FIELD POLES

However, the coils beyond the ground fault will have no current through them, and hence, will not attract the screwdriver blade. To identify the grounded coil, next connect the test lamp prod to the other side of the field coil as shown in Fig 5.

When the test lead is moved in succession to the next coils, it will be found that the coil in which ground fault exists, will draw heavy current. In this case also the grounded coil will produce less magnetism depending upon the location of the fault in the turns of the coil.

Fig 5



Intermittent ground fault indication may be due to loose field coils in the poles and could be identified by shaking the coils slightly with a gloved (insulated) hand.

Test for open circuit

This test is conducted to determine the correctness of winding continuity.

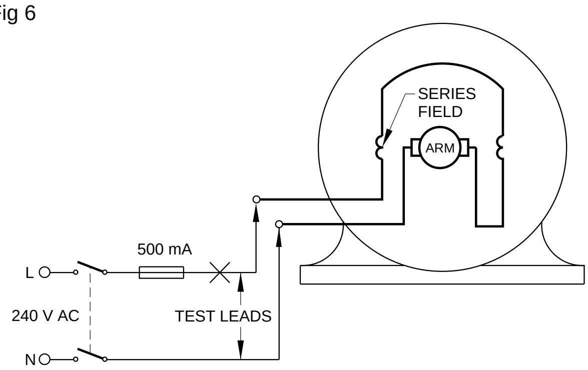
This test is a must before conducting the insulation test by a Megger so as to be sure to include the complete circuit to measure insulation resistance.

According to the type of DC machine, different tests need to be conducted.

Open circuits in DC series machine

In most of the small capacity machines only two wires are brought out by connecting the armature and series field internally as shown in Fig 6.

Fig 6



TEST ON SERIES MACHINE FOR OPEN CIRCUIT

By connecting the test lamp to the two terminals, the lamp should light. If it does not, the trouble may be due to the following reasons:

a the brushes not making proper contact with the commutator

b dirty or severely pitted commutator

c break in the pigtail connection or jumper connection of the brushes d break in the field circuit

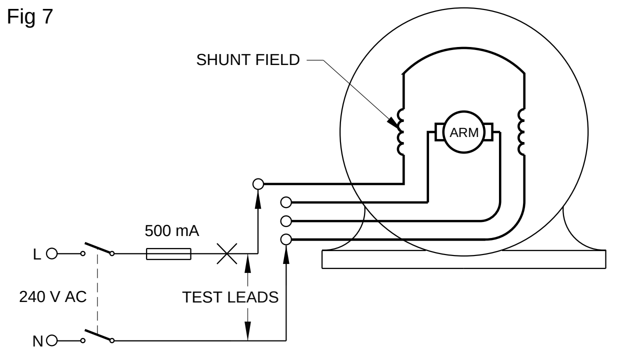
e break in the armature winding.

In four terminal DC series machines, the field and the armature could be checked individually.

Open circuits in DC shunt machines

Shunt field and armature circuits need to be tested with the test lamp individually as shown in Fig 7. In the armature circuit, the test lamp will burn bright due to the low resistance of the armature. However, in the field circuit depending on its resistance, the lamp will glow either dimly or produce sparks at the contact points of the prods.

Fig 7



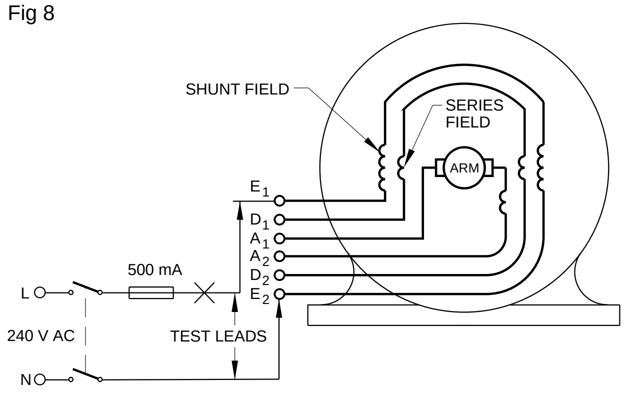
TEST ON SHUNT MACHINE FOR OPEN CIRCUIT

If there is no continuity in either one or both of the circuits, the defect may be traced as explained earlier.

Open circuits in DC compounded machines

Combining the methods indicated for series and shunt machines, the DC compounded machine could be checked for open circuit. Fig 8 shows the method of testing a DC compounded machine.

Fig 8



TEST ON COMPOUND MACHINE FOR OPEN CIRCUIT

Locating open circuit in field coils

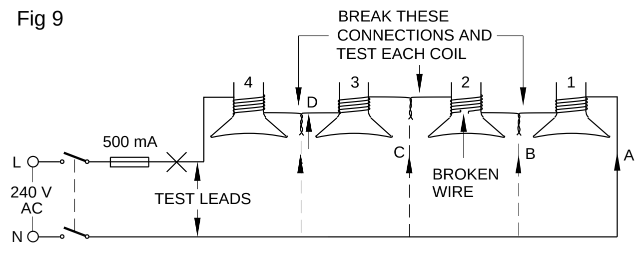
Normally an open circuit in the field circuit indicates that either the jumper connection is bad or open exists in the winding wire in any one of the field coils. Fig 9 illustrates the method of locating the open in a four-pole machine which could be applied equally to any machine with any number of poles.

Remove the insulation in the jumper connections and connect the test lamp as shown in Fig 8 between all the coils. Move the neutral wire prod from position A to B and so on until the lamp lights or gives a spark.

If the lamp does not light at position A but lights at position B, then coil 1 is open. If the lamp lights at point C but not at positions B or A then the coils 2 is open. Likewise the opened coil could be detected. Continuity shown between the ends of the individual field coils are not reliable because there may be shorted turns within the winding.

The best method to check this is to measure individual resistances of the field coils with the help of a good ohmmeter. If the readings of all the field coils are the same or even within 5% of accuracy it can be taken there is no short between the turns within the winding.

Fig 9



OPEN TEST IN INDIVIDUAL FIELDS

Setting the rocker arm position of the commutator

One of the necessary operations is to set the rocker arm position such that the brushes will be at neutral axis. To avoid this alignment, normally during overhauling, the rocker position with respect to end plates is marked and during assembly the rocker arm is fitted in the same position.

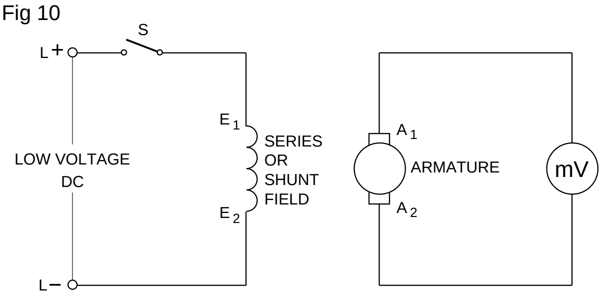
Where there is no marking prior to dismantling of the machine or there is a complaint regarding sparking and bad performance of the machine on load due to suspected improper positioning of brushes the following method is suggested to locate the neutral position of the brushes.

The brush rocker is to be fixed such that brushes are to be in neutral position. This is to be done by what is known as the **'Kick Neutral Method'**. A low voltage DC supply is connected as shown in Fig 10 to either the shunt winding or the series winding such that a current of about 20% of the rated current is to be passed through either shunt or series winding. Except two brushes of opposite polarity the rest of the brushes need to be lifted.

A millivoltmeter is connected across the armature as shown in Fig 10. If the field circuit is suddenly broken through the switch the voltmeter will deflect. While turning the brush rocker round the commutator and keeping it at different positions, the field circuit is opened and closed each time.

Where there is no deflection in the voltmeter during break or make operation of the field circuit, it indicates neutral position. The brush rocker has to be fixed at this position.

Fig 10



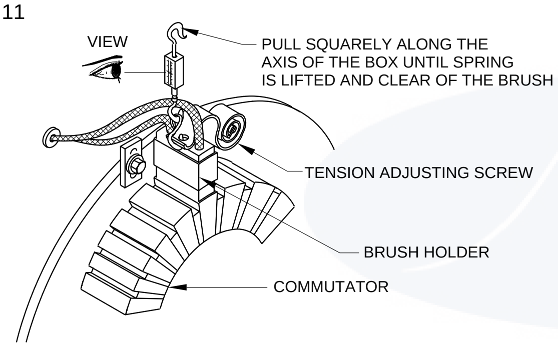
TEST TO DETERMINE THE ROCKET ARM POSITION

Testing the brush tension

Most of the defects, indicated in the course of testing the armature circuit for open, may be related to brush connections. Bad brush tension is one of the major causes of an open circuit in armature circuits.

Normally the manufacturer of the machine recommends the brush pressure in kg/cm^2, and it varies from 0.08 to 0.2 kg/cm^2. A small spring balance is used as shown in Fig 11, to determine the pressure applied to each brush. By adjusting the tension adjusting screw, the brush tension can be adjusted to the specified value.

Fig 11



METHOD OF ADJUSTING BRUSH TENSION

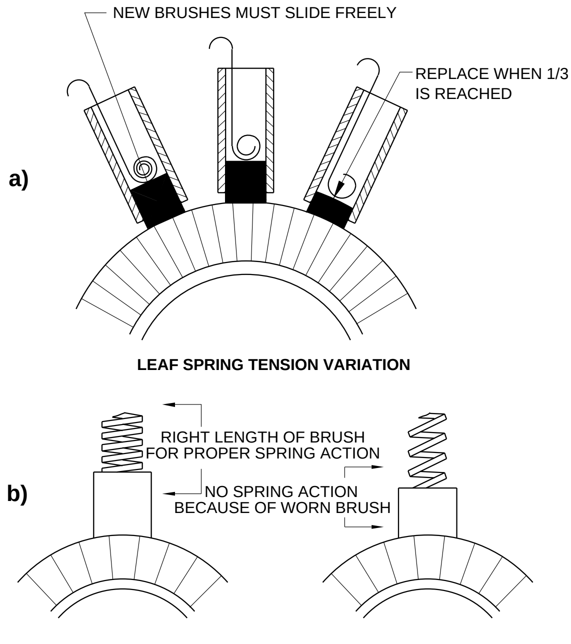
When the brushes become worn out due to long usage, the brush tension may also vary. This is particularly very much predominant in the case of leaf spring or spiral spring loaded brush tension devices shown in Figs 12 a and b.

In both the cases, the main culprit is the worn out (shortened) brush. In such cases the brushes need to be replaced with those of similar grade and having a similar shape. While changing brushes it is advisable to change all the brushes at the same time rather than one at a time, to maintain homogeneous current distribution by even pressure and brush resistance.

The general rule is t hat the brushes which are shortened more than 2/3rd of the original length need to be replaced. Do not keep different brushes in the same machine.

While changing the brushes, the same grade as recommended by the manufacturer should be strictly followed. Most of the new brushes supplied from the market will be flat as shown in Fig 13a and need to be shaped as shown in Fig 13b to suit the contour of the commutator of the machine.

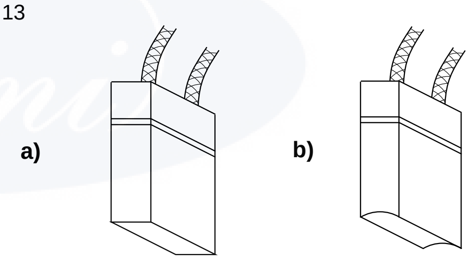
Fig 12



SPIRAL SPRING TENSION VARIATION

The brushes should just slide through the brush boxes without much friction. At the same time too loosely or too tightly fitted brushes in the brush boxes are likely to get damaged while in operation.

Fig 13



FLAT BRUSH SHAPED BRUSH

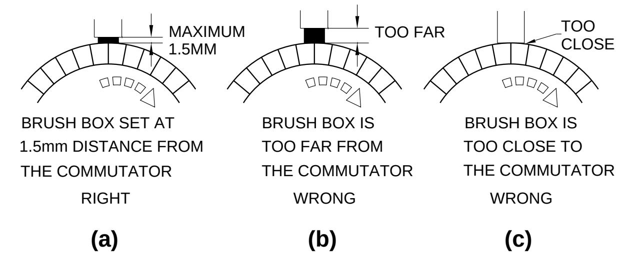
Brush box-to-commutator spacing should be about 1.5 mm as shown in Fig 14a. If the distance is more as shown in Fig 14b the brushes may chatter during rotation and break.

A brush box too close to the commutator as shown in Fig 14c may result in rubbing of the commutator by the box due to slight wobbling of the shaft and result in complete damage to the commutator.

To shape the brushes in line with the curvature of the commutator, a sandpaper is used. This operation is called bedding the brushes. This is done by placing a smooth sand paper over the commutator curvature with the rough side against the brush as shown in Fig 15a and the commutator rotated by hand.

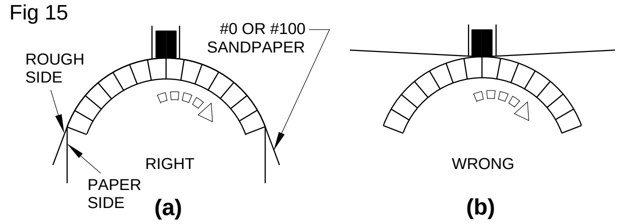
The wrong method of placing the sandpaper is shown in Fig 15b.

Fig 14



THE CORRECT AND INCORRECT POSITIONS OF A CARBON BRUSH

Fig 15



HOW TO HOLD SANDPAPER FOR BEDDING BRUSHES

By this operation the brush attains the same shape as the commutator curvature. After this operation the sandpaper and dust should be removed from the commutator.

The connection of the leads to the brush boxes is often a point of failure. Ensure that flexible (pigtail) connections do not foul moving parts.

Sometimes mica insulation between the commutator segments may protrude beyond the surface of the commutator segments. This results in excessive sparking and noise. These mica insulations need to be undercut either by a fine hacksaw blade or by a special cutting tool.

Excess oil or grease used for lubrication may lodge in the commutator resulting in forming an insulation coating over the commutator.

Further, these oil residues will deteriorate the mica insulation between the segments. Hence, cleaning of the commutator is essential at intervals. Also excess use of lubricants for the machine should be avoided.

Cleaning the commutator brushes and rocker arm is an essential operation during weekly maintenance programme and needs to be done during non running periods of the machine as well.

Troubleshooting of DC machine

Objective: At the end of this lesson you shall be able to
- **use the troubleshooting chart to rectify defects in i) DC machines in general ii) DC motors iii) DC generators.**

DC machines have electrical problems, not normally found in AC machines. DC motors and generators have commutators and brushes, which cause special problems. If the commutator is properly maintained, it will give many years of useful service.

CHART 1

Troubleshooting chart for DC machine

Symptoms	Cause	Remedies
- Very rapid wearing out of the brushes or - Heavy sparking at the commutator or overheating of the commutator. - Over heating of pig tails	(a) Improper brush tension. (b) Brushes not fully bedded. (c) Incorrect size of grade of replaced brushes. (d) Overloading. (e) Insufficient or unequal brush pressure due to brushes sticking in the holder. (f) Short circuit in commutator segment. (g) Uneven commutator surface. (h) Brushes may not be magnetic neutral axis. (i) Dirty, oily or tarnished commutator surface. (j) Incorrect direction of rotation.	(a) Test brush tension. (b) Inspect the brush faces and bed the brushes. (c) Use correct grade of brush for replacement. (d) Reduce the load. (e) Check the free motion of brushes in the holder. (f) Clean the commutator and test for shorts. Rectify the defect. Inspect the commutator surface. (g) Undercut the mica and skin the commutator if necessary. (h) Adjust the rocker arm to magnetic neutral axis. (i) Clean and polish the commutator. (j) Check the direction of rotation and rectify the defect.
Brush chatter or hissing noise.	(a) Excessive clearance of brush-holders. (b) Incorrect angle of brushes. (c) Incorrect brushes grade. (d) High mica. (e) Incorrect brush spring pressure.	(a) Adjust the holders. (b) Adjust to correct angle. (c) Get the manufacturer's recom-mendation. (d) Undercut mica. (e) Adjust to correct value.
Selective commutation (one brush takes more load than it should)	(a) Insufficient brush spring pressure. (b) Unbalanced circuits in armature.	(a) Adjust the correct pressure making sure brushes ride free in the holders. (b) Eliminate high resistance in defective joints by checking armature or equalizer circuit or commutator risers. Check for poor contacts between the brush and brush rings.

Symptoms	Cause	Remedies
Sparking at light loads.	Paint, chemicals,oil or grease or other foreign material on the commutator.	Use the motor designed for the application. Clean the commutator, and provide protection against foreign matter. Install an enclosed motor designed for the application.
Field coils overheat.	Short circuit between turns or layers.	Replace the defective coil or rewind the coil.
Overheating of armature.	(a) More voltage across the armature. (b) More current in the armature (c) Armature winding shorted (d) Insufficient air circulation around the machine.	(a) In the case of generator the speed may be high or in the case of motor the applied voltage may be high. Measure and reduce it. (b) Reduce the overload. (c) Check the commutator and remove any metallic particle in between segments. Test the machine for shorts and rectify the defect. (d) Allow good ventilation around the machine by providing fan etc.
Machine operates but overheats.	(a) Overloading. (b) Worn out bearing. (c) Tight bearing. (d) Shorted or earthed winding. (e) Wrong alignment of pulley	(a) Reduce load. (b) Replace bearing. (c) Grease it. (d) Test the winding and rectify it if necessary (e) Align properly.
Vibration while running.	(a) Loose foundation bolts. (b) Loose coupling pulleys. (c) Wrong alignment. (d) Loose internal parts. (e) Bent shaft. (f) Unbalanced armature. (g) Damaged bearing.	(a) Tighten them. (b) Tighten them. (c) Align properly. (d) Tighten them. (e) True the shaft in a lathe. (f) Balance it. (g) Inspect the bearing and replace it, if necessary.
Mechanical noise.	(a) Foreign matter in air gap. (b) Defective alignment. (c) Defective bearing. (d) Loose internal parts	(a) Clean the machine. (b) Align the machine. (c) Replace the bearing. (d) Tighten them
Bearing overheating	Incorrect grade or quantity of grease (roller type).	Remove incorrect grade or surplus grease and replenish with correct quantity of recommended grease.

CHART 2

Troubleshooting chart for DC motors

Symptoms	Cause	Remedies
Motor will not start.	(a) Open circuit in the starter open switch or open fuse.	(a) Check for open starting resistor/ Switch/Fuse
	(b) Low or no terminal voltage.	(b) Check the incoming voltage with the name-plate rating and correct the supply voltage.
	(c) Bearing frozen.	(c) Recondition the shaft and replace the bearing.
	(d) Overload.	(d) Reduce the load.
	(e) Excessive friction.	(e) Check the bearing lubrication to make sure that the oil has been replaced after installing the motor. Disconnect the motor from the driven machine and turn the motor by hand to see if trouble is in the motor. Dismantle and reassemble the motor. True or replace the bent shaft.
Motor stops after running for a short time.	(a) Motor is not getting power.	(a) Check voltage in the motor terminals also check the fuses and overload relay. Correct it, if necessary.
	(b) Motor is started with weak torque	(b) If it is an adjustable speed motor, check rheostat for correct setting. If correct, check the condition of the rheostat. Correct it, if necessary. Check the field coils for open winding. Check the wiring for loose or broken connection. Correct it, if necessary.
	(c) Motor torque insufficient to drive the load.	(c) Use a larger motor or one with suitable. characteristic to match the load.
Motor runs too slow, underload.	(a) Line voltage too low.	(a) Rectify the supply voltage or check and remove any excess resistance in supply line, connections or controller.
	(b) Brushes ahead of the neutral plane.	(b) Set the brushes on neutral plane.
	(c) Overload.	(c) Check to see that load does not exceed allowable load on motor.
Motor runs too fast, underload.	(a) Weak field.	(a) Check for resistance in shunt-field circuits. Check for grounds. Correct them if necessary.
	(b) Line voltage too high.	(b) Correct the high voltage condition.
	(c) Brushes are out of the neutral plane.	(c) Set the brushes on neutral plane.

CHART 3

Troubleshooting chart for DC generator

Symptoms	Cause	Remedies
Generator fails to build up voltage.	(a) The direction of rotation must have been reversed.	(a) Change the direction of rotation.
	(b) Brushes not resting on the commutator.	(b) Set the brushes in correct position.
	(c) Residual magnetism is completely lost.	(c) Run the generator as a DC motor for few seconds or connect the field circuit to a battery or a DC voltage to re-establish the residual magnetism.
	(d) Generator speed is too low.	(d) Generator speed should be restored to normal speed by increasing the prime mover speed.
	(e) Short circuit in the armature.	(e) Rectify the short circuit in the armature.
	(f) Open circuit in the armature.	(f) Test and rectify the open circuit.
	(g) Short circuit in the field circuit.	(g) Test and rectify the short circuit which may be in the coil. The faulty coil will show much less resistance than the good coil.
	(h) Open circuit in the field winding.	(h) Check the continuity of the circuit and rectify the defect.

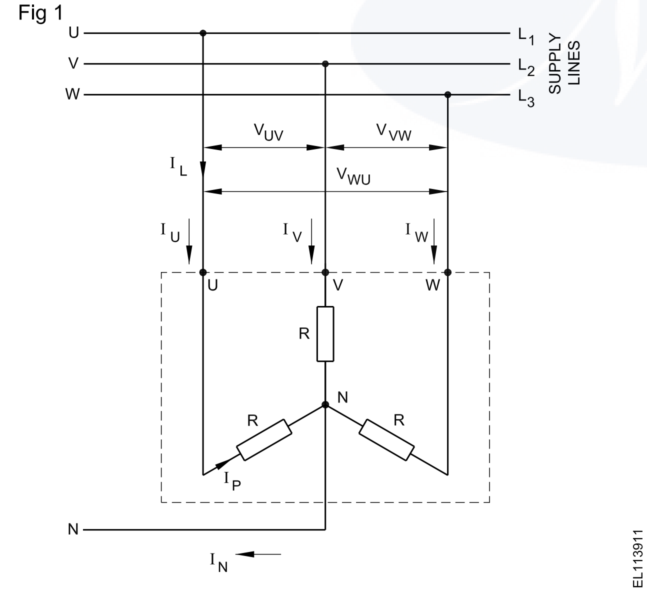
Systems of connection in 3-phase AC

Objectives: At the end of this lesson you shall be able to
- **explain the star and delta systems of connection**
- **state phase relationship between line and phase voltages in a star connection**
- **state and describe the relationship between phase and line current in a star connection**
- **state the relationship between phase and line voltage in a delta connection**
- **state and describe the relationship between phase and line current in a delta connection.**

Methods of 3-phase connection: If a three-phase load is connected to a three-phase network, there are two basic possible configurations. One is `star connection' (symbol Y) and the other is `delta connection' (symbol Δ).

Star connection: In Fig 1 the three-phase load is shown as three equal magnitude resistances. From each phase, at any given time, there is a path to the terminal points U, V, W of the equipment, and then through the individual elements of the load resistance. All the elements are connected to one point N: the `star point'. This star point is connected to the neutral conductor N. The phase currents i_U, i_V, and i_W flow through the individual elements, and the same current flows through the supply lines, i.e. in a star connected system, the supply line current (I_L) = phase current (I_P).

Fig 1



The potential difference for each phase, i.e. from a line to the star point, is called the phase voltage and designated as V_P. The potential difference across any two lines is called the line voltage V_L. Therefore, the voltage across each impedance of a star connection is the phase voltage V_P. The line voltage V_L appears across the load terminals U-V, V-W and W-U and designated as V_{UV}, V_{VW} and V_{WU} in the Fig 1. The line voltage in a star-connected system will be equal to the phasor sum of the positive value of one phase voltage and the negative value of the other phase voltage that exist across the two lines.

Fig 2

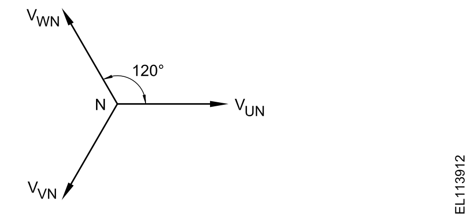


Fig 2 shows the 3 phase vector diagram displaced at 120^0

Thus

$V_L = V_{UV}$ = (phasor V_{UN}) − (phasor V_{VN})

= phasor $V_{UN} + V_{VN}$.

In the phasor diagram (Fig 3)

$V_L = V_{UV} = V_{UN}\cos 30^o + V_{NV}\cos 30^o$

But $\cos 30^o = \frac{\sqrt{3}}{2}$.

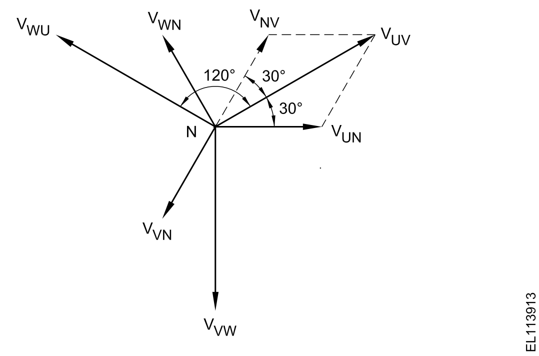
Thus as $V_{UN} = V_{VN} = V_P$

$V_L = \sqrt{3}\, V_P$.

This same relationship is applied to V_{UV}, V_{VW} and V_{WU}.

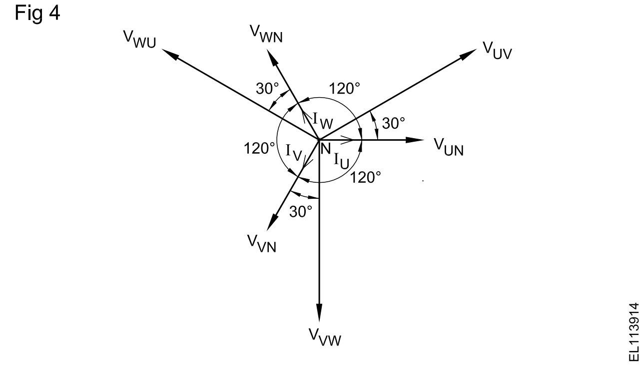
In a three-phase star connection, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$.

Fig 3



The voltage and current relationship in a star connection is shown in the phasor diagrams. (Fig 4) The phase voltages are displaced 120° in phase with respect to each other.

Fig 4



Derived from these are the corresponding line voltages. The line voltages are displaced 120^0 in phase with respect to each other. Since the loads in our example are provided by purely resistive impedances, the phase currents I_P (I_U, I_V, I_W) are in phase with the phase voltages V_P (V_{UN}, V_{VN} and V_{WN}). In a star connection, each phase current is determined by the ratio of the phase voltage to the load resistance R.

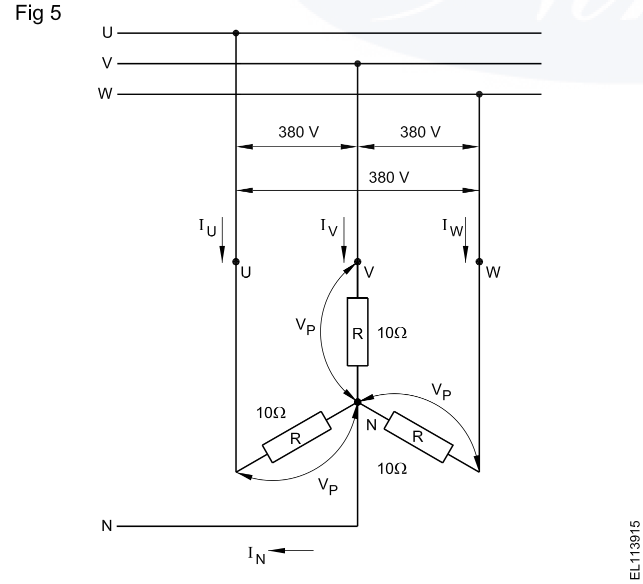
Example 1: What is the line voltage for a three-phase, balanced star-connected system, having a phase voltage of 240V?

$$V_L = \sqrt{3}\, V_P = \sqrt{3} \times 240$$

$$= 415.7V.$$

Example 2*:* What is the magnitude of each of the supply line currents for the circuit shown in Fig 5?

Fig 5



Because of the arrangements of a star connection there is a voltage (i.e. between V_{PU} - N, V_{PV} - N and V_{PW} - N is $(380/\sqrt{3}) = 220V$)

$$V_P = \frac{380}{1.73} = 220\ V$$

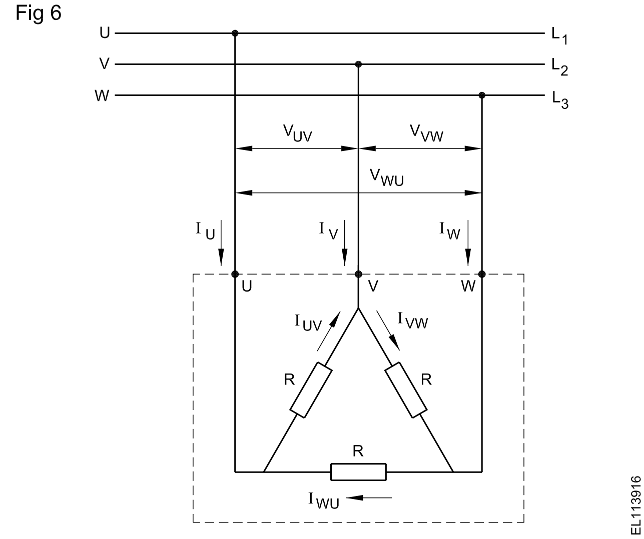
across each of the purely resistive loads R.

The three-supply line currents have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = \frac{V_P}{R} = \frac{220}{10} = 22A = I_L = I_P$$

Delta connection: There is a second possible arrangement for connecting a three-phase load in a three-phase network. This is the delta or mesh connection (Δ).(Fig 6)

Fig 6



The load impedances form the sides of a triangle. The terminals U, V and W are connected to the supply lines of the L_1, L_2 and L_3.

> **In contrast to a star connection, in a delta connection the line voltage appears across each of the load phases.**

The voltages, with symbols V_{UV}, V_{VW} and V_{WU} are, therefore, the line voltages.

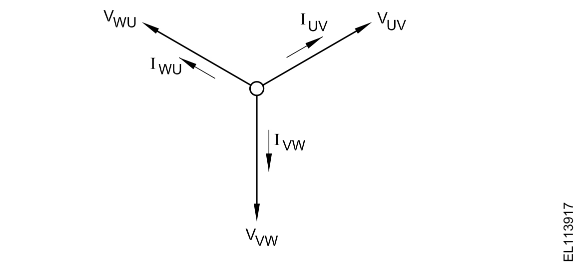
The phase currents through the elements in a delta arrangement are composed of I_{UV}, I_{VW} and I_{WU}. The currents from the supply lines are I_U, I_V and I_W, and one line current divides at the point of connection to produce two phase currents.

The voltage and current relationships of the delta connection can be explained with the aid of an illustration. The line voltages V_{UV}, V_{VW} and V_{WU} are directly across the load resistors, and in this case, the phase voltage is the same as the line voltage. The phasors V_{UV}, V_{VW} and V_{WU} are the line voltages. This arrangement has already been seen in relation to the star connection.

Because of the purely resistive load, the corresponding phase currents are in phase with the line voltages. (Fig 7) Their magnitudes are determined by the ratio of the line voltage to the resistance R.

On the other hand, the line currents I_U, I_V and I_W are now compounded from the phase currents. A line current is always given by the phasor sum of the appropriate phase currents. This is shown in Fig 8. The line current I_U is the phasor sum of the phase currents I_{UV} and I_{UW}. (See also Fig 8)

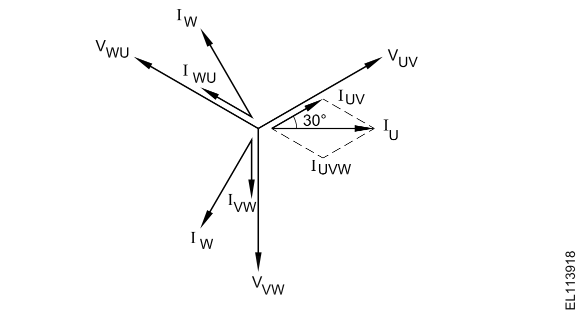
Fig 7



Hence, $I_U = I_{UV} \text{Cos } 30^o + I_{UW} \text{Cos } 30^o$

But $\text{Cos } 30^o = \dfrac{\sqrt{3}}{2}$.

Fig 8



Thus $I_L = \sqrt{3}$ Iph

Thus, for a balanced delta connection, the ratio of the line current to the phase current is $\sqrt{3}$.

Thus, line current = $\sqrt{3}$ x phase current.

Example 3: What are the values of the line currents, I_U, I_V and I_W in the above example? (Fig 9)

Solution

Since the load is balanced (i.e. the resistance of each phase is the same), the phase currents are of equal magnitude, and are given by the ratio of the line voltage to the load phase resistance

$$I_{UV} = I_{VW} = I_{WU} = \frac{V_P}{R} = \frac{V_L}{R} = \frac{380}{10} = 38\text{A}.$$

Thus, the phase current in the case of delta is 38A. Expressed in words:

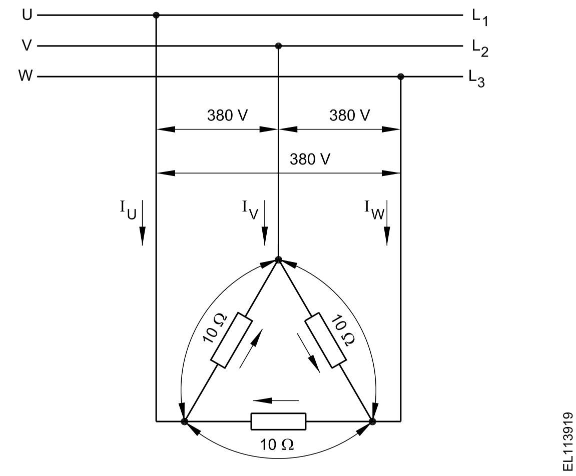
$$\text{Phase current} = \frac{\text{line or phase voltage}}{\text{phase resistance}}$$

The line current is $\sqrt{3}$ times the phase current.

Therefore the line current is

$I_U = I_V = I_W = \sqrt{3}$ x 38A = 1.73 x 38A = 66A.

Fig 9



Example 4: Three identical coils, each of resistance 10 ohms and inductance 20mH is delta connected across a 400-V, 50Hz, three-phase supply. Calculate the line current.

For a coil,

reactance $X_L = 2\text{pfL} = 2 \times 3.142 \times 50 \text{ X } \dfrac{20}{1000} = 6.3$ ohms.

Impedance of a coil is thus given by

$$Z = \sqrt{(R^2 + X^2)} = \sqrt{(10^2 + 6.3^2)} = 11.8 \text{ ohms.}$$

For a delta connected system, according to equation

$V_L = V_P$.

Thus V_P = 400V.

Hence the phase current is given by

$$I_P = \frac{V_P}{Z} = \frac{400}{118} = 33.9 \text{ A.}$$

But for a delta connected system, according to equation,

$I_L = \sqrt{3}\, I_P = \sqrt{3}$ x 33.9 = 58.7A.

Application of star and delta connection with balanced loads

An important application is the `star-delta change over switch' or star-delta starter.

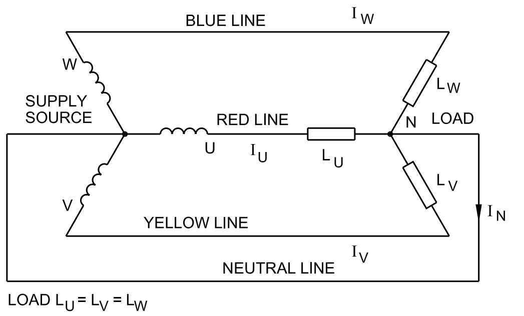
For a particular three-phase load, the line current in a delta connection is three times as great as for a star connection for a given line voltage, i.e. for the same three-phase load (Δ line current) = 3 (Y - line current).

This fact is used to reduce the high starting current of a 3-phase motor with a star-delta change over switch.

Application of star connection: Alternators and secondoary of distribution transformers, have their three, single-phase coils interconnected in star.

Neutral: In a three-phase star connection, the star point is known as neutral point, and the conductor connected to the neutral point is referred as neutral conductor (Fig 10).

Fig 10



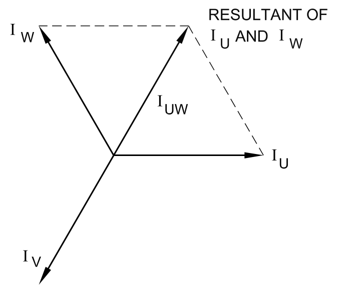
THREE-PHASE SUPPLY AND LOAD

Current in the neutral conductor: In a star-connected, four-wire system, the neutral conductor N must carry the sum of the currents I_U, I_V and I_W. One may, therefore, get the impression that the conductor must have sufficient area to carry a particularly high current. However, this is not the case, because this conductor is required to carry only the phasor sum of the three currents.

I_N = phasor sum of I_U, I_V and I_W

Fig 11 shows this phasor addition for a situation where the loads are balanced and the currents are equal. The result is that the current in the neutral line I_N is zero. This can also be shown for the other instantaneous values.

Fig 11

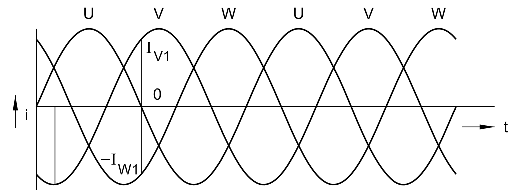


FOR A BALANCED LOAD THE RESULTANT OF I_W AND I_U IS EQUAL IN MAGNITUDE BUT OPPOSITE TO I_V.

At a particular instant in time, t_1, the instantaneous value $i_U = 0$ (Fig 12), i_V and i_W, have equal magnitudes, but they have opposite signs,i.e. they are in opposition and the phasor sum is zero. Taking the other values of t, it can be seen that the sumof the three phase currents to equal to zero.

Therefore, for a balanced load the neutral conductor carries no current.

Fig 12



RESULTANT OF THREE-PHASE CURRENTS

With unequal value the phase currents are different in magnitude and the neutral current is not zero. Then a `neutral' current I_N does flow in the neutral conductor, but this, however, is less than any of the supply line currents. Thus, neutral conductors, when they are used, have a smaller cross-section than the supply lines.

Effect of imbalance: If the load is not balanced and there is no neutral conductor, there is no return path for the sum of the phase currents which will be zero. The phase voltages will not now be given by the line voltage divided by $\sqrt{3}$, and will have different values.

Earthing of neutral conductor: Supply of electrical energy to commercial and domestic consumers is an important application of three-phase electricity. For `low voltage distribution' - in the simplest case, i.e. supply of light and power to buildings - there are two requirements.

1 It is desirable to use conductors operating at the highest possible voltage but with low current in order to save on expensive conductor material.

2 For safety reasons, the voltage between the conductor and earth must not exceed 250V.

A voltage distribution system according to criterion 2, only possible with a low line voltage below 250 V. However, this is contrary to criterion 1. On the other hand, with a star connection, a line voltage of 400V is available. In this case, there is only 230V between the supply line and the neutral conductor. Criterion 1 is satisfied and, to comply with 2, the neutral conductor is earthed.

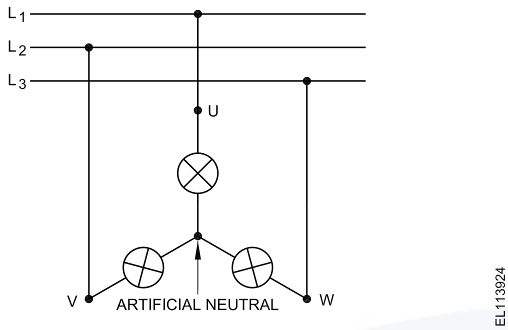
Indian Electricity Rules: I.E.Rules insist that the neutral conductor must be earthed by two separate and distinct connections to earth. Rule No.61(1)(a), Rule No.67(1)(a) and Rule No.32 insist on the identification of neutral at the point of commencement of supply at the consumer's premises, and also prevent the use of cut outs or links in the neutral conductor. BIS stipulate the method of earthing the neutral. (Code No.17.4 of IS 3043-1966)

Cross-sectional area of neutral conductor: The neutral conductor in a 3-phase, 4-wire system should have a smaller cross-section. (half of the cross-section of the supply lines).

Artificial neutral: Normally neutral conductors are available with a 3-phase, 4-wire system only. Neutral conductors are not drawn for a 3-phase, 3-wire system. Neutral conductors are also not available with the delta-connected supply system.

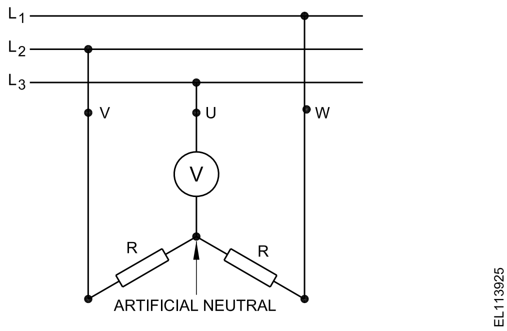
A neutral conductor is required for measuring phase voltage, energy, power to connect indicating lamps, etc. An artificial neutral for connecting indicating lamps can be formed by connecting them in star. (Fig 13) Artificial neutral for instruments can be formed by connecting additional resistors in star. (Fig 14)

Fig 13



In this method, the value of R must be equal to the resistance of the voltmeter. The same method can be used while measuring power or energy by connecting resistors of equal resistance as of potential coil.

Fig 14

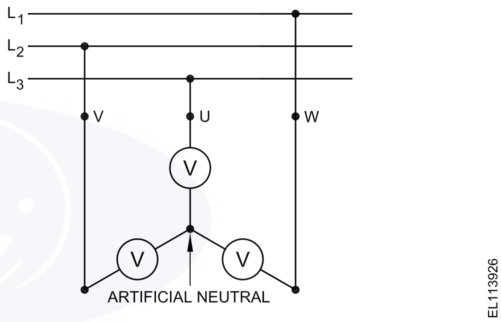


When three instruments of a similar kind are in use, their pressure coils can be connected to form an artificial neutral. (Fig 15)

This type of neutral cannot allow a large current. When earthing of a delta-connected system is required, neutral earthing compensators are used. These can sink or source large currents while keeping neutral to phase voltages constant.

IS 3043 Code No.17, provide a method to obtain neutral for earthing purposes by an earthing compensator.

Fig 15



Principle of induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the method of producing a rotating field**
- **state the principle of a 3-phase induction motor.**

Three-phase induction motors are used, more extensively than any other form of electrical motor due to their simple construction, troublefree operation, lower cost and fairly good torque speed characteristic.

Principle of 3-phase induction motor

It works on the same principle as DC motor. The current carrying conductors kept in a magnetic field will tend to create a force. However, rotor of the induction motor differs from the DC motor. The rotor of the induction motor is not electrically connected to the stator, but induces a voltage/current in the rotor by the transformer action as the stator magnetic field sweeps across the rotor.

The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The three-phase winding in the stator produces a rotating magnetic field in the stator core which will be explained later in this lesson. The rotor of the induction motor may have either shorted rotor conductors in the form of squirrel cage or in the form of 3-phase winding to facilitate circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in the clockwise direction as shown in Fig 1. This makes the relative motion of the rotor in anticlockwise direction as shown in Fig 1a.

Applying Fleming's right hand rule, the direction of emf induced in the rotor will be towards the observer as shown in Fig 1b. As the rotor conductors have closed the electric path, due to their shorting, a current will flow through them as in a short circuited secondary of a transformer.

The magnetic field produced by the rotor currents will be in counter-clockwise direction as shown in Fig 1b according to Maxwel's corkscrew rule. The interaction between the stator magnetic field and the rotor magnetic field results in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator as shown in Fig 1c. As such the rotor follows the stator field in the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating field.

At higher speeds of the rotor nearing synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator gets reduced which results in a smaller induced emf in the rotor.

Fig 1a

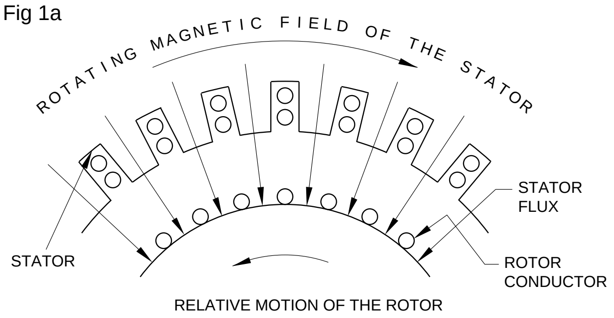


Fig 1b

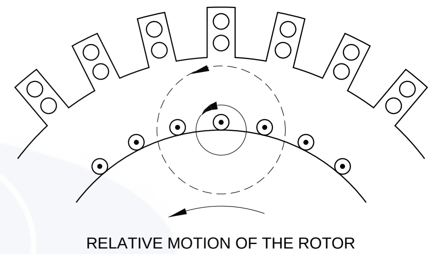
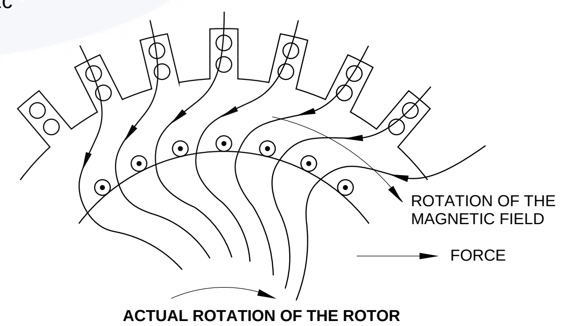


Fig 1c



Theoretically if we assume the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and rotor, and consequently, no induced emf or current in the rotor. Therefore, there will not be any torque in the rotor.

Hence the rotor of the induction motor cannot run at the synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force, thereby the relative speed increases, the induced emf and current increase in the rotor resulting in increased torque.

To reverse the direction of rotation of a rotor

The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator magnetic field as well as the direction of rotation of the rotor, the phase sequence of the supply to be changed by changing any two leads connected to the stator.

Rotating magnetic field from a three-phase stator

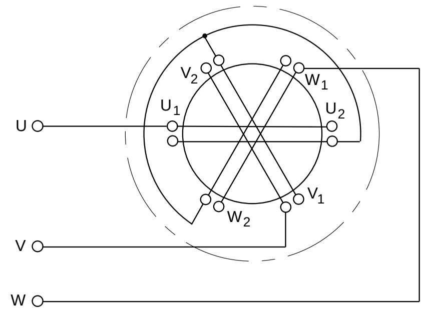
The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three phase windings placed at 120 electrical degrees apart from each other. These windings are placed on the stator core to form non- salient stator field poles. When the stator is energized from a three-phase supply each phase winding will set up a pulsating field.

However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement flux is called the 'Rotating Magnetic Field' and its speed is called the 'Synchronous Speed'.

The manner, in which the rotating field is set up, may be described by considering the direction of the phase currents at successive instants during a cycle. Fig 2 shows a simplified star-connected, three- phase stator windings. The winding shown is for a two-pole induction motor.

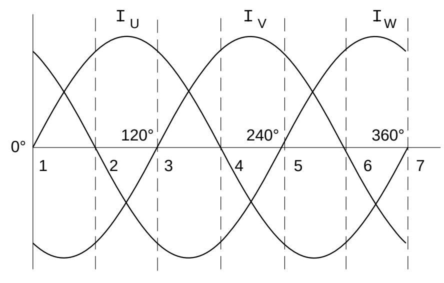
Fig 3 shows the phase currents for the three-phase windings. The phase currents will be 120 electrical degrees apart as shown in Fig 3 and the resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current in Fig 4.

Fig 2



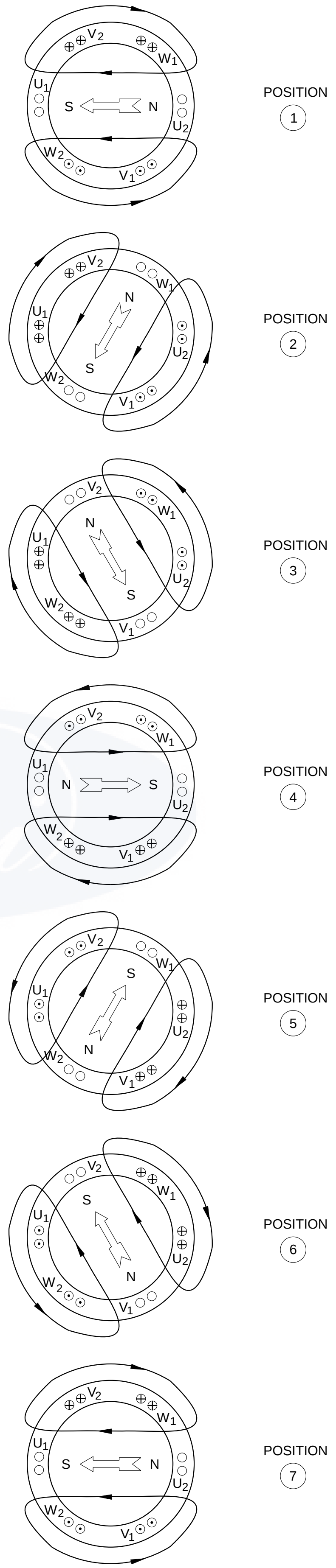
THREE-PHASE WINDING IN THE STATOR

Fig 3



SINUSOIDAL WAVE-FORM OF 3-PHASE CURRENTS

Fig 4



At position (1) in Fig 3 the phase current I_U is zero and hence coil U will be producing no flux. However, the phase current I_W is positive and I_V is negative.

Let us see the current position in the coil at positions from 1 to 7. Considering the instantaneous current directions of these three phase winding as shown in Fig 3 at position 1 we can indicate the current direction in Fig 4.

For convenience the +ve current is shown as + and the –ve current is shown as – in Fig 4. Accordingly V_2 and W_1 are shown as positive and V_I and W_2 are shown as negative. Using Maxwell's corkscrew rule, the resulting flux by these currents will produce a flux as shown in Fig 4(1) and the arrow shows the direction of the magnetic field and the magnetic poles with the stator core.

At position 2, as shown by Fig 4(2), 60 electrical degrees later phase current I_W is now zero, the current I_U is positive and the current I_V is negative. From Fig 4 the current is now observed to be flowing into the conductors at coil ends U_1 and V_2 and out of the conductors at coil U_2 and V_1. Therefore, as shown in Fig 4(2) the resultant magnetic poles are now at new positions in the stator core. In fact the poles in position 2 have also rotated 60^o from position (1).

Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7 it will be seen that for each successive increment of 60 electrical degrees, the resultant stator field will rotate a further 60° as shown in Fig 4 from 1 to 7 positions. Note that the resultant flux from position (1) to position (7) for each cycle of applied voltage the field of the two- pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings placed 120^o electrical degrees apart and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed and depends upon the frequency of supply and the number of poles for which the stator is wound.

$$\text{Hence } N_s = \text{Synchronous speed in rpm}$$

$$= \frac{120f}{P}$$

where P is the number of poles in the stator, and f is the frequency of the supply.

Construction and characteristics of 3-phase squirrel cage induction motor

Objectives: At the end of this lesson you shall be able to
- **describe the construction of a 3-phase squirrel cage induction motor**
- **explain slip, speed, rotor frequency, rotor copper loss, torque and their relation.**

Three-phase induction motors are classified according to their rotor construction. Accordingly we have two major types.

- Squirrel cage induction motors
- Slip ring induction motors.

Squirrel cage motors have a rotor with short circuited bars whereas slip ring motors have wound rotor having three windings connected in star. The terminals of the rotor windings of the slip ring motor are brought out through slip rings which are in contact with stationary brushes.

Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency.

For certain application of loads where high starting torque and lower running torque are necessary, then the rotor resistance should be high at the time of starting and needs to be low while the motor is running. If the motor circuit is left with high resistance the rotor copper loss will be more, resulting in low speed and poor efficiency. Hence, it is advisable to have low resistance in the rotor while in operation.

Both these requirements are possible in slip ring motors by adding external resistance at the start and cutting it off while the motor runs. As this is not possible in squirrel cage motors, the above requirements are met by developing a rotor called double squirrel cage rotor where there will be two sets of short circuited bars with high resistance in the top bar and low resistance in the bottom bar.

Stator of an induction motor

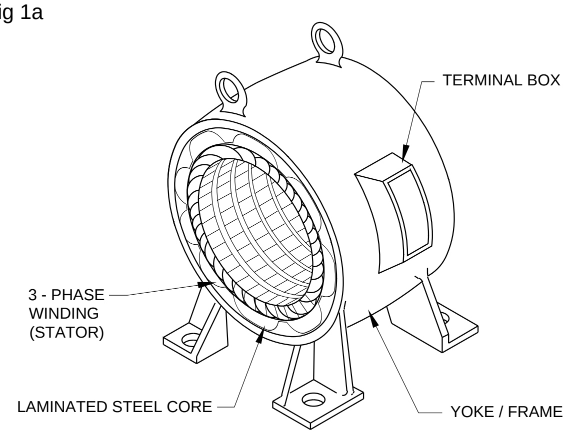
There is no difference between the squirrel cage and slip ring motor stators.

The induction motor stator resembles the stator of a revolving field three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1a. The phase windings are placed 120 electrical degrees apart and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Rotor of a squirrel cage induction motor

The rotor of the squirrel cage motor shown in Fig 1b contains no windings; instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end ring at either end of the rotor core.

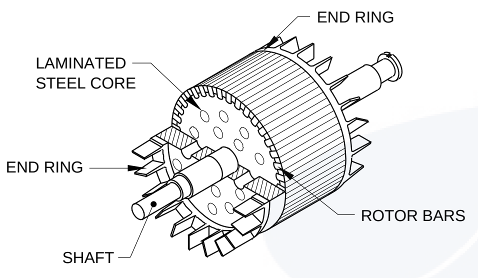
Fig 1a



STATOR ASSEMBLY

On large machines these conductor bars and the end rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig 2. On small machines the conductor bars and end rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

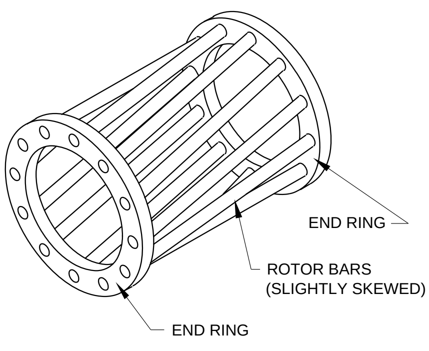
Fig 1b



CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

The rotor or the rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason the stator is sometimes called the primary and the rotor is referred to as secondary of the motor. Since the motor operates on the principle of induction and the construction of rotor with the bars and end rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 2)

Fig 2



DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

The rotor bars are not insulated from the rotor core. Because they are made of metals having less resistance than the core the induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This design feature tends to produce a more uniform rotor field torque, and also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields

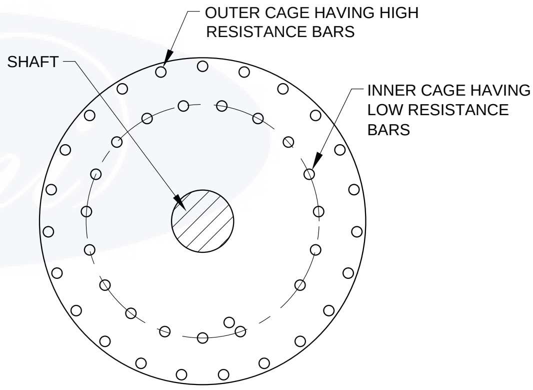
The function of the two end shields is to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

Double squirrel cage motor

Rotor construction and its working

This consists of two sets of conductor bars called outer and inner cages as shown in Fig 3. The outer cage consists of bars of high resistance metal like brass and short circuited by end rings. The inner cage consists of low resistance metal, like copper, bars and short circuited by the end rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

Fig 3



ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables the production of a high starting torque.

As the speed increases, the rotor frequency reduces. At low frequency, the total resistance offered for the current flow in the inner cage reduces due to reduction of reactance ($X_L = 2\pi f_r L$), and the major part of the rotor current will be in the inner cage rather than in the high resistance outer cage.

As such the low resistance of the inner cage becomes responsible for producing a torque just sufficient to maintain the speed.

Slip and rotor speed

In the earlier discussions we found that the rotor of an induction motor must rotate in the same direction as the rotating magnetic field, but it cannot rotate at the same speed as that of the magnetic field. Only when the rotor runs at a lesser speed than the stator magnetic field, the rotor conductors could cut the stator magnetic field, an emf could be induced, rotor current could flow and the rotor magnetic field will set up to produce a torque.

The speed at which the rotor rotates is called rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the 'slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed it is called fractional slip.

Therefore,

$$S = \frac{N_s - N_r}{N_s}$$

$$\left(\begin{matrix}\text{Then percentage slip} \\ \text{(\% slip)}\end{matrix}\right) S = \frac{N_s - N_r}{N_s}$$

where

N_s = Synchronous speed of the stator magnetic field

N_r = actual rotating speed of the rotor in rpm.

Most squirrel cage induction motors will have a slip of 2 to 5 percent at the rated load.

Example

Calculate the percentage slip of an induction motor having 4 poles fed with 50 cycles supply rotating with actual speed of 1400 rpm.

Given:

Poles = 4

N_r = Rotor speed = 1400 rpm.

f = frequency of supply = 50 Hz

N_s = Synchronous speed = 120 f/P

$$= \frac{120 \text{ x } 50}{4} = 1500 \text{ rpm}$$

$$\% \text{ Slip} = \frac{N_s - N_r}{N_s} \text{ x } 100$$

$$= \frac{1500 - 1400}{1500} \text{ x } 100 = 6.6 \text{ \%}$$

Generated voltage in the rotor and its frequency

As the rotor cuts the stator flux, it induces voltage in the rotor conductors and it is called rotor voltage. The frequency of this rotor voltage is equal to the product of, slip and stator (supply) frequency.

Frequency of the rotor voltage

f_r = Fractional slip x Stator frequency

$$= \frac{N_s - N_r}{N_s} \text{ x } f_s$$

From the above formula, we find that at the time of starting, the rotor is at rest, the slip will be equal to one and the rotor frequency will be the same as the stator frequency. When the motor is running at high speed the slip will be low, and the frequency of the rotor will also be low.

Example 1

A 3-phase induction motor is wound for 6 poles and is supplied from a 50 Hz supply. Calculate a) the synchronous speed b) the speed of the rotor when the slip is 5 percent and c) the rotor frequency.

$$\left(\begin{matrix}\text{Synchronous} \\ \text{Speed}\end{matrix}\right) = N_s = \frac{120f}{P}$$

$$= \frac{120 \text{ x } 50}{6} = 1000 \text{ rpm}$$

To Find the actual speed of the rotor N_r

$$\text{Percentage slip} = \frac{N_s - N_r}{N_s} \text{ x } 100$$

$$\text{i. e. } N_s - N_r = \frac{N_s \text{ x Percentage Slip}}{100}$$

$$\text{i. e. } N_r - N_s = \frac{N_s \text{ x \% slip}}{100}$$

$$= 1000 - \frac{1000 \text{ x } 5}{100}$$

= 950 rpm

Rotor frequency (f_r) = Slip x Stator frequency (f_S)

$$= \frac{N_s - N_r}{N_s} \text{ x } f_s$$

$$= \frac{(1000 - 950)50}{1000}$$

$$= \frac{50 \text{ x } 50}{1000} \text{ 2.5 Hz}$$

Rotor copper loss

Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

The above statement could be reduced to the following formula:

Rotor copper loss = Fractional slip x Input power to the rotor

$= S \times 2\pi n_S T.$

Torque

The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current; similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

This statement can be reduced to a formula

$$T \alpha \frac{S K E_1^2 R_2}{R_2^2 + S^2 \text{ x } 2^2}$$

$$T \alpha \frac{\text{Rotor copper loss}}{\text{Fractional Slip}}$$

$$\text{Starting torque } \alpha \frac{R_2}{R_2^2 + X_2^2}$$

as fractional slip S = 1 at the time of starting. Where X_2 is the inductive reactance of the rotor at standstill and is a constant.

To obtain maximum torque at the time of starting the rotor resistance R_2 should be equal to the rotor inductive reactance X_2. For this the rotor resistance should be higher. But higher rotor resistance reduces running efficiency of the motor.

Motor torque calculation

Since the stator flux and induced rotor current for an induction motor are not easily measured, the torque equation $T = K \text{ø}_s I_R \text{ Cos } q$ is not the most practical equation to be used for determining the motor torque. Instead the Prony Brake torque equation described earlier may be used, provided the motor's output power and Rev/min are known.

Output power in watts

$$= \frac{2\,\pi \text{ torque x Rev/min}}{60}$$

$$\left(\begin{matrix}\text{Torque}\\ \text{in Nm}\end{matrix}\right) = \frac{(60 \text{ x Output Watts})}{(2\,\pi \text{ Rev/min})}$$

$$= \frac{(9.55 \text{ x Output watts})}{(\text{Rev/min})}$$

A motor's power may also be stated in British horsepower (hp). In this case the output power in watts will be equal to the output horsepower multiplied by 746 (1 hp = 746w).

In case the motor power is given in metric horsepower the output power in watts will be equal to the metric horsepower multiplied by 735.6 (1 metric horsepower = 735.6 watts).

Example

Determine the torque in newton metres produced by a 2 hp squirrel cage motors rotating at 1440 rpm.

Assuming it is British horsepower

Output power in watts

= hp x 746

= 2 x 746 = 1492 watts.

$$\left(\begin{matrix}\text{Torque}\\ \text{in Nm}\end{matrix}\right) = \frac{(60 \text{ x Output Watts})}{(2\,\pi \text{ Rev/min})}$$

$$= \frac{60 \text{ x } 1492}{2 \text{ x } 3.14 \text{ x } 1440} = 9.9 \text{ Nm}$$

Insulation test on induction motors

Objectives: At the end of this lesson you shall be able to
- **state the method of testing continuity and insulation resistance in a 3-phase induction motor**
- **state the necessity of earthing a 3-phase induction motor**
- **state the NE code and BIS recommendations pertaining to insulation test and earthing of 3-phase induction motors.**

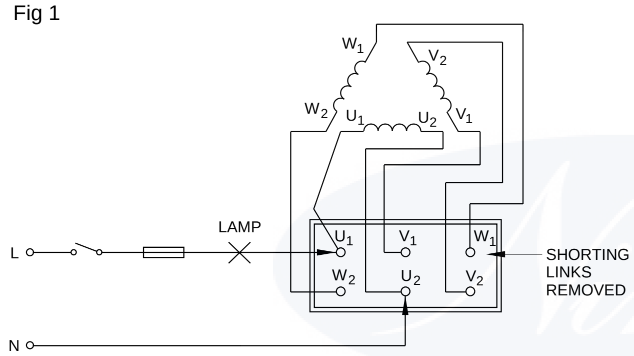
Before conducting the tests, the star connection/ delta connection of windings should be disconnected. At first the continuity test and then insulation resistance test should be carried out.

Continuity test

The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

The test lamp is connected in series with a fuse and a switch to the phase wire and the end is connected to one of the terminals (say U_1 in Fig 1). And the neutral of the supply wire is touched one by one by the other terminals.

Fig 1



CONTINUITY TEST CIRCUIT

The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U_2 in Fig 1). Likewise the other pairs are to be found. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminal shows short between windings.

Limitations of lamp continuity test

However, this test only shows the continuity but will not indicate any short between the turns of the same winding. A better test would be to use an ohmmeter having an accurate low resistance range to measure the resistance of the individual windings. In a 3-phase induction motor the resistance of the three windings should be the same, or more or less equal. If the reading is less in one winding it shows that the winding is shorted.

Method of testing insulation resistance of the electrical motor and the recommended value of the resistance as per National Electrical code

Before putting into operation, any electrical motor must be tested for its insulation resistance. This is to make sure that there is no leakage between the current carrying parts of the motor and the non-current carrying metal parts of the motor. As the insulation resistance may fail during the course of operation due to the reasons mentioned above, it is utmost necessary to check the insulation resistance at intervals, say once in a month for any motor which is in operation, as a preventive maintenance check. These values of insulation resistance must be recorded in the maintenance card and whenever the value goes below the accepted value, the motor winding has to be dried and varnished to improve the conditions.

Condition and acceptable test results

According to NE code, the insulation resistance of each phase winding against the frame and between the windings shall be measured. A megohmmeter of 500 V or 1000 V rating shall be used. The star points should be disconnected while testing.

To avoid accidents due to weak insulations first the insulation resistance value between any conducting part of the machine and the frame of the machine should be tested and the measured value should not be lesser than one megohm as a thumb rule or more precisely should not be less than a value based on the voltage and rated power of the motor as given below in the National Electrical Code.

Insulation resistance $R_i = (20 \times E_n) / (100 + 2P)$

where

R_i - is the insulation resistance in megohms at 25°C

E_n - related phase to phase voltage and

P - rated power in kW.

If the resistance is measured at a temperature different from 25°C, the value shall be corrected to 25°C.

General instruction for the measurement of insulation resistance

The insulation resistance of an electric motor may be in the range of 10 to 100 megohms but as it varies greatly in accordance with the temperature and humidity of the electric motor, it would be difficult to give a definite value. When the temperature of such a motor is raised, the insulation resistance will initially drop considerably, even below the acceptable minimum. If any suspicion exists on this score, motor winding should be dried out, the equation given above being used to calculate the insulation resistance as a standard value. However it should not be less than 1 megohm as an acceptable value.

Secondly, in case of accidental leakage of currents from any current carrying part to non-current carrying metal part, there should be a ground system which should provide minimum impedance path for the faulty (leakage) current to flow. Thereby protective devices like fuses or circuit breakers or earth leakage circuit breakers or earth fault relays would function and disconnect the supply to the defective motor circuit.

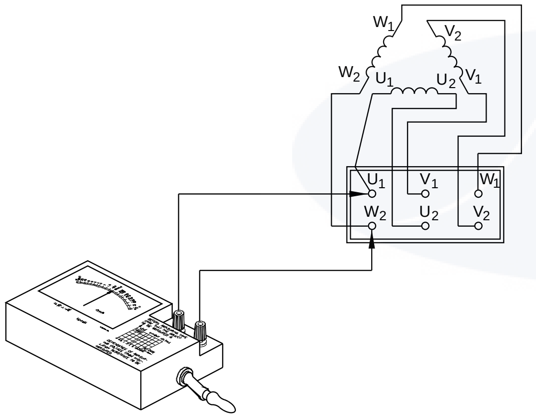
However, this will not be possible unless and until the ground (earth) system has very low impedance. This could be achieved by the following means.

- Using low resistance earth continuity conductors between the frame of the motor and the earth electrode.
- Providing rust-proof metal parts like bolts, nuts and lugs for connecting the earth continuity conductor (ECC) with the frame as well as the main electrode. (Galvanised nuts and bolts are to be used.)
- Keeping the earth electrode resistance value as low as possible such that in case of leakage, any one of the protective systems will operate to isolate the motor from supply.

Insulation test between windings

As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U_1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W_2 in Fig 2).

Fig 2

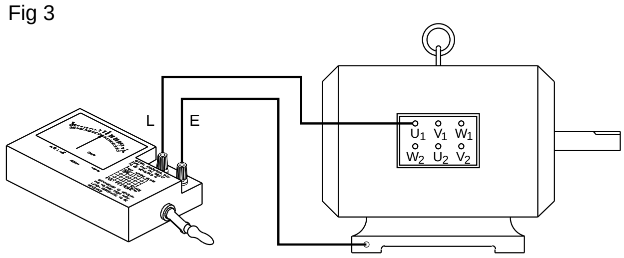


When the Megger is operated, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings and needs to be improved. Likewise the insulation resistances between the other windings are tested and the values are recorded in the maintenance card of the machine.

Insulation resistance between winding and frame

As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger is operated, the reading obtained should be more than one megohm. A reading lower than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Fig 3



Likewise the other windings are tested and the readings are tabulated.

Necessity of frame earthing

The frame of the electrical equipment/machines needs to be earthed because:

- the earthing system provides safety to persons and apparatus against earth faults
- the object of an earthing frame is to provide as nearly as possible a surface under and around the motor which shall be of uniform potential and as nearly as zero or absolute earth potential as possible.

According to I E rules, for reasons of safety, the frame of the motor has to be connected by two distinct earth connections to two earth electrodes with the help of proper sized earth continuity conductors. Further, the earth system resistance (earth electrode 5 ohms and earth continuity conductor one ohm, if not specified) should be sufficiently low such that the protective devices in the motor circuit will operate and isolate the circuit in case of an earth fault.

Starters for 3-phase induction motor, their necessity, basic contactor circuit parts and their functions

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **draw and explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of overload relay, types of overload relays (magnetic and thermal types), construction and method of setting overload relay according to the current rating of motor**
- **state the function of a no-volt coil, its rated voltage, position of operation, common troubles, their causes and remedies**
- **state the method of cleaning contact points of a contactor (starter).**

Necessity of a starter

A squirrel induction motor just before starting is similar to a polyphase transformer with a short circuited secondary. If normal voltage is applied to the stationary motor, then as in the case of a transformer, a very large initial current to a tune of 5 to 6 times the normal current will be drawn by the motor from the mains. This initial excessive current will produce a large line voltage drop, and sometimes cause the motor windings to burn.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then full normal voltage being applied when the motor has run up to speed. For small capacity motors say up to 3 HP, full normal voltage can be applied at start. However, to start and stop the motor, and to protect the motor from overload currents and under-voltages a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters

The following are the types of starters used for starting squirrel cage induction motors.

1 Direct on-line starter

2 Star-delta starter

3 Step down transformer starter

4 Auto-transformer starter

In the above starters except direct on- line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting and regular voltage is applied once the motor picks up the speed.

Selection of a starter

Many factors must be considered when selecting starters. These factors include starting current, full load current voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors

The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. They may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

Contactors shown in Fig 1 consist of main contacts, auxiliary contacts, no-volt coils. As per the Fig 1 there are three sets of normally open main contacts between terminals (1-2), (3-4), (5-6), two sets of normally open auxiliary contacts between terminals (23-24), (13-14), and one set of normally closed auxiliary contact between terminals (21-22). Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push- button stations and O.L. relay as a part but will have to be used as separate accessories along with the contactor to form the starter function.

The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with a fused switch (ICTP), push-button stations OL relay for connecting to a squirrel cage motor for starting directly from the main supply. A direct on-line starter consist of a contactor, OL relay and push-button stations in an enclosure.

Functional Description

Power circuit

As shown in Fig 2, when the main ICTP switch is closed and the contactor K1 is operated, all the three windings U V & W of the motor are connected to the supply terminals L_1, L_2, L_3 via the ICTP switch, contactor and OL relay. This forms the power circuit.

The overload current relay (bimetallic relay) protects the motor from overload ('motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

Fig 1

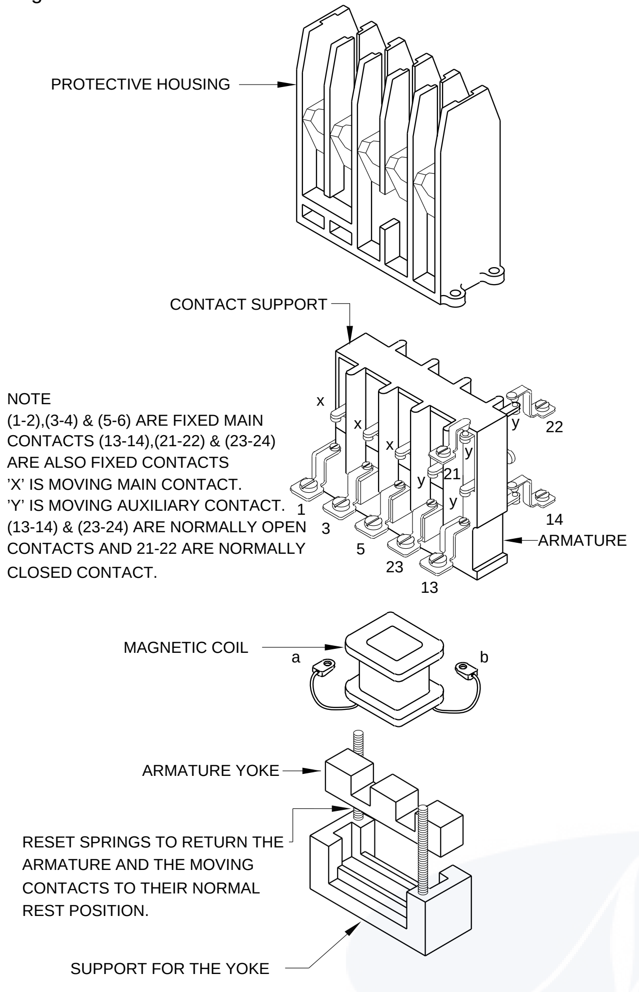
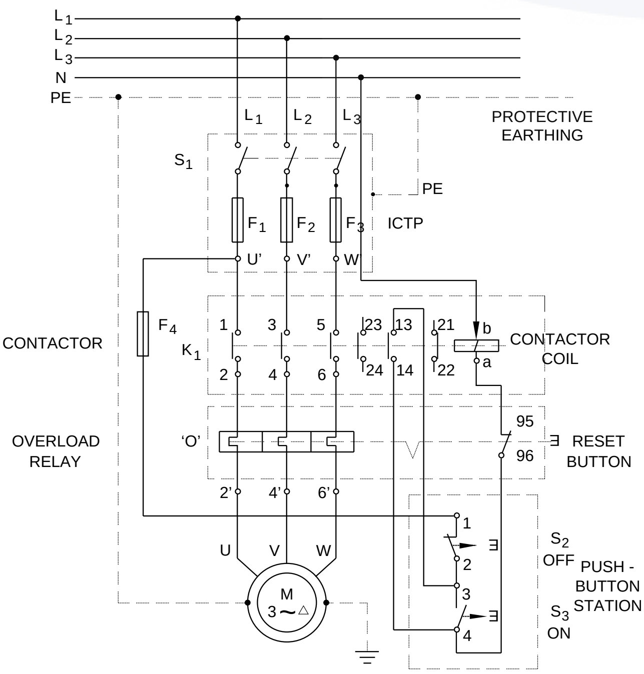


Fig 2

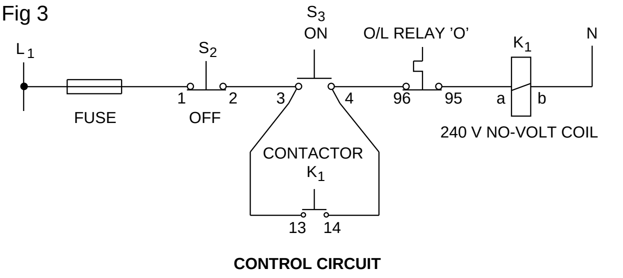


Control Circuits

Push button actuation from one operating location

As shown in the complete circuit in Fig 2, and the control circuit shown in Fig 3, when the 'ON' push button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary normally open contact 1_3,1_4 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3 it is called a self-holding auxiliary contact.

Fig 3



After S_3 is released, the current flows via this self-holding contact 1_3,1_4, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally-closed contact 95 and 96 of overload relay 'O' opens, and switches off the control circuit, thereby K_1 switches 'OFF' the motor circuit.

Once the contact between 95 and 96 is opened due to the activation of the overload relay 'O', the contacts stay open and the motor cannot be started again by pushing the 'ON' button S_3. It has to be reset to normally closed position by pushing the reset button. (Fig 2) In certain starters, the reset could be done by pushing the 'OFF' button which is in line with the overload relay 'O'.

Purpose of overload relays

The overload relays protect the motor against repeated excessive momentary surges, normal overloads existing for long periods, or high currents caused in two phases by a single phasing effect. These relays have such characteristic that the relay opens the contactor in 10 seconds if the motor current is 500 percent of the full load current or in 4 minutes if the current is 150 percent of the full load current.

Types of overload relay

There are two types of overload relays. They are:

- magnetic overload relay
- thermal (bimetallic) overload relay

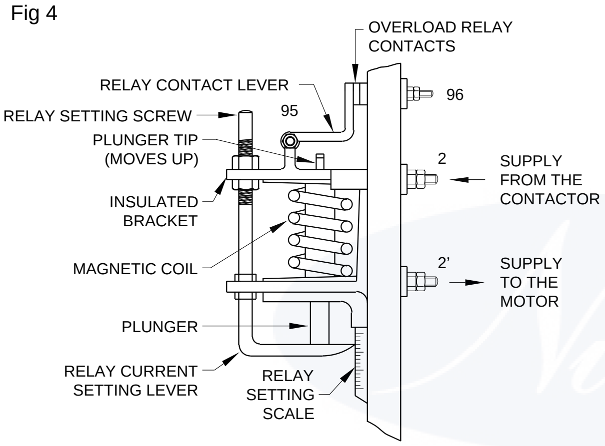
Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing, thereby burning out of the motor winding could be avoided.

Magnetic overload relay

The magnetic overload relay coil is connected in series with the motor circuits as shown in Fig 2. The coil of the magnetic relay must be wound with a wire large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat they are faster than bimetal relays.

As shown in Fig 4 the magnetic coil carries the motor current through terminals 2 and 2' which are in series with the power circuit. The relay contacts 95 and 96 are in series with the control circuit. When a current more than the stipulated value as set by the relay set scale passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in the upward direction. This upward movement makes the plunger tip to push the relay contact lever and the contact between terminals 95 and 96 opens. This breaks the hold on the coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest button (not shown in figure) is pressed.

Fig 4



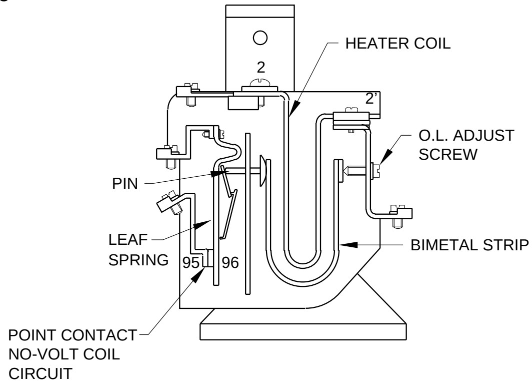
MAGNETIC OVERLOAD RELAY

Bimetallic overload relays

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused together. Movement occurs if one of the metal expands more than the other when subjected to heat. A U-shaped bimetallic strip is used in the relay as shown in Fig 5. The U-shaped strip and a heater element inserted in the centre of the U compartments for possible uneven heating due to variations in the mounting location of the heater element.

As shown in Fig 5, under normal conditions the bimetallic strip pushes the pin against the leaf spring tension and the point contact 95 and 96 are in closed position and hence the no-volt coil circuit is completed while the motor is running. When a higher current passes through the heater coil connected to terminals 2 and 2', the heat generated in the coil heats up the bimetal strip and it bends inward. Hence, the pin retracts to right hand direction and the leaf spring opens the contact 95 and 96 to open the contactor. The relay cannot be reset immediately as the heat in the bimetallic strips requires some time for cooling.

Fig 5



BIMETALLIC OVERLOAD RELAY

Relay setting

The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

For all direct on-line starters, relays should be set to the actual load current of the motor. This value should be equal to or lower than the full load current indicated on the motor name-plate. Here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase the setting to 85% or more till the relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn by a motor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Tripping of starters

A starter may trip due to the following reasons.

a Low voltage or failure of power supply.

b Persistent overload on the motor.

In the first instance, the tripping occurs through the coil which opens the contacts when voltage falls below a certain level. The starter can be restarted as soon as supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and the load becomes normal.

No-volt coil

A no-volt coil consists generally of more number of turns of thin gauge of wire.

Coil voltages

Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24 V, 40 V, 110, 220 V 230/250 V, 380 V 400/ 440 V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor

(Table 1 gives the common symptoms, their causes and remedies)

TABLE 1

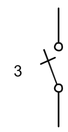
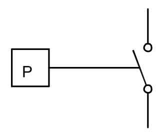
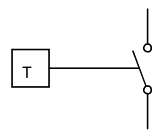
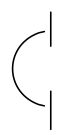
Symptoms	Causes	Remedies
Motor starts when the 'ON' button is pressed. It however stops immediately when the 'ON' button is released.	Auxiliary contact in parallel withthe start button is not closing.	a Check the parallel connection from the 'ON' button terminals to the auxiliary contact of the contactor. Rectify the defect. b Check the, auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective.
Motor does not start when the 'start' button is pressed. However, on pressing the armature of the contactor manually,the motor starts and runs.	Open in no-volt coil circuit.	a Check the main voltage for lower than acceptable value. Rectify the main voltage. b Check the control circuit wiring for loose connection c Check the resistance of the no-volt winding. If found incorrect replace the coil.
Motor does start when the start button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	a Dust or dirt or grit between the mating surfaces of the electromagenetic core. Clean them. b Low voltage supply. Find the cause and rectify the defect. c Break the shading ring in case of AC magnet.
Motor does not restart immedia-tely after tripping of OL relay even though OL relay is reset.	It takes a little time for the thermal bimetal to cool and reset.	Wait for 2-4 minutes before restarting.
Failure of contactor due to too much heating of the no-volt coil.	a Higher incoming rating. b No-volt coil rating is not proper.	a Higher supply voltage than normal. Reduce the incoming voltage. b Voltage rating of the no- volt coil is less. Replace with standard rating according to the main supply.
Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	a Open circuited NVC. b NVC burnt.	a Check the nylon strip on relay. b Check the nylon button below start button. c Replace if necessary.
Humming or chattering noise.	a Low voltage. b Magnetic face between yoke and armature is not clean. c Shading ring on iron core missing.	a Feed rated voltage b Cllean the surfaces of yoke and armature. c Provide shading ring in the core.
Relay coil has been changed, however motor does not start when the start button is pressed.	Control circuit of relay open.	a Check the control circuit for open. b Clean the control station contacts. c Overload relay not set.

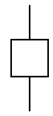
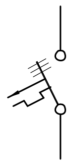
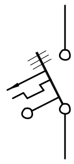
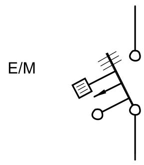
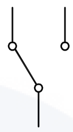
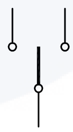
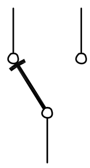
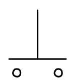
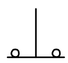
B.I.S. symbols pertaining to contactor and machines

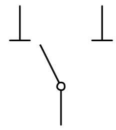
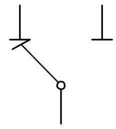
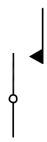
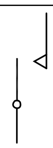
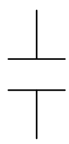
Objectives: At the end of this lesson you shall be able to
- **identify and draw B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).**

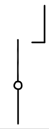
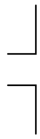
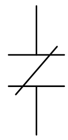
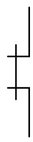
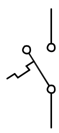
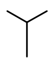
The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.

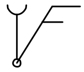
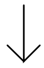
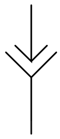
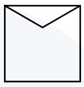
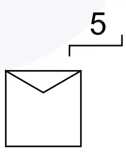
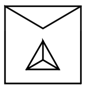
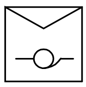
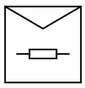
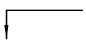
TABLE

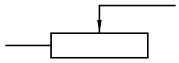
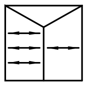
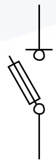
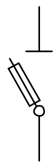
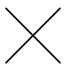
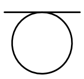
S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 (Part XXV)-1980			
	9	**Switch gear, accessories**		
1	9.1	Switch, general symbol		
2	9.1.1	Alternate symbol for switch.		
3	9.2	Three-pole switch, single line representation.		
4	9.2.1	Alternate symbol for three-pole switch, single line representation.		
5	9.3	Pressure switch		
6	9.4	Thermostat		
7	9.5	Circuit-breaker		
8	9.5.1	Alternate symbol of circuit-breaker. **Note : The rectangle of symbol 9.5 should contain some indication that a circuit-breaker is concerned.**		

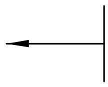
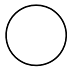
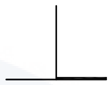
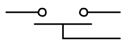
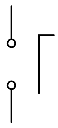
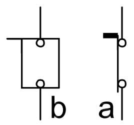
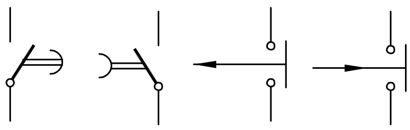
S.No.	BIS Code No.	Description	Symbol	Remarks
9	9.5.2	Alternate symbol for circuit breaker.		
10	9.5.3	Circuit-breaker with short circuit under voltage and thermal overload releases.		
11	9.5.4	Hand-operated circuit-breaker with short circuit, thermal overload protection and no-volt tripping.		
12	9.5.5	Motor - solenoid operated air circuit-breaker with short circuit and no-volt tripping (triple pole).		
13	9.6	Change over contact, break before make. NOTE : The fixed contacts may be placed at any angle except at 60°. In order to facilitate the work of the draughtsman, the contacts may be arranged differently.		
14	9.7	Two-way contact with neutral position		
15	9.8	Make-before-break contact.		
16	9.9	Contactor, normally open.		
17	9.9.1	Contactor, normally closed.		
18	9.10	Push-button with normally open contact.		
19	9.10.1	Push-button with normally closed contact.		

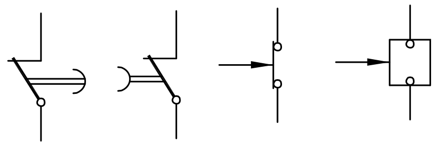
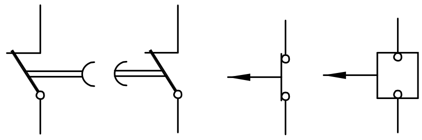
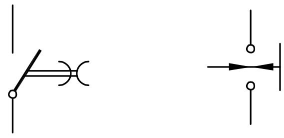
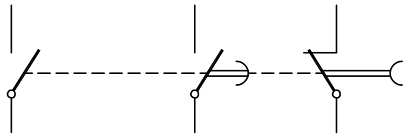
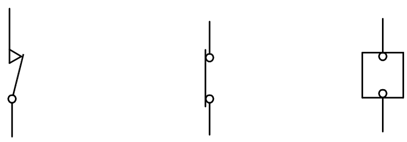
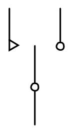
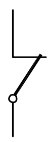
S.No.	BIS Code No.	Description	Symbol	Remarks
20	9.11	Isolator.		
21	9.12	Two-way isolator with interruption of circuit.		
22	9.13	Two-way isolator without interruption of circuit.		
23	9.14	Make contact, general symbol.		
24	9.14.1	Alternate symbol for make contact, general symbol.		
25	9.14.2	Alternate symbol for make-contact.		
26	9.14.3	Alternate symbol for make-contact.		
27	9.14.4	Alternate symbol for make-contact.		
28	9.14.5	Alternate symbol for make-contact.		
29	9.14.6	Alternate symbol for make-contact.		
30	9.14.7	Alternate symbol for make-contact.		

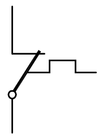
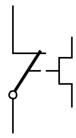
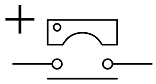
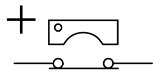
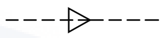
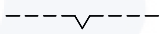
S.No.	BIS Code No.	Description	Symbol	Remarks
31	9.14.8	Alternate symbol for make-contact.		
32	9.14.9	Alternate symbol for make-contact.		
33	9.15	Break-contact, general symbol.		
34	9.15.1	Alternate symbol for break-contact.		
35	9.15.2	Alternate symbol for break-contact.		
36	9.15.3	Alternate symbol for break-contact.		
37	9.15.4	Alternate symbol for break-contact.		
38	9.15.5	Alternate symbol for break-contact.		
39	9.16	Thermal overload contact.		
40	9.17	Socket(female).		
41	9.17.1	Alternate symbol for socket (female).		

S.No.	BIS Code No.	Description	Symbol	Remarks
42	9.17.2	Socket with switch.		
43	9.18	Plug (male).		
44	9.18.1	Alternate symbol for plug (male).		
45	9.19	Plug and socket (male and female).		
46	9.19.1	Alternate symbol for plug and socket (male and female).		
47	9.20	Starter, general symbol.		
48	9.21	Starter by steps (Example: 5 steps).		
49	9.22	Star-delta starter.		
50	9.23	Auto-transformer starter.		
51	9.24	Pole-changing starter (Example, 8/4 poles).		
52	9.25	Rheostatic starter.		
53	9.26	Direct on-line starter.		
54	9.27	Sliding contact, general symbol.		

S.No.	BIS Code No.	Description	Symbol	Remarks
55	9.27.1	Resistor with moving contact, general symbol.		
56	9.28	Combined control panel for two motors (multiple speed and reversible).		
57	9.29	Fuse.		
58	9.29.1	Alternate symbol for fuse.		
59	9.29.2	Alternate symbol for fuse where supply side is indicated by a thick line.		
60	9.29.3	Alternate symbol for fuse where supply side is indicated by a thick line.		
61	9.30	Isolating fuse-switch, switching on load.		
62	9.31	Isolating fuse-switch.		
    63	BIS 2032 Part(XXV11) 1932 3.2 3.2.1	**Contactors** **Qualifying symbols** Contactor function.		
64	3.2.2	Circuit-breaker function.		
65	3.2.3	Disconnector (isolator) function.		
66	3.2.4	Switch-disconnector (isolator switch) function.		

S.No.	BIS Code No.	Description	Symbol	Remarks
67	3.2.5	Automatic release function.		
68	3.2.6	Delayed action. Convention - delayed action in direction of movement from the arc towards its centre. **Note: This symbol must be linked by a double line to the symbol of the device, the action of which is delayed.**		
69	3.2.6.1	Delayed action convention - delayed action in the direction of movement of the arrow mark.		
70	3.2.7	Non-spring return (stay put) function. NOTE : The symbols shown above may be used to indicate spring-return and stay-put contacts. When this convention is invoked, its use should be appropriately referenced. These symbols should not be used together with the qualifying symbols Nos. 3.1 to 3.4.		
71	3.2.8	Hand reset.		
72	3.3.7	Contact with two makes.		
73	3.3.8	Contact with two breaks.		
74	3.3.9	Three-point contact.		
75	3.3.10	Make contact-hand reset.		IR
76	3.3.11	Break contact-hand reset.		IR
77	3.3.19	Make-contact delayed when operating.		

S.No.	BIS Code No.	Description	Symbol	Remarks
78	3.3.20	Break-contact delayed when operating.		
79	3.3.21	Break-contact delayed when releasing.		
80	3.3.22	Make-contact delayed when operating and re-leasing.		
81	3.3.23	Contact assembly with one make-contact not delayed. One make contact delayed when operating and one break-contact delayed when releasing.		
82	3.3.24	Make-contact with spring return.		
83	3.3.25	Make-contact without spring return (stay-put)		SR
84	3.3.26	Break-contact with spring return.		SR
85	3.3.27	Two-way contact with centre off position with spring. Return from the left-hand position but not from the right hand one (stay-put).		
86	3.3.28	Temperature-sensitive make-contact. **Note: May be replaced by the value of the operating temperature conditions.**		
87	3.3.29	Temperature sensitive break-contact. NOTE : may be replaced by the value of the operating temperature conditons.		

S.No.	BIS Code No.	Description	Symbol	Remarks
88	3.3.30	Self-operating thermal-break contact. NOTE : It is important to distinguish between a contact as shown and a contact of a thermal relay, which in detached representation is shown in the example below.		
		Example: Break contact of a thermal relay.		
89	3.3.32	Blow-out magnetic make-contact.		
90	3.3.33	Blow-out magnetic break-contact.		
BIS:2032 (PART VII) 1974		**Mechanical controls**		
91	8.4	**Mechanical interlock**		
92	8.5	Reset a Automatic reset		
		b Non-automatic reset **Note : These symbols should be used only if it is essential to indicate the type of reset.**		

Direct-On-Line (DOL) starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a DOL starter; explain its operation, and its application**
- **explain the necessity of back up fuse and their rating according to the motor rating.**

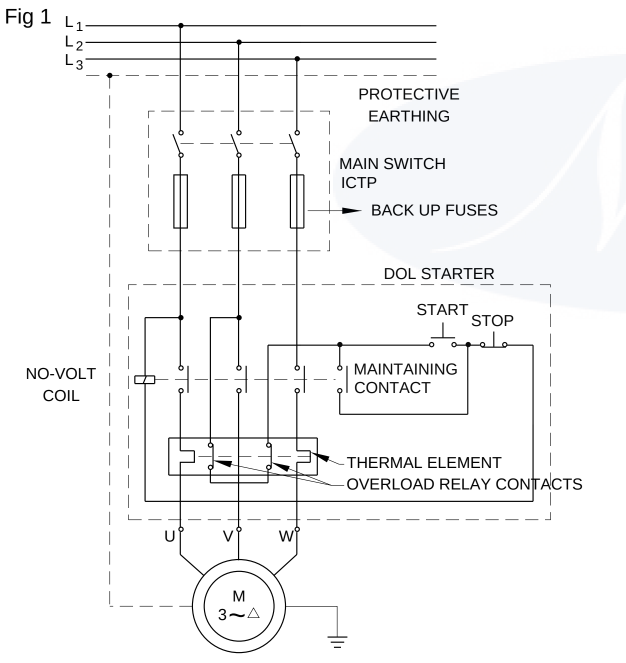
A DOL starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation

A push-button type direct on-line starter, which is very common in use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 3.4.03 and the DOL starter except that the DOL starter is enclosed in a metal or PVC case and in most cases the no-volt coil is rated for 415 V and to be connected across two phases as shown in Fig 1.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Further the over load relay can be situated between the ICTP switch and contactor or between the contactor and the motor as shown in Fig 1 depending upon the starter design. Trainees are advised to write the working of the DOL starter on their own by going through the explanation given in Exercise 3.4.03 which is for a complete contactor circuit.

Specification of DOL starters

The following data are to be given in the specification of a DOL starter.

- Phases - single or three.
- Voltage 240 or 415 V.
- Current rating 10, 16, 32, 40, 63, 125 or 300 amps.
- No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.
- Number of main contacts 2, 3 4 which are normally open.
- Number of auxiliary contacts 2 or 3, 1 NC + 1 NO or 2 NC + 1 NO respectively.
- Push-button one ‘ON’ and one ‘OFF’ button. Overload setting - Amp to - Amp. Enclosure metal sheet or PVC.

Applications

In an induction motor with a DOL starter, the starting current will be about 6 to 7 times the full load current. As such, DOL starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Necessity of back up fuses

Motor starters must never be used without back up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays due to their inherent operating mechanism take a longer time to operate and open the circuit.

Such delays will be sufficient to damage the starter, motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick action, high rupturing capacity fuses which when used in the motor circuit, operate at a faster rate and open the circuit.

Hence, HRC diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits the back up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for different motor rating are given below.

It is recommended that the use of semi-enclosed, rewirable tinned copper fuses may be avoided as far as possible.

Table of relay ranges and back up fuses for motor protection

Sl. No.	Motor 240 V	Ratings Single Phase	Motor 415 V	Ratings 3-Phase	Relay range A	Nominal back up fuse recom-mended
	hp	kW	hp	kW		
1	–	–	0.05	0.04	0.15 - 0.25	1 A
2	0.05	0.04	0.1	0.075	0.25 - 0.4	2 A
3	–	–	0.25	0.19	0.6 - 1.0	6 A
4	0.125	0.11	0.50	0.37	1.0 - 1.5	6 A
5	0.25	0.18	1.0	0.75	1.5 - 2.5	6 A
6	0.5	0.4	1.5	1.1	2.5 - 4.0	10 A
7	–	–	2.0	1.5	2.5 - 4.0	15 A
8	0.75	0.55	2.5	1.8	4.0 - 6.5	15 A
9	–	–	3.0	2.2	4.0 - 6.5	15 A
10	1.0	0.75	5.0	3.7	6.0 - 10.0	20 A
11	2.0	1.5	7.5	5.5	9.0 - 14.0	25 A
12	3.0	2.25	10.0	7.5	10.0 - 16.0	35 A

Note: Fuses up to and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).

Jogging (inching) control circuits for motors - Rotary switches

Objectives: At the end of this lesson you shall be able to
- **define the process of jogging/inching control**
- **state the purpose of jogging/inching control**
- **describe the operation of a jogging control using a selector switch**
- **describe the operation of a jogging control using push-button station**
- **describe the operation of a jogging control using a control relay.**

Jogging (inching)

In some industrial applications, the rotating part of a machine may have to be moved in small increments. This could be done by a control system called jogging (inching).

Jogging is defined as the repeated closure of the circuit to start a motor from rest, producing small movements in the driven machine. By pressing the jog push-button the magnetic starter is energised, and the motor runs; when the jog push-button is released, the motor stops.

When a jogging circuit is used, the motor can be energised only as long as the jog button is depressed. This means the operator has instantaneous control of the motor drive.

Purpose of jogging/inching controls

Normally jogging (inching) controls are incorporated in the following machines for operational convenience shown against each.

1 Lathe machine controls - for checking the trueness of the job and setting the tool initially.

2 Milling machine controls - for checking the concentric running of the cutter at the initial setting and also to set the graduated collar for depth of feed of the cutter.

3 Grinding machine controls - for checking proper mounting of the wheel.

4 Paper cutting machines - for adjusting the cut.

Apart from the above, the inch control is the prime control in cranes, hoists and conveyor belt mechanism so that incremental movements either vertically or horizontally could be achieved in the driven machinery.

Jogging may be accomplished by the following methods.

1 Selector switch

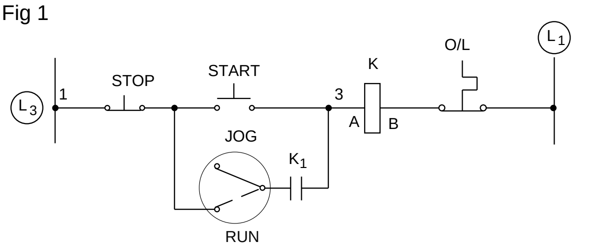
2 Push-button, and

3 Push-button with a jog relay.

Jogging control using a selector switch

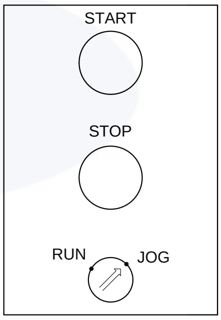
By using a selector switch, the existing start button can be used as a jogging push-button in addition to its function as a starting push-button. The holding contact of the

Fig 1



CONTROL CIRCUITS WITH JOG-RUN SELECTOR SWITCH.

Fig 2



A PANEL OF A STATION IN WHICH THE START BUTTON CAN BE USED FOR INCHING OR JOGGING.

contactor which is in parallel to the start button is disconnected when the selector switch is placed in the jog position as shown by the circuit in Fig 1 and the panel layout in Fig 2.

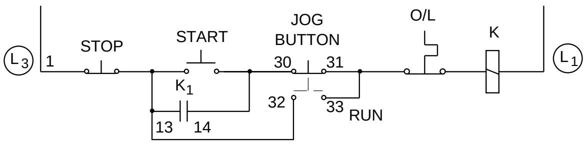
The motor can be started or stopped by jogging/inching the start button. The motor will operate as long as the start button is held pressed.

Jogging control using a push-button

Fig 3 shows the control circuit of a DOL starter connected to a start - jog - stop push-button station. When the start push-button is pressed coil K is energised as the no-volt coil circuit is complete through the normally closed ‘jog’ button contacts 30 & 31, thereby closing the main contactor, and the motor runs. The self-holding auxiliary contact K_1 between terminals 13 and 14 gets closed and keeps the no-volt coil circuit in function though the start button is released.

As soon as the jog push-button is pushed, as the circuit of the no-volt coil opens initially, the contactor is de-energised and the motor stops if it is running. Then the jog button closes the bottom contacts 32 & 33, thereby the no-volt coil circuit closes and the motor runs as long as the jog button is held pressed. By pushing and releasing the jog button repeatedly, the motor starts and stops causing the driven machinery to 'inch' forward to the desired position. On the other hand pressing the start button will make the motor to run normally.

Fig 3

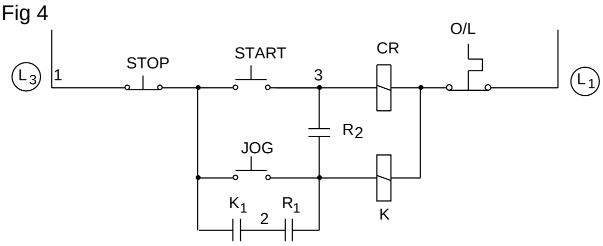


CONTROL CIRCUIT WITH JOG PUSH-BUTTON

Jogging control using a relay

Fig 4 shows the control circuit of a DOL starter connected to a control relay with other usual components. When the start button is pressed, the control relay coil CR is energised and closes the contacts R_1 and R_2, thereby momentarily completing the no- volt coil 'K' circuit through

Fig 4



LINE DIAGRAMS USING CONTROL RELAYS FOR JOGGING

relay contact R_2. This in turn closes the self-holding auxiliary contact K_1 of the no-volt coil relay K and the motor runs continuously even though the pressure on the start button is released.

When the motor is not running, if the jog button is pressed the no-volt coil K circuit is completed, and the motor runs only as long as the jog button is held pressed as the holding circuit through R_1 is not completed for the starter coil since the control relay CR is not energised.

For a 3-phase DOL starter, having a jog control through relay, four normally open contacts (3 for main 1 for auxiliary) are required and the control relay should have two normally open contacts as shown in Fig 4.

Rotary type switches

Objectives: At the end of this lesson you shall be able to

- **explain the type of rotary switches - specification like voltage rating, current rating, poles, function, position, type of mounting type of handle, number of operations per hour and special requirements, if any**
- **draw and explain the schematic diagram of rotary switches along with connection diagram of motors for ON/OFF three-pole switch, forward stop and reverse three-pole switch, star-delta switch and pole changing switch.**

Rotary switches are most commonly used in lathes, and milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which, in turn, operate cams inside the switch to contact the various terminals in sequence by the internal contact blocks. These cams and blocks are made from hard PVC and designed to withstand many operations. Combining various cams and variety of contact blocks, many circuit combinations are possible.

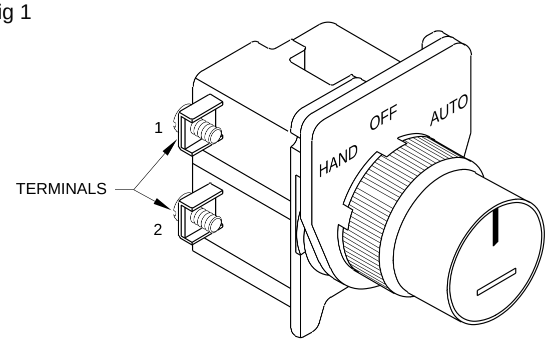
As the contact blocks, terminals and the cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs.

These rotary switches are classified according to a) poles b) function c) position d) mounting type e) handle design and f) frequency of operations.

Poles

According to the number of independent connecting terminals and operation they are called 2-pole (single phase, refer to Fig 1) or 3-pole (3-phase, refer to Fig 2) switches.

Fig 1



250 V AC 15 AMPS 2-POLE THREE POSITION
FLUSH MOUNTING COIN-SLOT OPERATOR

Function

Rotary switches can do a number of functions depending upon the cam and contact block combinations. Accordingly they can be

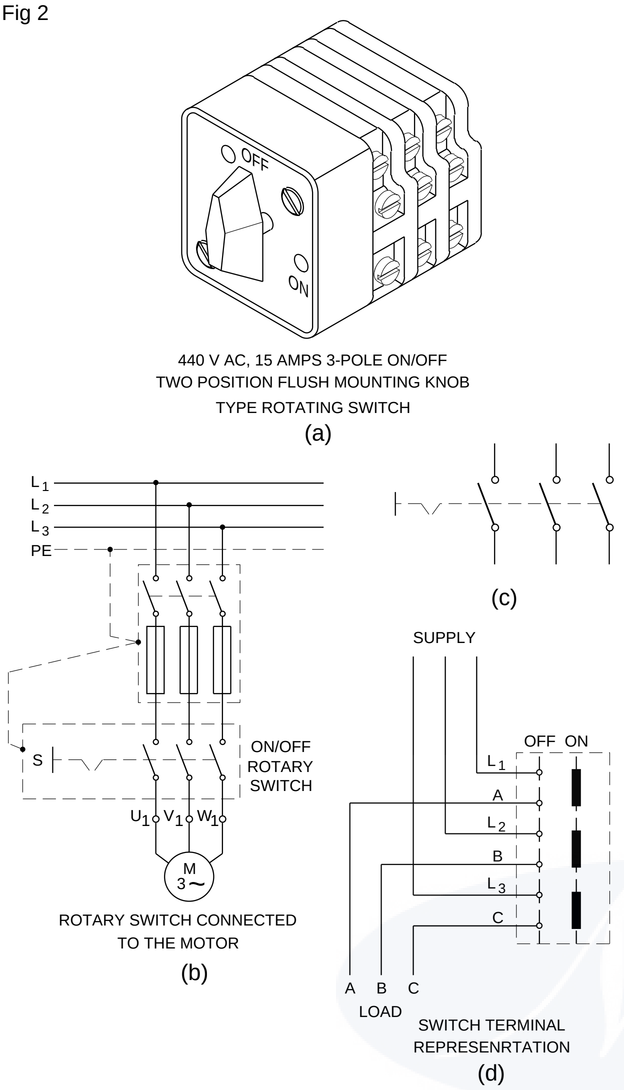
a ON/OFF switches(Fig 2a)

b manual forward/reversing switches (Fig 3a)

c manual star-delta switches (Fig 4a)

d pole changing switches for speed control (Fig 5a).

Fig 2



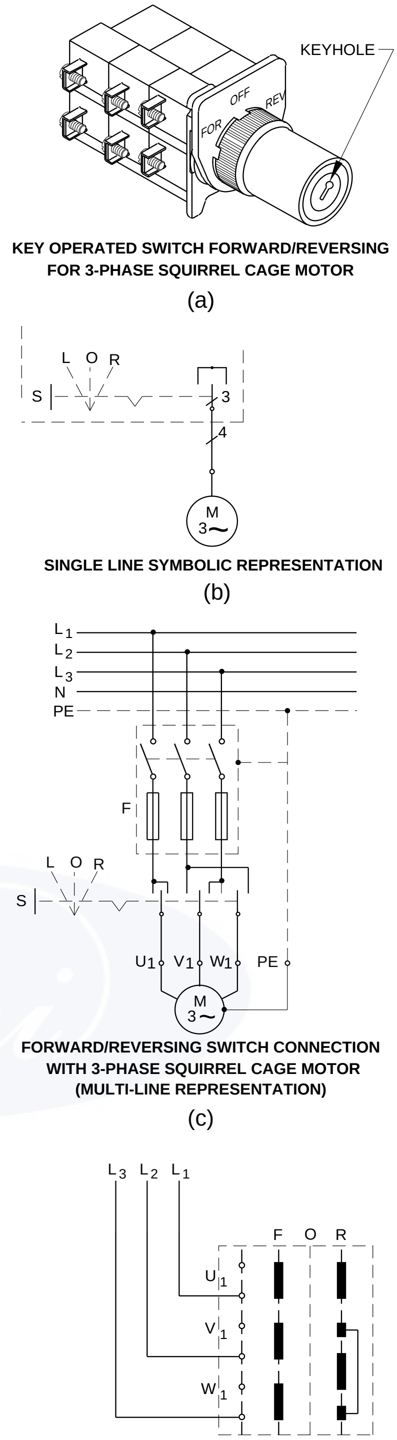
440 V AC, 15 AMPS 3-POLE ON/OFF
TWO POSITION FLUSH MOUNTING KNOB
TYPE ROTATING SWITCH
(a)

ROTARY SWITCH CONNECTED
TO THE MOTOR
(b)

(c)

SWITCH TERMINAL
REPRESENRTATION
(d)

Fig 3



KEY OPERATED SWITCH FORWARD/REVERSING
FOR 3-PHASE SQUIRREL CAGE MOTOR
(a)

SINGLE LINE SYMBOLIC REPRESENTATION
(b)

FORWARD/REVERSING SWITCH CONNECTION
WITH 3-PHASE SQUIRREL CAGE MOTOR
(MULTI-LINE REPRESENTATION)
(c)

SWITCH TERMINAL REPRESENTATION
(d)

In addition to the above voltmeter/ammeter selector switches, 4-position air conditioner switches are also available.

Position

Selector switches of rotary type are available in two (Fig 2), three (Figs 1, 3 and 4) and four positions. They provide maintained or spring return momentary control operation. Two position and three position switches can either be maintained or spring-returned whereas four position switches are maintained in all four positions.

Mounting type

According to the requirement we may select any one of the types for mounting

a Surface mounting type

b Flush mounting type (Fig 1)

c Box mounting type (Fig 4)

Handle design

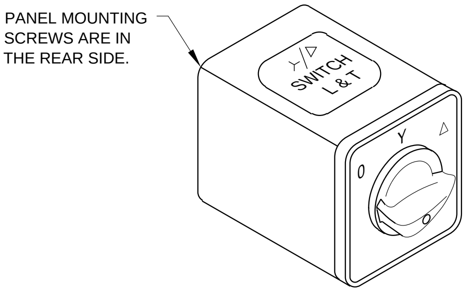
According to the case of operation the operation could be done by a

- knob (Fig 2a)
- lever (Fig 5a)
- coin slot (Fig 1) and
- key operation (Fig 3a).

Frequency of operation

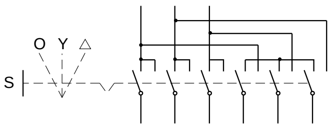
The number of operations of these switches per hour is specified in BIS 10118 (Part II) 1982. The details given below are taken from the BIS.

Fig 4

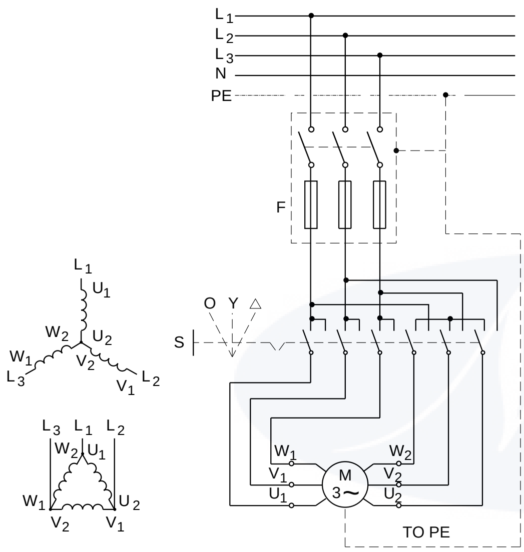


MANUAL STAR-DELTA SWITCH

(a)

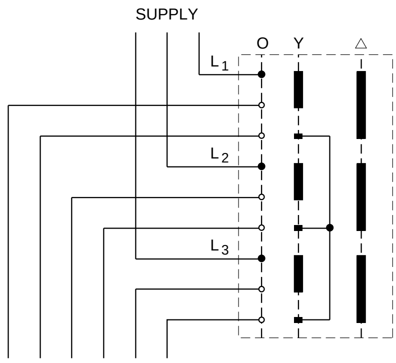


(b)



CIRCUIT DIAGRAM CONNECTED THROUGH STAR/DELTA SWITCH TO A MOTOR

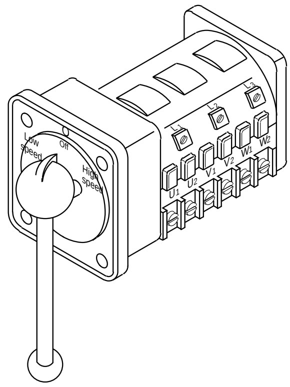
(c)



STAR-DELTA ROTATING SWITCH TERMINAL REPRESENTATION

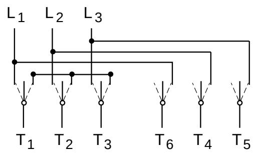
(d)

Fig 5

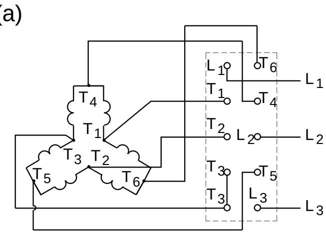


POLE CHANGING SWITCH

(a)

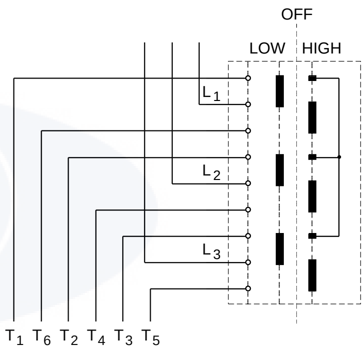


(b)



CONNECTIONS FOR MOTOR AND CONTROLLER OF A TWO-SPEED,CONSTANT-TORQUE INDUCTION MOTOR

(c)



SWITCH TERMINALS REPRESENTATION

(d)

Sl.	Description per hour	Operations
1	On-Off and system selector switch	Up to 150 times
2	Pole changing switch	Up to 150 times
3	Manual star-delta switch	Up to 30 times
4	Speed control switch	Up to 150 times

Specification

Specification of rotary switches should contain the following information for procurement from the market.

Working voltage and type of supply (AC or DC)

- Load current
- Poles
- Function
- Position of operation
- Type of mounting
- Desired handle type
- Frequency of operation
- Accepted maximum dimensions
- Type of casing

Schematic diagram of rotary switches

ON/OFF switch

These switches are used for 3-phase squirrel cage motor for direct starting which is symbolically represented by Fig 2c. The complete connection diagram shown in Fig 2b and Fig 2a shows the normal appearance of such a switch, with a knob type handle having box mounting type body.

Fig 2d shows a manufacturer's catalogue representation of an ON/OFF switch.

Manual forward-reversing switch

These switches are used for forward and reverse running operation of the squirrel cage induction motors. A symbolic representation is shown in Fig 3b, the complete circuit diagram is shown in Fig 3c and Fig 3a shows the normal appearance of such a switch, key operated type having box type enclosure mounting.

Fig 3d shows a manufacturer's catalogue representation of a forward/reversing rotary switch.

Manual star-delta starter switch

These switches are used for starting a 3-phase squirrel cage induction motor in star position and to run it in delta position.

Fig 4b shows the symbolic representation of the star-delta manual switch; the complete diagram of connection to the 3-phase induction motor is shown in Fig 4c, and Fig 4a shows the normal appearance of such a starter switch with knob operation having box type body. Fig 4d shows the manufacturer's catalogue representation of a manual star-delta rotary switch.

Pole changing rotary switch

This is used for changing the speed of a three-phase squirrel cage induction motor from one speed to another with the help of either two separate windings or by six windings arranged for series delta (low speed) or parallel star (high speed) connection.

Fig 5b shows the symbolic representation of the pole changing rotary switch, Fig 5c shows the complete connection diagram of the pole changing switch with motor winding and Fig 5a shows the normal appearance of such a switch with lever operation.

Fig 5d shows the manufacturer's catalogue representation of the pole changing rotary switch terminals.

Manual star-delta switch/starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **draw and explain the construction, connection and working of star-delta switch and starter**
- **specify the back up rating of the fuse in the motor circuit**
- **compare the voltages across the windings of the motor, current taken, power absorbed and torque produced in the star and delta positions of the starter.**

Necessity of star-delta starter for a 3-phase squirrel cage motor

If a 3-phase squirrel cage motor is started directly it takes about 5 to 6 times the full load current for a few seconds and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However, with large capacity motors, the starting current will cause too much voltage fluctuation in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting period and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at start.

- Star-delta switch or starter
- Auto-transformer starter
- Step down transformer starter

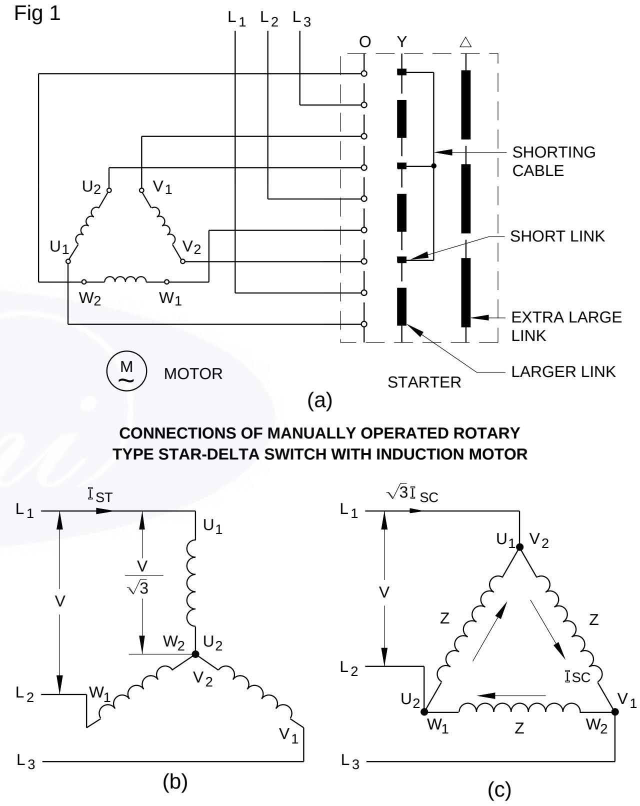
Star-delta starter

A star-delta switch is a simple arrangement of a cam switch which may have an overload relay and under-voltage protection in addition to fuse protection. In a star-delta switch/starter at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to1/ time the line voltage and when the motor picks up its speed the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L_1, L_2 and L_3 are connected to the beginning of windings U_1, W_1 and V_1 respectively by the larger links whereas the short links which connect V_2, U_2 and W_2 are shorted by the shorting cable to form the star point. This connection is shown in Fig 1b as a schematic diagram.

When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1, U_2 and V_1 W_2 respectively by the extra large links to form the delta connection. (Fig 1c)

Fig 1



Manual star-delta starter

Fig 2 shows the conventional manual star-delta starter. As the insulated handle is spring loaded it will come back to the OFF position from any position unless and until the no-volt (hold on) coil is energised. When the hold on coil circuit is closed through the supply taken from U_2 and W_2, the coil is energised and holds the plunger, and thereby, the handle is held in the delta position against the spring tension by the lever plate mechanism.

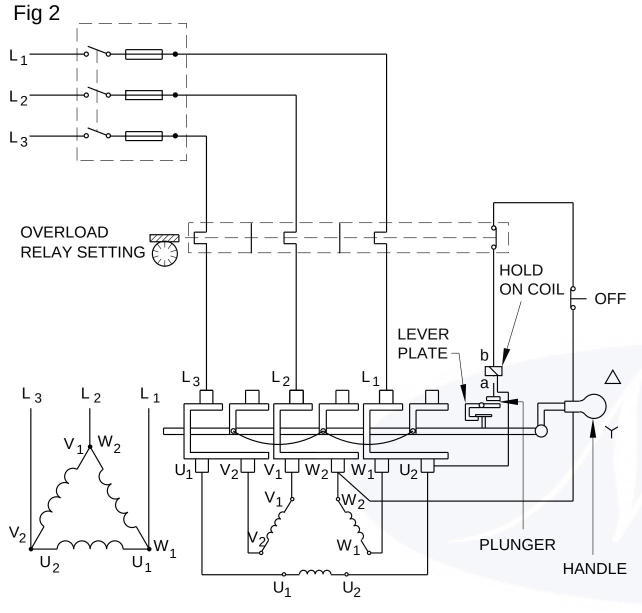
When the hold on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in the delta position in the first moment until and unless the handle is brought to star position first and when the motor picks up speed, the handle is pushed to the delta position.

The handle has a set of baffles insulated from each other and also from the handle.

When the handle is thrown to the delta position the larger end of the baffle connects the main supply line L_1, L_2 and L_3 to the winding terminals U_1V_2, V_1W_2 and W_1U_2 respectively to form the delta connection. (Fig 2)

When the handle is thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to the beginning of the 3-phase winding U_1, V_1 and W_1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 through the shorting cable to form the star point. (Fig 2)

Fig 2



STAR--DELTA SWITCH IN DELTA POSITION

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold on the coil circuit, and thereby, the coil is de-energised, and the handle returns to the off position due to the spring tension.

The motor also could be stopped by operating the stop button which in turn de-energises the hold on the coil.

Back up fuse protection

Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415 V 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example 10 HP 3-phase 415 V motor will have approximately 15 amps as its full load current.

However, to avoid frequent blowing of the fuse and at the same time for proper protection the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence, for 10 HP 15 amps motor the fuse rating will be 23 amps or say 25 amps.

Comparison of impact of star and delta connections on starting current and torque of the induction motor

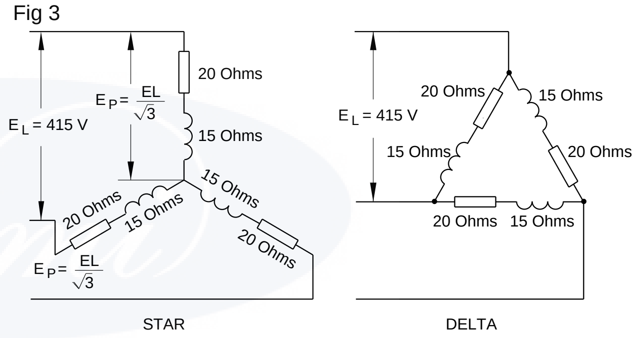
When the three-phase windings of the squirrel cage motor are connected in star by the starter, the phase voltage across each winding is reduced by a factor of $1/\sqrt{3}$ of the applied line voltage (58%), and hence, the starting current reduces to 1/3 of that which would have been drawn if the motor were directly started in delta. This reduction in starting current also reduces the starting torque to 1/3 of the starting torque which would have been produced in the motor if it was started directly in delta.

The above statement could be explained through the following example.

Example 1

Three similar coils of the 3-phase winding of a squirrel cage induction motor each having a resistance of 20 ohms and an inductive reactance of 15 ohms, are connected in (a) star (b) delta through a star-delta starter to a 3-phase 415 V 50 Hz supply mains. Calculate the line current and total power absorbed in each case. Compare the torque developed in each case.

Fig 3



Solution

Impedance per phase = Z_{ph}

$$Z_{ph} = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{20^2 + 15^2} = 25\Omega$$

$$\begin{pmatrix}\text{Star}\\\text{Connection}\end{pmatrix} \quad E_{ph} = \frac{E_L}{\sqrt{3}} = \frac{415}{\sqrt{3}}$$

$$= 239.6 = 240 \text{ V}$$

$$I_{ph} = \frac{E_{ph}}{Z_{ph}} = \frac{240}{25} = 9.6 \text{ amps}$$

$$\begin{pmatrix}\text{Power}\\\text{absorbed}\end{pmatrix} = \sqrt{3}\, E_L\, I_L \text{ Cosø}$$

$$= \sqrt{3} \text{ x } 415 \text{ x } 9.6 \text{ x } 1$$

Assuming PF = 1

we have 6900 watts in star connection:

Delta connection

$E_{ph} = E_L = 415$ V

$$I_{ph} = \frac{E_{ph}}{Z_{ph}} = \frac{415}{25} = 16.6 \text{ amps}$$

$$I_L = \sqrt{3}\, I_{ph} = 1.732 \text{ x } 16.6$$

= 28.75 amps

$$\begin{pmatrix}\text{Power}\\ \text{absorbed}\end{pmatrix} = \sqrt{3} \text{ x } E_L\ I_L\ \text{Cosø}$$

(assume PF = 1)

$$= \sqrt{3} \text{ x } 415 \text{ x } 28.75 \text{ x } 1$$

= 20664.9 Watts

The torque developed is proportional to the square of the voltage across the winding.

In the case of star, the voltage across the winding E_{ph}

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$\begin{pmatrix}\text{Hence}\\ \text{Torque}\end{pmatrix} = \left|\frac{E_L}{\sqrt{3}}\right|^2 K = \frac{E_L^2}{3}\ K \text{ in star}$$

In the case of delta, the voltage across the E_{ph} winding

$E_{ph} = E_L$.

Hence torque $(E_L)^2$ K = E_L^2 K.

By comparison the torque developed in star connection at the time of starting is 1/3 of the torque developed in delta connection (running).

As the torque is 3 times less in starting due to the star connection, whenever a motor has to be started with heavy loads, this star-delta starter is not used. Instead an auto- transformer or step down transformer starter could be used as the voltage tapping can be changed to more than 58% of the line voltage to suit the torque requirement.

Power in star and delta connections

Objective: At the end of this lesson you shall be able to
- **determine the power in 3 phase star and delta connected load.**

The method of connecting 3 phase load in star and delta mode and the relation between line voltage, phase voltage, line current and phase current are explained in related theory of Ex. 3.4.01.

Now let us discuss the power measurement in 3 phase load both in star and delta mode.

Fig 1 shows the load of three resistances in a star connection. So the power must be three times as great as the single phase power.

$P = 3V_pI_p$.

If the quantities $V_P$and $I_P$in the individual phases are replaced by the corresponding line quantities V_L and I_L respectively, we obtain:

$$P = 3\frac{V_L}{\sqrt{3}} I_L.$$

(Because $V_P = V_L$, $V_L/\sqrt{3}$ and $I_p = I_L$)

Since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form

$P = \sqrt{3}\ V_LI_L$

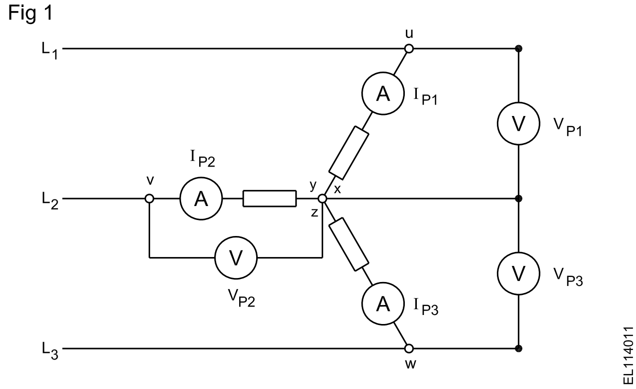
Note that power factor in resistance circuit is unity. Hence power factor is not taken into account.

Quanitity	P	V_L	I_L
Unit	W	V	A

The power in this purely resistive load(θ=0°, cosθ= 1) is entirely active power which is converted into heat. The unit of active power is the watt (W).

As the last formula shows, three-phase power in a star-connected load circuit can be calculated from the line quantities, and there is no need to measure the phase quantities.

Fig 1



$P = \sqrt{3} \times V \times I$ (Formula holds good for pure resistive load)

It is always possible, in practice, to measure the line quantities but the accessibility of the star point cannot always be guaranteed, and so it is not always possible to measure the phase voltages.

Three-phase power with a delta-connected load: Fig 2 shows the load of three resistances connected in delta. Three times the phase power will be dissipated.

$P = 3P_P= 3V_PI_P$

If the quantities $V_P$and $I_P$are replaced by the corresponding line quantities V_L and I_L, we obtain:

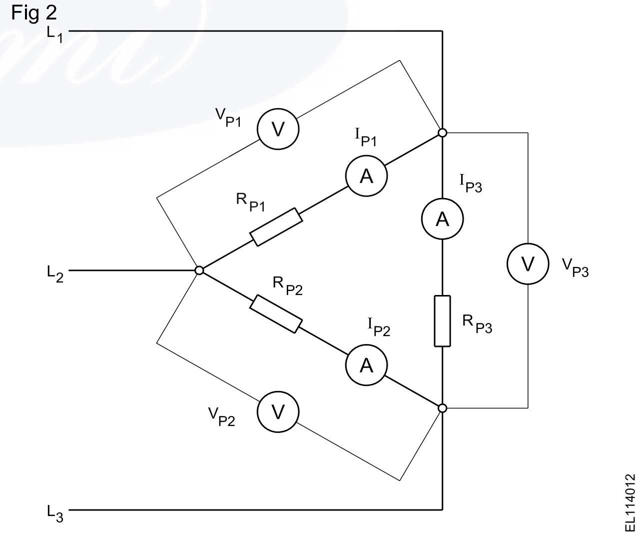
Since, $V_L = V_P$

$I_L = \quad I_P$ and $I_P = \frac{I_L}{\sqrt{3}}$

but since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form:

$P = \sqrt{3}\ V_LI_L$. (Formula holds good for pure resistive load)

Fig 2



If we compare the two power formulae for the star and delta connections, we see that the same formula applies to both. In other words, the way in which the load is connected has no effect on the formula to be used, assuming that the load is balanced.

Active,reactive and apparent power: As you already know from AC circuit theory, load circuits which contain both resistance and inductance, or both resistance and capacitance, take both active and reactive power because of the phase difference existing between the voltage and current in them.

If these two components of power are added geometrically, we obtain the apparent power. Precisely the same happens in each phase of the three-phase systems. Here we have to consider the phase difference f between the voltage and current in each phase.

Applying the factor $\sqrt{3}$, the components of power in a three-phase system follow from the formulae derived for single-phase, AC circuits, namely:

Apparent power S=VI	S = $V_L I_L$	VA
Active power P=VIcosθ	P = $\sqrt{3}\ V_L I_L \cos\theta$	W
Reactive power Q=VIsinθ	Q = $\sqrt{3}\ V_L I_L \sin\theta$	var

Finally, the well known relationships found in single-phase AC circuits apply also to three-phase circuits.

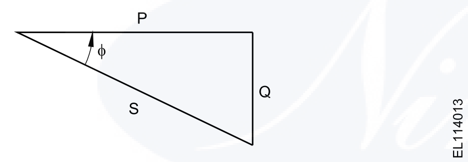
$$\text{Cos }\theta = \frac{\text{active power}}{\text{apparent power}} = \frac{P}{S}$$

$$\text{Sin }\theta = \frac{\text{reactive power}}{\text{apparent power}} = \frac{Q}{S}$$

This can also be seen from Fig 3.

Cos θ is called the power factor, while sin θ is sometimes called the reactive power factor.

Fig 3

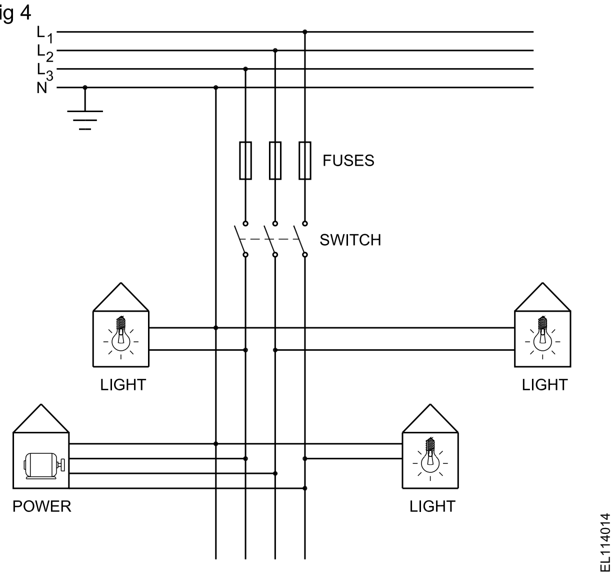


$\sqrt{3}$

Unbalanced load: The most convenient distribution system for electrical energy supply is the 415/240 V four-wire, three-phase AC system.

This offers the possibility of supplying three-phase, as well as single-phase current, to users simultaneously. Supply to buildings can be arranged as in the given example. (Fig 4)

Fig 4



The individual houses utilize one of the phase voltages. L_1, L_2 and L_3 to N are distributed in sequence (light current). However, large loads (eg.three-phase AC motors) may be fed with the line voltage (heavy current).

However, certain equipment which needs single or two phase supply can be connected to the individual phases so that the phases will be differently loaded, and this means that there will be unbalanced loading of the phases of the four-wire, three-phase network.

Balanced load in a star connection: In a star connection, each phase current is determined by the ratio of phase voltage and load impedance `Z'.

This fact will now be confirmed by a numerical example.

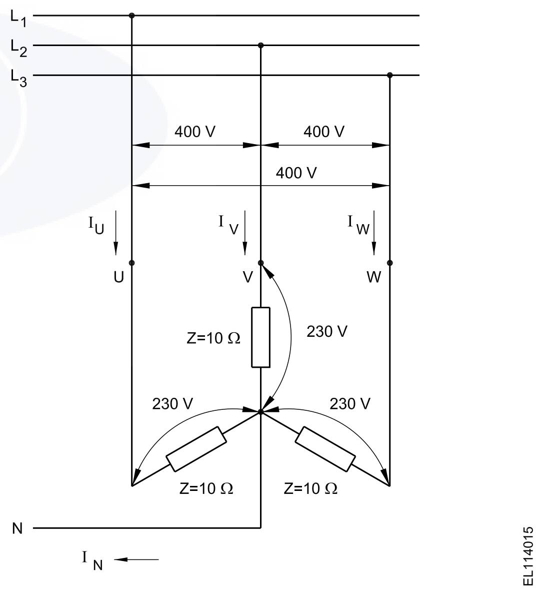
A star-connected load consisting of impedances `Z' each of 10 ohms, is connected to a three-phase network with line voltage V_L = 400V. (Fig 5)

Because of the arrangements of a star connection, the phase voltage is 230V (400/$\sqrt{3}$).

The three load currents taken from supply having the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = V_P / I = Z.$$

Fig 5



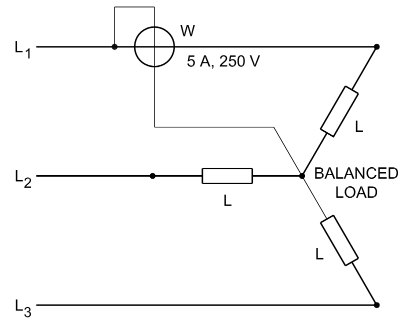
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible.

- Measurement of power in a a star-connected balanced load with neutral point is possible by a single wattmeter.
- Measurement of power in a star or delta-connected, balanced or unbalanced load (with or without neutral) is possible with two wattmeter method.

Single wattmeter method: Fig 6 shows the circuit diagram to measure the three-phase power of a star-connected, balanced load with the neutral point accessible the current coil of the wattmeter being connected to one line, and the voltage coil between that line and neutral point. The wattmeter reading gives the power per phase. So the total is three times the wattmeter reading.

i.e. $P = 3E_P I_P \cos\theta = 3P = 3W$.

Fig 6



The two-wattmeter method of measuring power

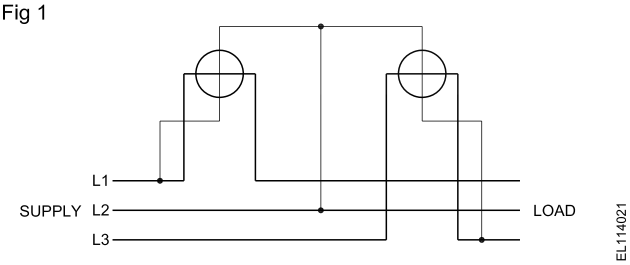
Objectives: At the end of this lesson you shall be able to:
- **measure 3-phase power using two single phase wattmeter**
- **calculate power factor from meter reading.**
- **explain the `two-wattmeter' method of measuring power in a three-phase, three-wire system**

Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, if the load is unbalanced and the assumption that $I_U + I_V + I_W = 0$ will not be valid.

The two wattmeters are connected to the supply system as shown in Fig 1. The current coils of the two wattmeters are connected in two of the lines, and the voltage coils are connected from the same two lines to the third line. The total power is then obtained by adding the two readings:

$P_T = P_1 + P_2$.

Fig 1



Consider the total instantaneous power in the system $P_T = P_1 + P_2 + P_3$ where P_1, P_2 and P_3 are the instantaneous values of the power in each of the three phases.

$$P_T = V_{UN}\, i_U + V_{VN}\, i_V + V_{WN}\, I_W$$

Since there is no fourth wire, $i_U + i_V + i_W = 0$; $i_V = -(i_U + i_W)$.

$$P_T = V_{UN} i_U - V_{VN}(i_U + i_W) + V_{WN}\, i_W$$

$$= i_U(V_{UN} - V_{VN}) + i_W(V_{WN} - V_{UN})$$

$$= i_U V_{UV} + i_W V_{WV}$$

Now $i_U V_{UV}$ is the instantaneous power in the first wattmeter, and $i_W V_{WV}$ is the instantaneous power in the second wattmeter. Therefore, the total mean power is the sum of the mean powers read by the two wattmeters.

It is possible that with the wattmeters connected correctly, one of them will attempt to read a negative value because of the large phase angle between the voltage and current for that instrument. The current coil or voltage coil must then be reversed and the reading given a negative sign when combined with the other wattmeter readings to obtain the total power.

At unity power factor, the readings of two wattmeter will be equal. Total power = 2 x one wattmeter reading.

When the power factor = 0.5, one of the wattmeter's reading is zero and the other reads total power.

When the power factor is less than 0.5, one of the wattmeters will give negative indication. In order to read the wattmeter, reverse the pressure coil or current coil connection. The wattmeter will then give a positive reading but this must be taken as negative for calculating the total power.

When the power factor is zero, the readings of the two wattmeters are equal but of opposite signs.

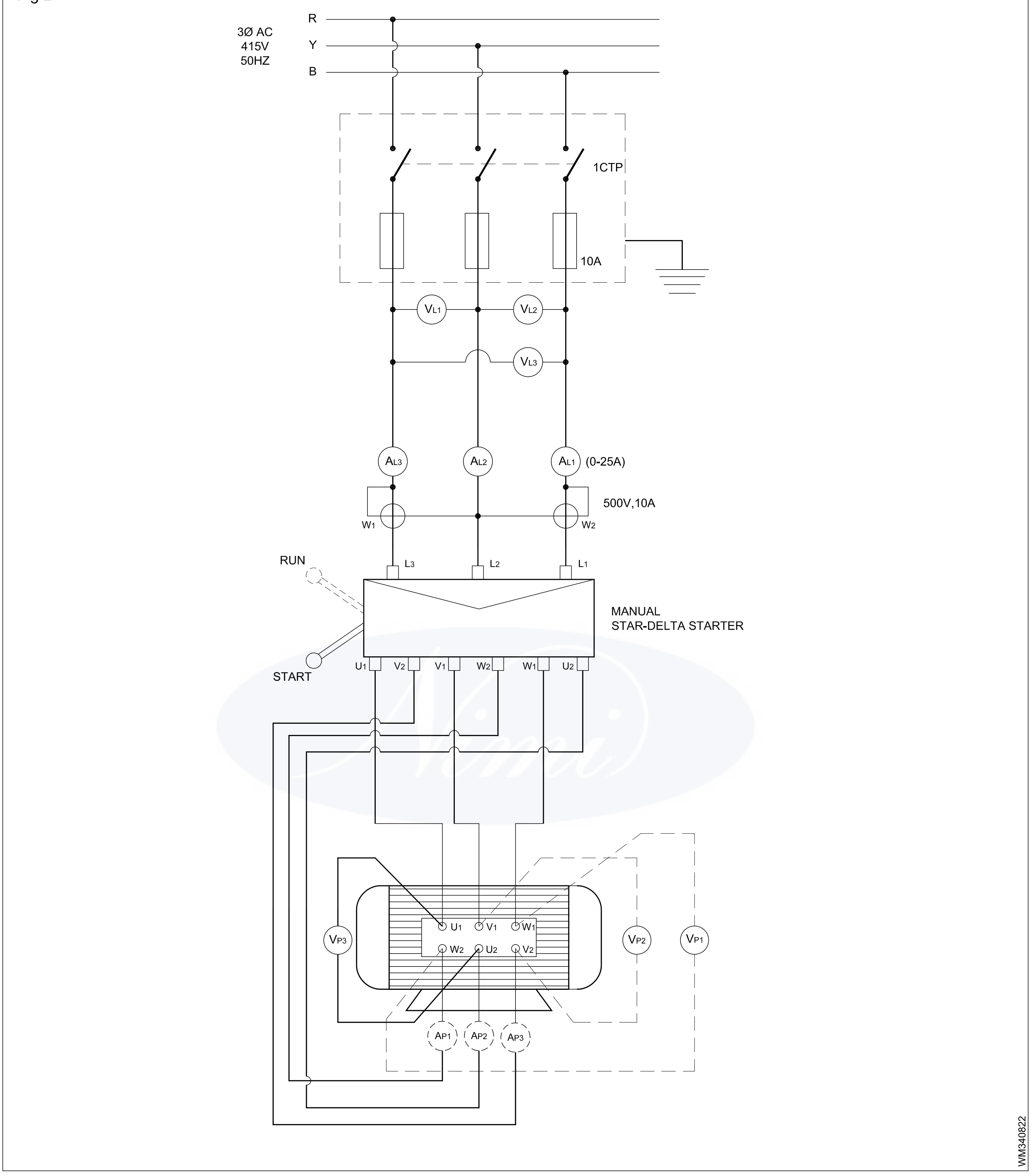
Power measurement in 3 phase induction motor

So far we have been discussing about the phase resistive load. A three phase inductive load such as 3 phase induction motor can also be measured by the methods discussed above. The Fig 1 shows the arrangement of measuring the total power taken by a 3 phase induction motor by two watt meter method.

During starting, when the handle of manual star/delta starter in “START” position, the wattmeter shows the power consumed by the motor in “STAR” mode. When the handle is in “RUN” position, the wattmeter shows the power consumed by the motor in “DELTA” mode.

It is seen that the power consumed in “STAR” mode is 1/3 times of that consumed in “DELTA” mode. This is because in “STAR” mode, “$1/\sqrt{3}$ times of line voltage only is applied across each winding.

Fig 2



R
Y
B
3Ø AC
415V
50HZ
1CTP
10A
VL1
VL2
VL3
AL3
AL2
AL1
(0-25A)
500V,10A
W1
W2
L3
L2
L1
RUN
START
MANUAL
STAR-DELTA STARTER
U1
V2
V1
W2
W1
U2
VP3
VP2
VP1
AP1
AP2
AP3
WM340822

Semi-automatic star-delta starter

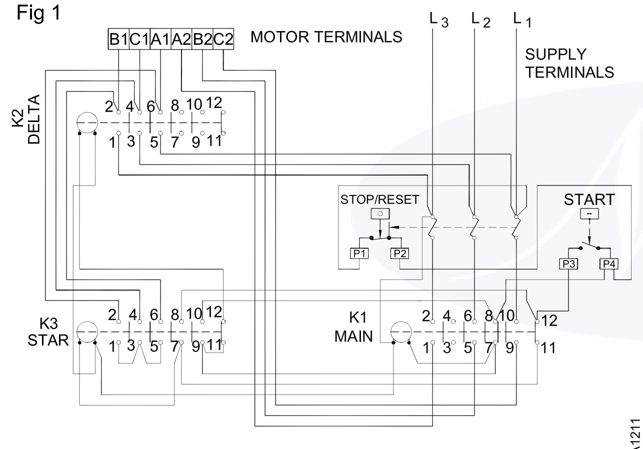
Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of the semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Figure 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.

Fig 1



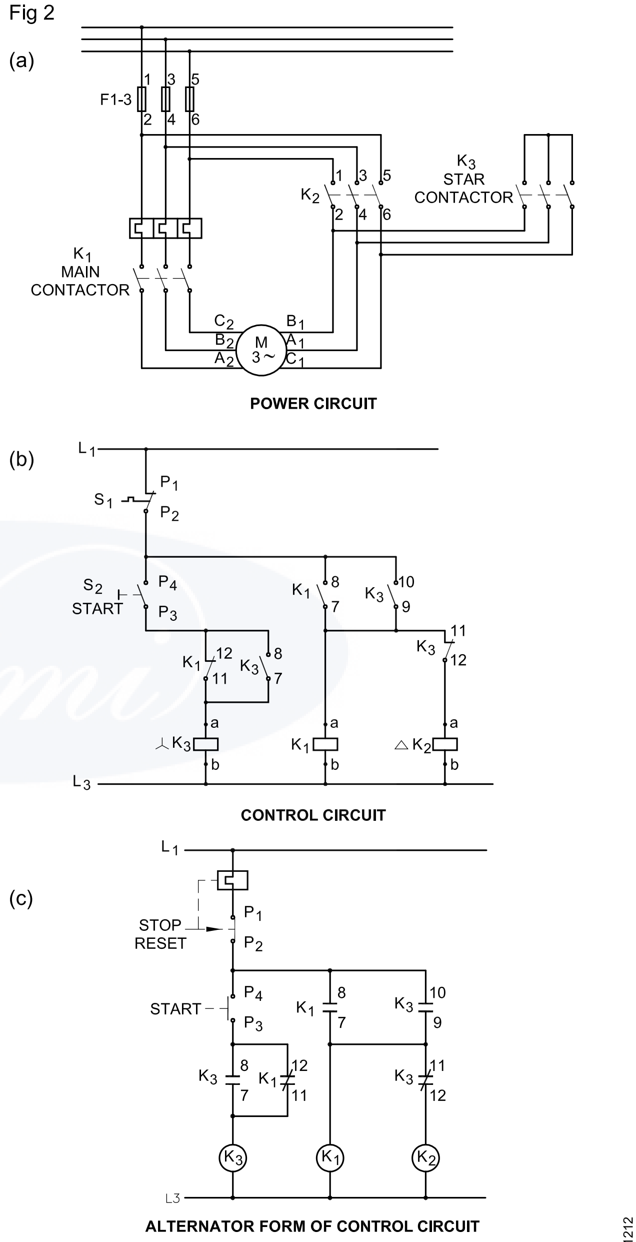
WIRING DIAGRAM

Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.

When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

Fig 2



LINE DIAGRAM OF SEMI - AUTOMATIC STAR - DELTA STARTER

The operator has to observe the motor starting and reaching 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2(c) shows the alternative form of drawing control circuit.

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **list the applications of the star-delta starter giving reasons**
- **read the line diagram of an automatic star-delta starter with open transition starting**
- **describe the procedure of setting overload relays on star-delta starters.**

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Figure 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S_2-energises the star contactor K_3. (Current flows through K_4 T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 1

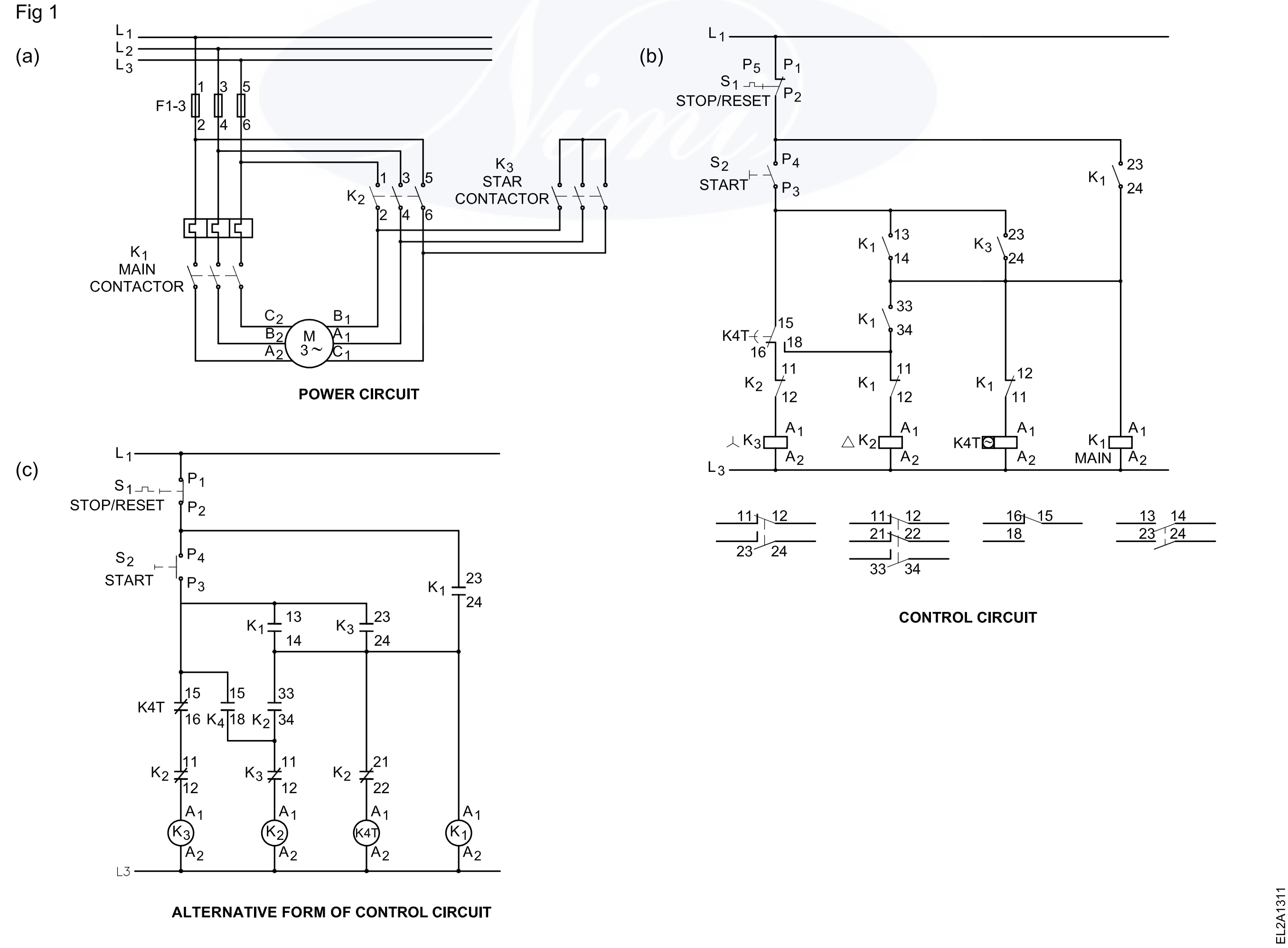
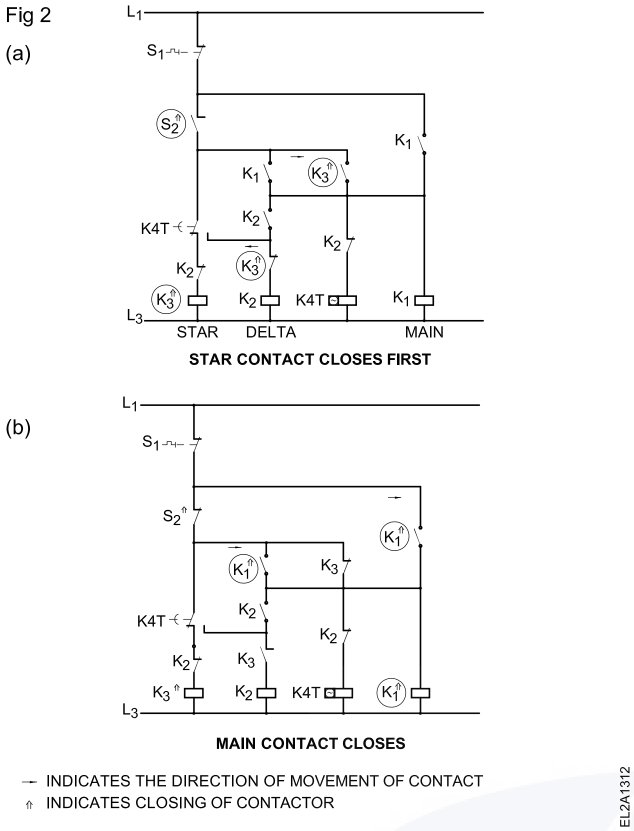


Figure 2 shows the current direction and closing of contacts as explained above.

Fig 2



Similarly Figure 3 shows the action taking place after the timer relay operating the contact K4T.

Time delay contact changes opening star contact.

Figure 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Delta contact closes.

Fig 3

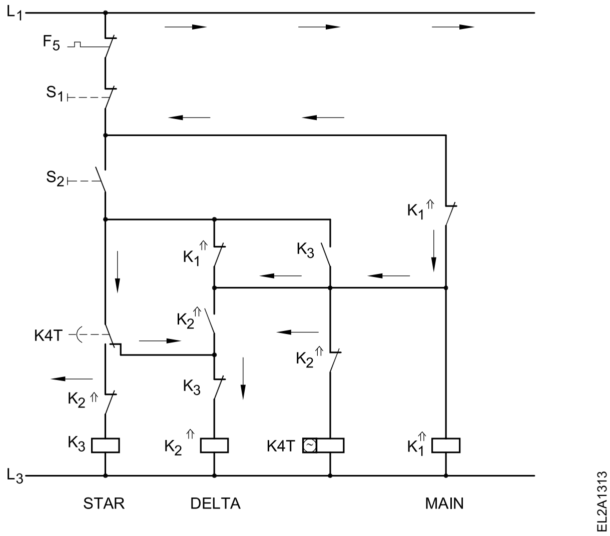
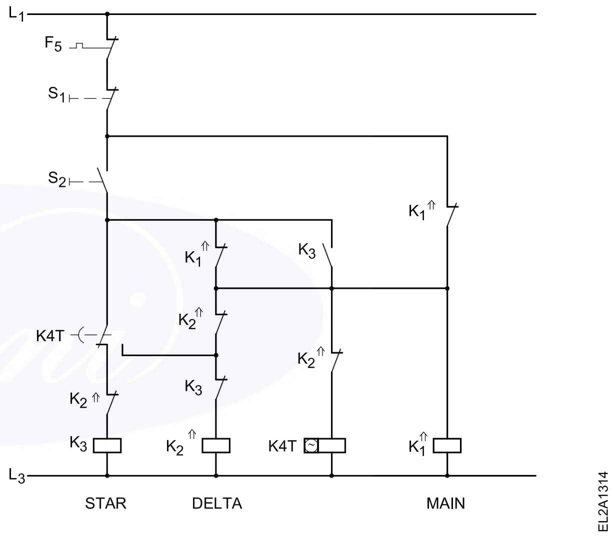


Fig 4



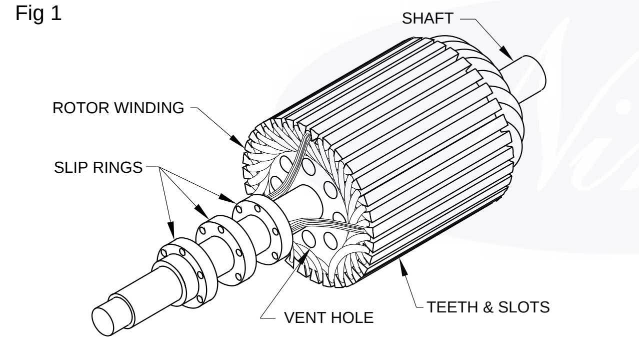
Three-phase slip ring induction motor

Objectives : At the end of this lesson you shall be able to
- **explain briefly the construction and working of three-phase slip ring induction motor**
- **state the characteristic of the slip ring induction motor**
- **compare the slip ring induction motor with the squirrel cage induction motor.**

Construction

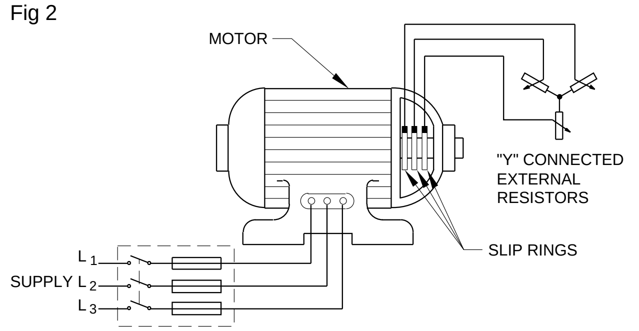
This type of motors could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip ring induction motor is very much the same as squirrel cage motor whereas the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in stator and so it is called a wound rotor. The rotor winding is connected in star and the open ends are connected to three slip rings mounted in the rotor shaft as shown in Fig 1. The rotor circuit is in turn connected to the external star connected resistances through the brushes as shown in Fig 2.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

Fig 2



CIRCUIT FOR A SLIP RING INDUCTION MOTOR

Working

When the stator winding of the slip ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor does. This rotating magnetic field induces voltages in the rotor windings and a rotor current will flow through the closed circuit formed by the rotor winding, the slip rings, the brushes and the star connected external resistors.

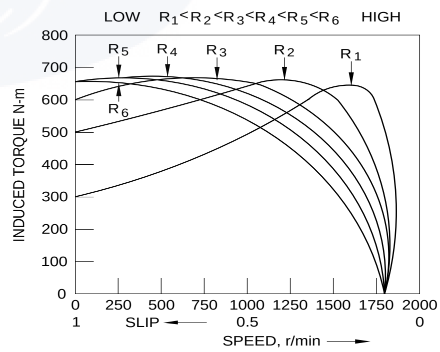
At the time of starting, the external resistors are set for their maximum value. As such the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the torque developed at the starting. This torque becomes higher than the torque developed in squirrel cage motors.

As the motor speeds up, the external resistance is slowly reduced and the rotor winding is made to be short circuited at the slip ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. Also the external resistance circuit could be designed to control the speed of the motor by 50 to 100 percent of the rated speed.

Characteristic and application of slip ring induction motor

Insertion of higher external resistance alters the starting torque to higher value as shown in Fig 3 by the torque speed characteristic.

Fig 3



THE TORQUE-SPEED CHARACTERISTIC FOR SLIP RING INDUCTION MOTOR

As shown in the curve higher external resistance improves the starting torque to higher value. However, the maximum torque remains constant for the variation of the rotor resistance.

By observing these curves it is clear that the slip ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

This motor could be used in machines which demand a higher starting torque and also variable speed controls such as compressors, conveyors, cranes, hoists, steel mills and printing presses etc.

COMPARISON BETWEEN SQUIRREL CAGE AND SLIP RING INDUCTION MOTOR

Sl.No.	Condition	Squirrel cage	Slip ring motor
1	Starting.	Can be started by DOL, star-delta auto-transformer starters.	Rotor resistance starter is required.
2	Starting torque.	Low.	Very high.
3	Starting current.	High.	Low.
4	Acceleration on load.	Just satisfactory.	Very good.
5	Speed variation.	Not easy, but could be varied in larger steps by pole changing or smaller incremental steps through thyristors or by frequency variation.	Easy to vary speed, but speed change through pole changing is not possible. Speed change possible through (a) insertion of rotor resistance (b) using thyristors (c) using frequency variation (d) injecting emf in the rotor circuit (e) cascading.
6	Rotor construction.	Bars are used in the rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slip rings.	Winding wire is to be used. Wound rotor requires attention. Slip-ring and brush gear need frequent maintenance.
7	Maintenance.	Almost nil.	Requires frequent maintenance.
8	Cost.	Low.	Comparatively high.

Resistance starter for 3-phase slip ring induction motor

Objective : At the end of this lesson you shall be able to

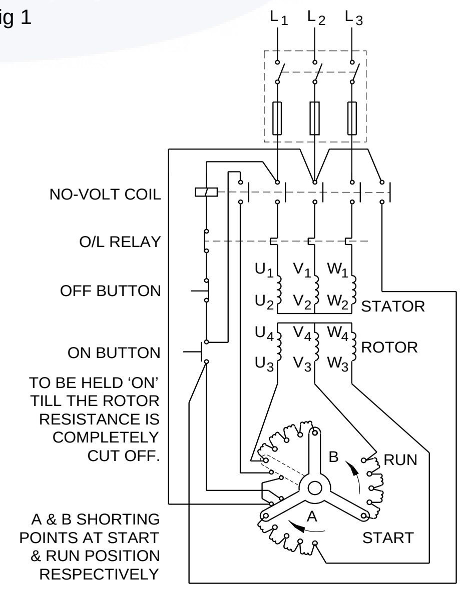
- **draw and explain the circuits of a rotor resistance starter used for a 3-phase slip ring induction motor and its general construction.**

As explained in Related Theory the slip ring motors are started with full line voltage by keeping the external resistance in the rotor circuit and the resistance is cut out when the motor picks up the speed. If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in the completely cut out position resulting in heavy rush of starting current. This could be eliminated by use of protective circuitry in the resistance starter, thereby the motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter circuit is shown in Fig 1.

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at rotor resistance is in the closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cut out the rotor resistance.

The position of the handle clearly indicates that at the start position the contact 'A' is in closed position and at run position contact 'B' is in closed position and both cannot close at the same time. The 'ON' push-button needs to be held in pushed position till the handle is brought to run position. During run position the handle contact 'B' closes the no-volt coil circuit and the pressure on the 'ON' button can be released.

Fig 1



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

In general, for small machines the rotor resistance is air cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown above is intended to start the motor only. As speed regulation through rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Auto-transformer starter

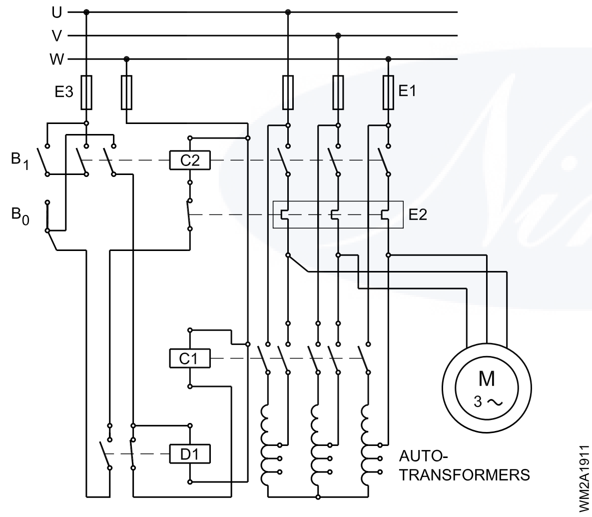
Objectives: At the end of this lesson you shall be able to
- **the construction of auto-transformer starter**
- **power circuit and control circuit of auto-transformer starter.**

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements, since the contacts frequently break large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

Fig 1



The power circuit of the auto-transformer is shown in Fig 2(a) and control circuit of auto-transformer is shown in Fig 2(b).

Auto-transformer starter - Operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. while starting the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 2

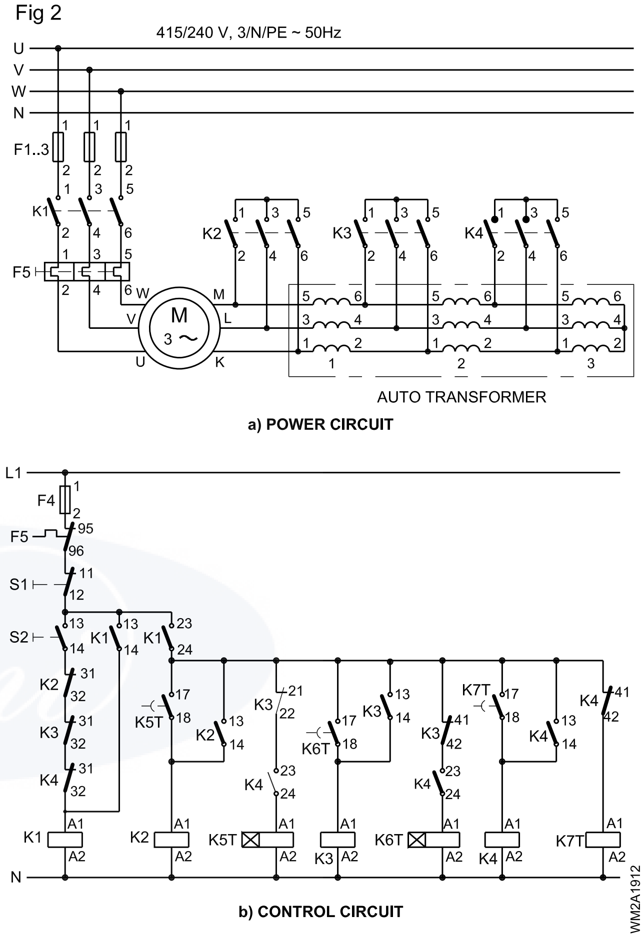
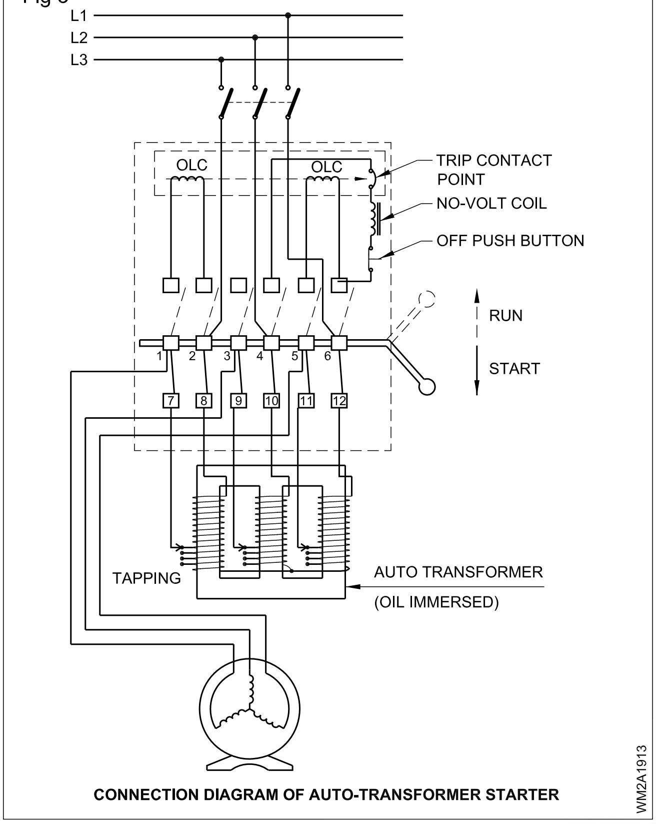


Figure 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.

Fig 3



CONNECTION DIAGRAM OF AUTO-TRANSFORMER STARTER

Single phasing preventer/phase failure relay

Objectives: At the end of this lesson you shall be able to
- **define single phasing**
- **state the effect of single phasing**
- **explain the necessity of a single phasing preventer**
- **classify the single phasing preventers**
- **explain the installation procedure**
- **explain the procedure for troubleshooting and servicing of single phasing preventer.**

Single phasing preventer / phase failure relay

When one of the three lines of a three-phase supply system fails or opens, the load current flows between the other two lines only and the fault is known as single phasing.

Generally induction motors burn out due to excessive voltage during off hours, very low voltage during peak hours, unequal phase voltage and single phasing (missing of one phase completely from 3-phase supply). It is therefore essential to install a single phasing preventer in addition to the starters. Starters provide only over load protection and therefore cannot prevent the motor from burning out under above. Stated condition of supply voltage. But the single phasing preventer protects the motor by stopping it automatically under low and high unbalanced voltage single phasing and ensures complete safety for 3-phase motors.

Effect of single phasing

The effect of single phasing is different with different types of loads as follows

- In 3-phase heating loads, the heat produced decreases to around 50%; at the same time it does not harm the equipment.
- The blowing of fuse in one line or open circuit in one of the phase winding causes a motor to keep on running on two phase supply. If the motor is loaded to its normal output heavy current flows through & will burn the motor.
- In three-phase motors, the effect of single phasing is different on different occasions.

i) During starting, if single phasing occurs, the motor fails to start or stalls as proper rotating magnetic field is not created. But the motor draws a very large current and motor windings gets heated up.

ii) During running, if single phasing occurs, the motor may or may not run depending upon the load condition and the phase in which supply is available will draw a large current and the winding is likely to burn out due to overheating.

Necessity of single phasing preventer / phase failure relay.

If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire connected to the motor breaks while the motor is running, the motor will continue to operate on two phase but will experience serious overheating. To protect motors against these conditions of phase failure, a single phasing preventer is used.

Types of preventers

Single phasing preventers are available in three types.

- Mechanical
- Current sensing
- Voltage sensing.

Single phasing preventer - Mechanical type

One type of single phasing preventer is incorporated with bimetal relays which opens the NVC circuit similar to that of normal OLR. This type of single phasing preventer is slow in operation and also not fully reliable and hence not preferred nowadays.

The second type of mechanical phase failure relay uses coils connected to two lines of the three-phase supply. The currents in these coils set up a rotating magnetic field that tends to turn a copper disc clockwise. This clockwise torque actually is the resultant of two torques acting in opposite direction. Out of two torques, one polyphase torque tends to turn the disc clockwise, and one single-phase torque tends to turn the disc anticlockwise.

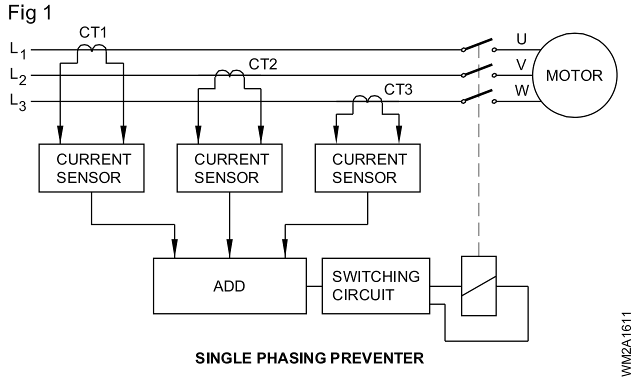
The disc is kept from turning in the clockwise direction by a projection resting against a stop. However, if the disc begins to rotate in the anti-clockwise direction, the projecting arm will move a toggle mechanism to open the starter and disconnect the motor from the line. In other words, if one line is opened, the poly-phase torque disappears and the remaining single-phase torque rotates the disc in anti-clockwise direction. As a result, the motor is disconnected from the line. In the case of phase reversal, the poly-phase torque helps the single-phase torque to turn the disc anti-clockwise and again the motor is disconnected from the line.

Single phasing preventers - Current sensing

It operates on the principle of equal currents with balanced loads developing secondary voltage on current transformers. These secondary voltages are connected so as to add and the added voltage is rectified, filtered and sensed and applied to operate a relay which operate to close the NVC circuit of the starter.

Fig 1 shows the block diagram of a current sensing single phasing preventer.

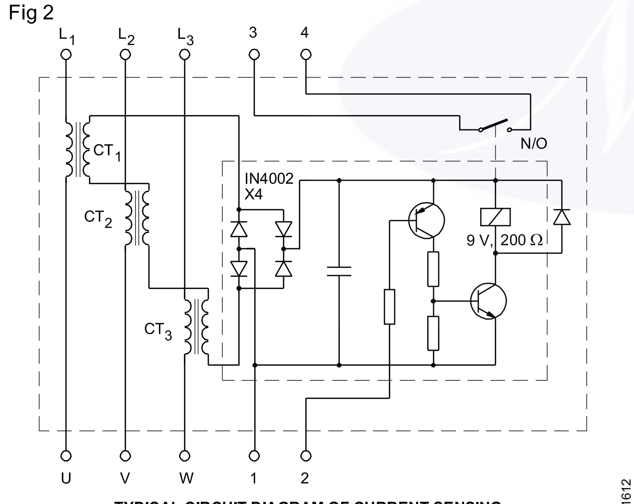
Fig 1



SINGLE PHASING PREVENTER

Fig 2 shows a typical circuit diagram of current sensing single phasing preventer. The terminals 1 and 2 are used to introduce time delay circuit. Otherwise they are kept shorted.

Fig 2



TYPICAL CIRCUIT DIAGRAM OF CURRENT SENSING SINGLE PHASING PREVENTER

Terminals 3 and 4 are connected in series with the NVC circuit of starter. The relay will not operate if the motor draws a current lesser than the specified value or the circuit is unbalanced there by keeps the motor off.

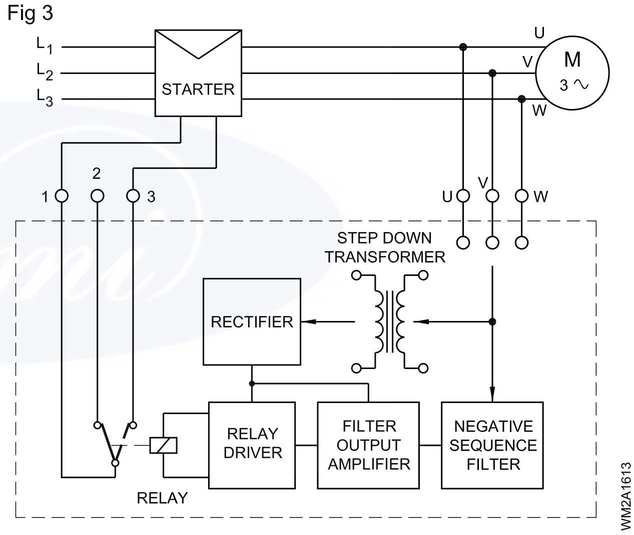
This type of single phasing preventers are suitable only where the motors run with a constant load such as pump motors, compressor motors etc. It also serves as dry run protection unit as and when the motor is out of load, such as a pump running without water, the load current decreases and the circuit senses and trips the motor circuit.

Single phasing preventer - Voltage sensing

In an AC three-phase supply the order in which three-phase voltage reach the maximum value is known as phase sequence. the phase voltage reaches their maximum positive value one after another at 120° in clockwise known as positive phase sequence and in anti-clock wise known as negative phase sequence. In the case of phase reversal or unbalanced voltages or not voltage in a line it results in a super-imposition of negative phase sequence over the normal positive phase sequence of supply voltages. This negative sequence is filtered by a resistance capacitance or resistance, capacitance and inductor network and de-energise the relay in the voltage the sensing single phasing preventor.

Fig 3 and Fig 4 shows the block diagram and circuit diagram of a typical voltage sensing single phasing preventer. In this resistance, capacitance network is utilized to sense the negative phase sequence. When phase sequences and voltages are correct, no voltage will be generated across the filtered output i.e. across capacitor. C_4 in the circuit which drives the transistor Q_1 to cut off and transistor Q_2 to drive the relay.

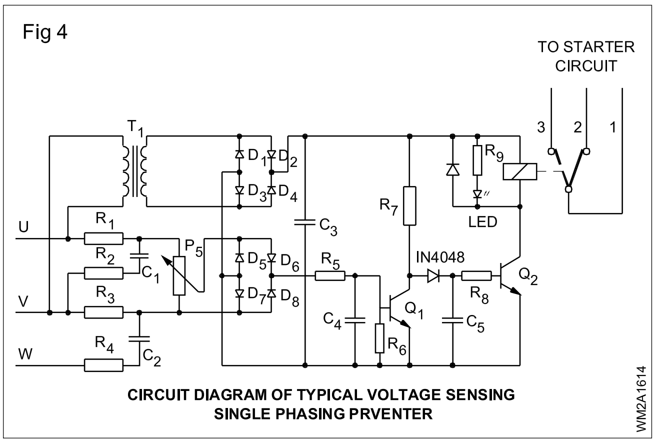
Fig 3



When the negative sequence occurs due to unbalanced supply voltage or phase reversal, a voltage is developed across the capacitor C_4 which drives the transistor Q_1 to saturation and transistor Q_2 to cut off. This results in switching off the relay circuit.

Some of the single phasing preventers are provided with the facility to adjust unbalanced settings. For example when the relay is found to operate very frequently for the set value, the unbalanced pre-set can be changed by operating the pre-set P_5 in Fig 4.

Fig 4



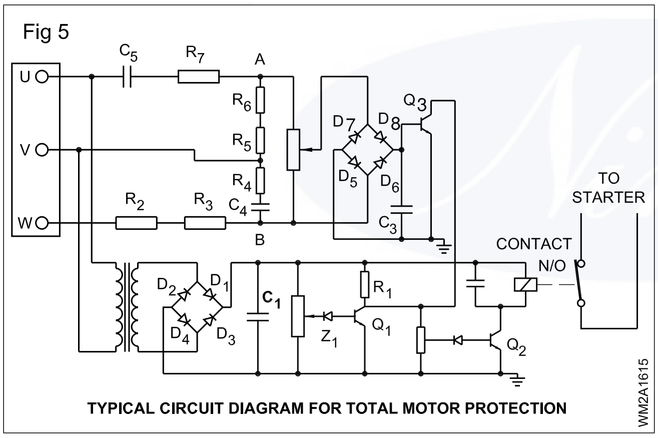
CIRCUIT DIAGRAM OF TYPICAL VOLTAGE SENSING SINGLE PHASING PRVENTER

Single phasing preventer with over-voltage and under voltage cut off (Total motor protection)

When a motor is fed with reduced voltage, the motor draws excess current to drive the load and with an over voltage, also it draws excess current. To protect the motor from under-voltage or over-voltage and also singe phasing a preventer with over and under voltage protection is used for total motor protection.

Fig 5 shows an arrangement of over-voltage and under-voltage cut off circuit along with single phasing preventer.

Fig 5



TYPICAL CIRCUIT DIAGRAM FOR TOTAL MOTOR PROTECTION

In the circuit transistor Q_1 serves as over-voltage cut off and transistor Q_2 serves as under-voltage cut off whereas transistor Q_3 serves as single phasing preventer.

Installation of single phasing preventer

Installation and connection of single phasing preventer shall be done as recommended by the manufacturer. Preferably single phasing preventers shall be located nearer to the equipment and not subjected to abnormal vibration. Care should be taken to locate the unit away from a heat generating source such as oven, furnace etc.

A single phasing preventer shall be connected with the supply line and starter to the appropriate terminals and circuits.

Some of the commonly used single phasing preventers and their connection with starter are shown in Figs 6 & 7 for your reference.

Fig 6

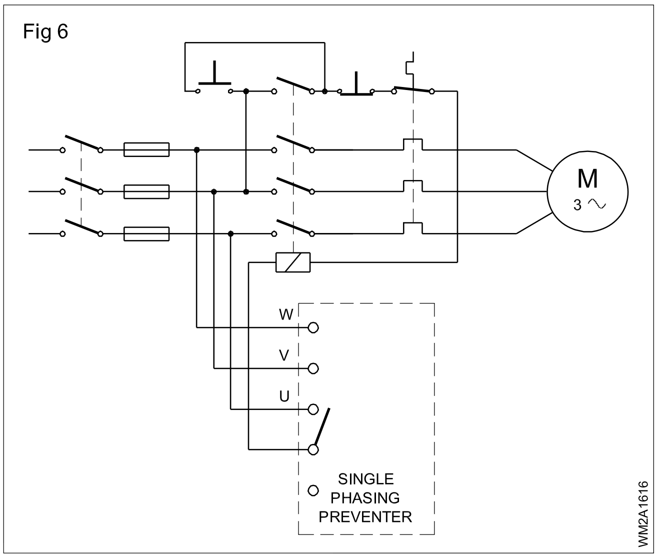
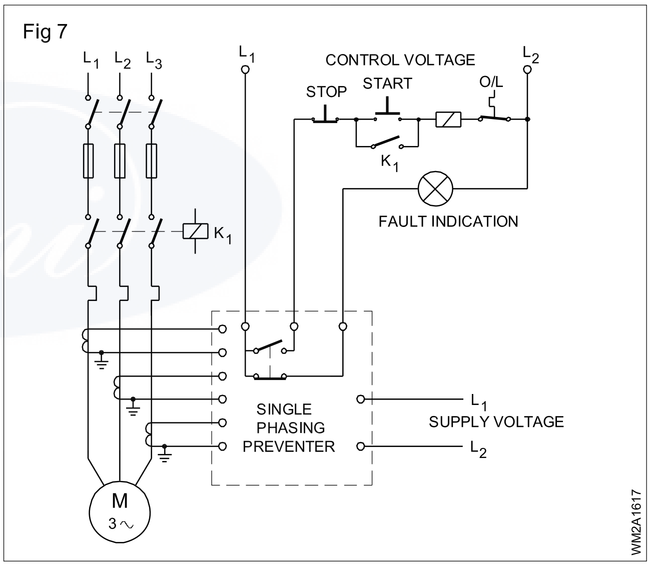


Fig 7



Troubleshooting and maintenance of single phasing preventer

The arrangement of components and their circuits of single phasing preventers vary from one make to another make as well as from one type to another type.

It is preferred to follow the manufacture's recommendations for troubleshooting and maintenance of single phasing preventers. A few general guide lines for trouble shooting of single phasing preventers are given in the table.

Troubleshooting of single phasing preventor

Sl. No.	Symptoms	Possible causes	Remedy
1	Starter with single phasing preventer does not start	No supply.	Check and resume supply.
		Low supply voltage.	Verify and correct the voltage.
		Unbalanced line voltage.	Verify and correct the voltage.
		Improper phase sequence.	Reverse the phase sequence by inter-changing any two incoming lines.
		Single phasing	Check the supply and rectify
		No control circuit voltage.	Check the control circuit & rectify.
2	Starter with single phasing does not hold on	Low supply voltage..	Measure the voltage and correct it.
		Unbalanced line voltages.	Verify and correct.
		Single phasing.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence.
		Defect in single phasing preventer (in electronic circuit).	Check and repair it.
		Relay of single phasing preventer is not energised.	Check and repair it.
		Improper function of relay contacts.	Check and rectify it.
		Open in holding circuit.	Check and correct it.
3	Starter with single phasing preventer trips frequently	Abnormal fluctuation in supply voltages.	Check the voltage and rectify it.
		Improper settings or unbalanced settings.	Adjust the setting for balance.
		Loose contact in supply lines/control circuit.	Check the contacts and rectify it.

Characteristics of squirrel cage induction motor & speed control methods

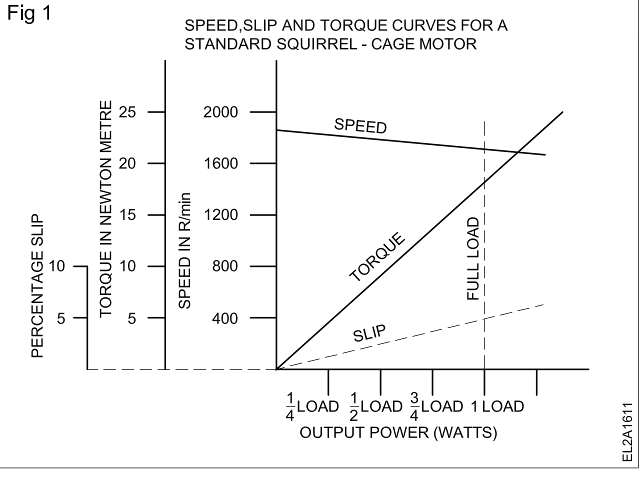
Objectives: At the end of this lesson you shall be able to
- **describe the characteristics and application of a 3-phase squirrel cage induction motor.**
- **describe the various speed control methods of induction motor.**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

Speed, torque and slip characteristics : It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1



Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig 1.

Relationship between torque, slip rotor resistance and rotor inductive reactance : It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K f_S I_R \cos\theta$

where T = torque in Newton metre

K = a constant

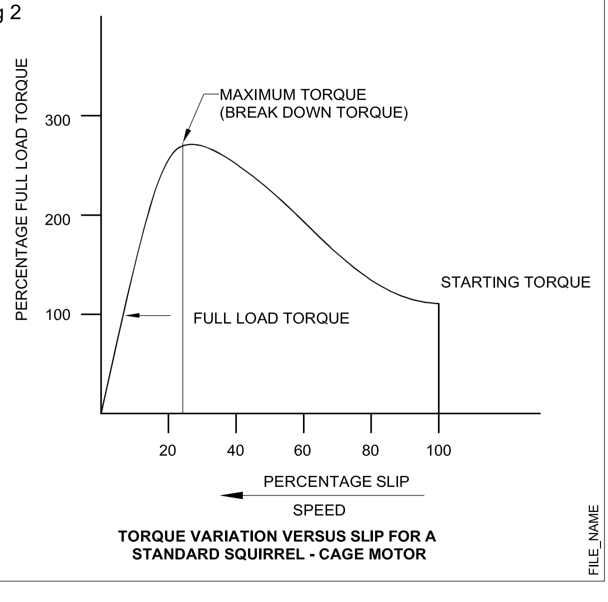
f_S = stator flux in weber

I_R = rotor current in ampere

$\cos\theta$ = rotor power factor

From no load to full load, the torque constant (K), the stator flux (f_s) and the rotor power factor ($\cos\theta$) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current (I_R) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig 2.

Fig 2



TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

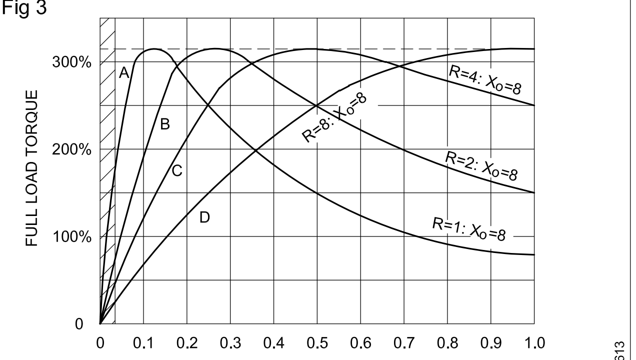
The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig 2, the rotor torque will increase in almost a straight relationship with the slip.

Inbetween 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

Effect of rotor resistance upon the torque/slip relationship: Fig 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.

Fig 3



FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

Breakdown torque : In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

Starting torque : At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the full load torque for the rotor having maximum resistance as shown by curve D of Fig 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

Running torque : While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

Application of squirrel cage induction motor : Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

Speed Control of Induction Motor

The speed of a 3∅ Induction motor can be changed broadly two ways.

1. Startor side control

2. Rotor side control

The rotor side speed control is only possible for slip ring induction motors.

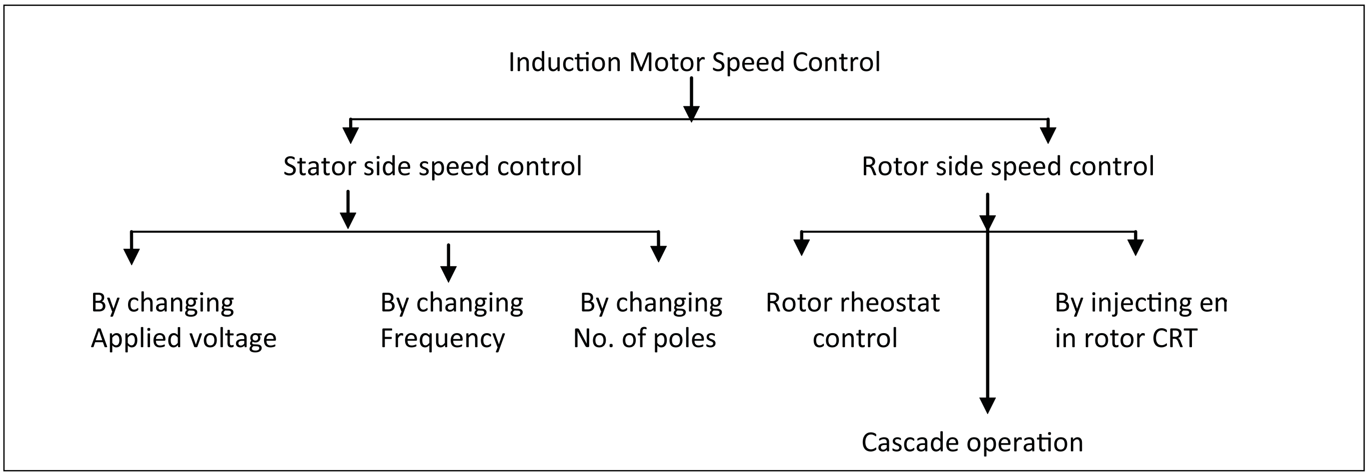
Startor side control

1. By Changing Applied voltage

As in 3∅ Induction motors torque αV^2, thus if the supply voltage is decreased, the torque decreases and hence the speed decreases.

This method is easiest and cheapest, but rarely used because : -

(i) A large change in voltage is required for relative small change in speed .



(ii) Large change in voltage will change the magnetic condition (flux density) of motor.

2. By Changing the applied frequency

In 3∅ Induction motors the synchronous speed of rotating magnetic field is given by

$$N_s = \frac{120f}{p}\ \text{rpm}$$

Where f = supply frequency

p = No of stator poles

Thus the $N_S \alpha f$

Hence the running speed of motor changes with change in supply frequency.

3. By Changing No. of stator poles

From above eqn. of N_s

$$N_s \alpha \frac{1}{p}$$

Hence the runing speed of the motor changes with change in No. of stator poles

The speed increases with decrease in no. of poles. The speed decreases with in No. of poles.

E.g. if a 3∅ induction motor is having 2 pole, 50Hz motor the N_s will be how much?

$$Ns = \frac{120f}{p} = \frac{120 \times 50}{2} = 3000\text{rpm}$$

If the No. of poles are 4 and frequency is constant. i.e 50Hz

then $Ns = \frac{120f}{p} = \frac{120 \times 50}{4} = 1500\,\text{rpm}$

mean no. of pole = 2 Ns = 3000

no. of poles = 4 Ns = 1500

e.g. if 3∅ induction motor is having 2 pole, 50 Hz the N_s will be

$$Ns = \frac{120f}{p} = \frac{120 \times 50}{2} = 3000\text{rpm}$$

if in same motor the frequency is reduced to 25Hz and no. of pole is 2

$$Ns = \frac{120f}{p} = \frac{120 \times 25}{2} = 1500\text{rpm}$$

f = 50Hz Ns = 3000

f = 25Hz Ns = 1500

2. Rotor side speed control

i) Rotor Rehostat Control

This method is similar to that of armature rehostat control of DC shunt motor. The rehostat is connected in rotor side of the slip ring motor & the speed is changed by varying the rehostat.

ii) Cascade operation

In this method two motors are used. Both motors are mounted on the same shaft so that both motors run on same speed one of the motor is fed from the 3∅ supply and other motor is fed from the rotor of the 1st motor via slip rings as shown in Fig 4 below.

If no. of poles of motor $M_1 = P_1$

If no. of poles of motor $M_2 = P_2$

$$Ns_1 = \frac{120f}{p_1 + p_2}$$

then we get 4 different speeds from this set

a) When motor M1 alone is connected

$$Ns_1 = \frac{120f}{p_1}$$

b) When motor M2 alone is connected to supply

$$Ns_2 = \frac{120f}{p_2}$$

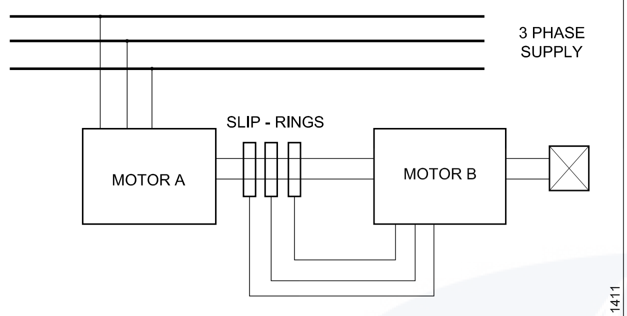
c) When motor M1 & M2 are connected in cummulative cascading

$$Ns_3 = \frac{120f}{p_1 + p_2}$$

d) When motor M1 & M2 are connected in differential cascading

$$Ns_4 = \frac{120f}{p_1 - p_2}$$

Fig 4



CASCADE OPERATION

iii) By injecting e.m.f. in rotor circuit

In this method, the speed of the induction motor is controlled by injecting a voltage of rotor frequency in the rotor circuit. If the injected e.m.f. is in same phase that of induced e.m.f. of rotor then resaultant rotor resistance decreases. But, if the injected e.m.f. is in opposite phase then rotor resistance increases. Thus by changing the phase of the injected e.m.f. the speed of the motor can be changed to a wide range (above normal as well as below normal)

The e.m.f. can be injected by various methods such as Kramer system, scherbius system etc.,

From above all the speed control methods, all the methods are too much complicated, costly or loss of electrical enregy, as no. of poles of a motor are fixed from manufacturer or winding cannot be changed there after.

The supply frequency in India is fixed that is 50Hz so that is also not variable.

So to control the speed of the motor AC drive is usedwhich changes speed by changing the frequency and voltage simultaneously.

It is important to know that with change in frequency, the voltage is also changed to keep the flux constant (constant torque).

This method is known as VVVf (Variable voltage variable frequency) or V/f control

i.e., Assume 3∅ induction motor 440V, 2 Pole, 50Hz motor

$$Ns = \frac{120f}{p} = \frac{120 \times 50}{2} = 3000 rpm$$

if we want to change the speed to 1500 then the drive will calculate the frequency required for this speed

$$Ns = \frac{120f}{p} = 1500 = \frac{120f}{2}$$

i.e. f = 25 Hz

Now drive will calculate for f = 25Hz how much voltage should be supplied

if f = 50 Hz V = 440 V

if f = 25 Hz then $V = \frac{440}{50} \times 25 = 220V$

So, like this voltage and frequency both will be changed 25Hz, 220 V will be applied to get 1500 rpm upon to motor.

Efficiency of induction motor

Objectives: At the end of this lesson you shall be able to
- **draw the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I_2 to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s\ I_2 \cos\ \phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined.

Fig 1

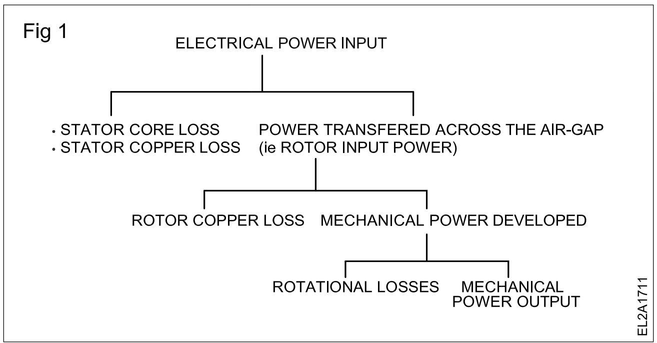
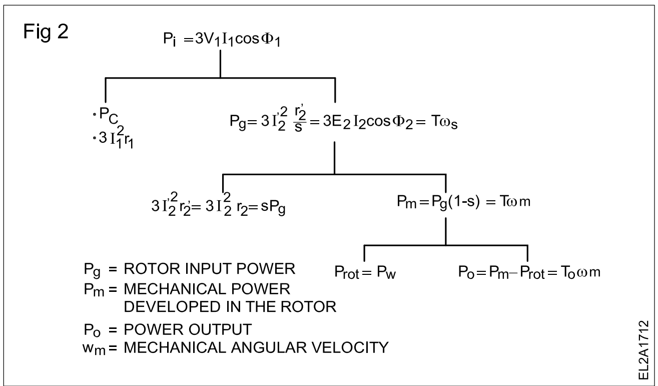


Fig 2



The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Figure 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Torque, Mechanical power and Rotor output : Stator input P_i = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input P_g = stator output.

Rotor gross output, P_m = rotor input P_g = rotor cu. losses.

This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque T_o.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

T x 2πn = rotor gross output in watts, P_m.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts}, P_m}{2\pi\ n}\ \text{N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\ n}\ \text{Kg m}$$

$$= \frac{P_m}{9.81 \times 2\pi\ n}\ \text{Kg m}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\pi\ n_s}$$

From the above two equation we get,

Rotor gross output = $P_m = T\omega = T \times 2\pi n$

Rotor input = $P_g = T\omega_s = T \times 2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input
= s x power across air gap
= sP_g.

Rotor gross output P_m = Input P_g - rotor cu.loss
= $(1 - s) P_g$

$$\text{or } \frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$$

rotor gross output. $Pm = (1 - s)P_g$

$$\text{Therefore rotor efficiency} = \frac{n}{n_s}$$

Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the winding and friction losses are 1.8 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

No. of poles	P = 4
Frequency	f = 50 Hz
Phases	= 3
Input kW	= 50
Slip	s = 5%
Stator losses	= 1.2 kW
Friction & Windage losses	= 1.8 kW

Find:

rotor speed	= N
rotor copper loss	= s x input power to rotor
efficiency	= η

SOLUTION

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor
= 0.05 x 48.8
= 2.44 kW.

Rotor output windage = Rotor input - (Friction and loss + rotor cu.loss) = 48.8 - (1.8 + 2.44)
= 44.56 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 89.12\%.$$

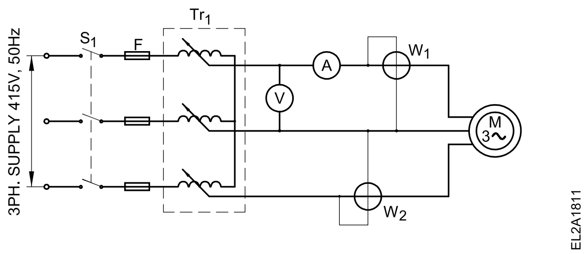
No-load test of induction motor

Objectives: At the end of this lesson you shall be able to

- **determine the constant (mechanical and iron losses of induction motor)**
- **calculate the total equivalent resistance per phase.**

No-load test

Fig 1



The induction motor is connected to the supply through a 3-phase auto-transformer. The 3-phase auto-transformer is used to regulate the starting current by applying low voltage at the start, and then gradually increased to rated voltage. The ammeter and voltmeters are selected based upon the motor specification. The no-load current of the motor will be very low, up to 30% of full load.The circuit diagram is shown in Fig 1.

As the power factor of the motor on no-load is very low, in the range of 0.1 to 0.2, the wattmeters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will be approximate equal to the product of the ammeter and voltmeter full scale deflection values.

The calculation is done as follows to determine the constant losses of the induction motor.

At no-load, the output delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Calculation

V_{NL} is $\rightarrow$ line stator voltage
I_{NL} is $\rightarrow$ line current
P_{NL} is $\rightarrow$ Three-phase power input.

The input power consists of the core loss P_c, friction and windage loss $P_{(rot)}$, and the stator copper loss.

$P_{NL} = P_c + P_{rot} + 3\ I^2_{NL}\ R_S$

This permits the sum of rotational loss to be evaluated.

$P_{rot+C} = P_{NL} - 3\ I^2_{NL}\ R_S$

where the stator resistance R_s per phase obtained from a resistance measurement at the stator terminal.

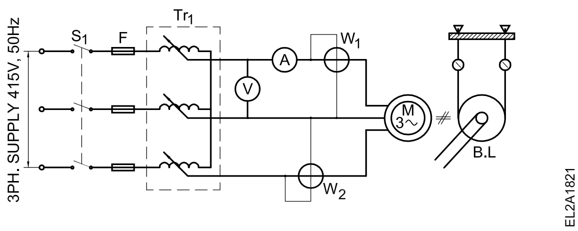
In star connection $R_S = R/2$.

Delta connection $R_S = 2/3\ R$.

Blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **determine the full load copper loss of a 3-phase induction motor without actually loading it**
- **calculate the total equivalent resistance per phase.**

Fig 1



The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeters will be of a suitable range and its power factor is 0.5 to unity.

An auto-transformer is used to give a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. One such arrangement is shown in Fig 1. The belt is over-tightened on the pulley to prevent rotation.

As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. Therefore, a small induced voltage in the rotor cage winding will be sufficient to cause a large current to flow in the cage.

It is very essential to limit the supply voltage to a value less than 5% at start and then gradually increase until the starter current is equal to the full load current. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 HP 400V, 50 Hz, four-pole, three-phase induction motor was tested and the following data were obtained.

Blocked rotor test: $V_S = 54$. $P_S = 430$, $I_S = 7.5$ A.

The resistance of the stator winding gives a 4 V drop between the terminals' rated DC current flowing.

Find the power factor at short circuit and R_e and X_e and full load copper loss.

Given:

Output	= 5 HP
Voltage	= 400 V
Frequency	= 50 Hz.
Blocked rotor voltage, V_s	= 54 V
Power P_S,	= 430 W
Current, I_S	= 7.5 A

Find:

Power factor at short circuit $= \cos\phi_S$
Equivalent resistance, R_e/phase
Equivalent reactance X_e/phase
Full load copper loss $= 3I^2 R_e$.

Known:

$W_s = \sqrt{3}\ V_s I_s \quad \cos\phi_s$

$$\text{Equivalent impedance } Z_e = \frac{V_s}{\sqrt{3}I_S} = \sqrt{R_e^2 + X_e^2}$$

$$R_e = \text{equivalent resistance} = \frac{P_s}{3I_s^2}$$

$$X_e = \text{equivalent reactance} = \sqrt{Z_e^2 - R_e^2}$$

SOLUTION:

$W_s = \sqrt{3}\ V_s I_s \quad \cos\phi_s$

$$\cos\phi_s = \frac{W_s}{\sqrt{3}\ V_s I_s}$$

$$\cos\phi_S = \frac{430}{1.72 \times 54 \times 7.5}$$

$$= \frac{430}{696.6}$$

$$= 0.61$$

$$\text{Equivalent resistance } R_e/\text{phase} = \frac{P_s}{3 \times I_s^2}$$

$$= \frac{430}{3 \text{ x } (7.5)^2}$$

$$= \frac{430}{168.75} = 2.5\Omega$$

$$X_e = \text{equivalent reactance/phase} = \sqrt{Z_e^2 - R_e^2}$$

$$Z_e = \frac{54}{\sqrt{3} \text{ x } 7.5} = \frac{54}{12.90} = 4.1$$

$$X_e = \sqrt{4.1^2 - 2.5^2} = \sqrt{16.81 - 6.25}$$

$$= \sqrt{10.56} = 3.4\Omega.$$

Full load copper loss $= 3 I^2 R_e$

$= 3 \text{ x } 7.5^2 \text{ x } 2.5 = 421.875$ Watts

ANSWER

(i) $\text{Cos } \phi_s = 0.61$

(ii) Equivalent resistance R_e /phase = 2.5 Ω

(iii) Equivalent reactance X_e/phase = 3.25 Ω

(iv) Full load copper loss = 421.875 Watts

Efficiency from no-load and blocked rotor test

Objective: At the end of this lesson you shall be able to
- **determine the efficiency at full load.**

Example

A 5 HP 220V, 50 Hz four-pole, three-phase induction motor was tested and the following data were obtained.

No load test = V_{NL} = 220V, P_{NL} = 340 W, I_{NL} = 6.2 A

Blocked rotor test = V_{BR} = 54V, P_{BR} = 430W,

I_{BR} = 15.2 A

Application 4V DC across two stator terminals causes the rated current flow with stator (assume star connection). Determine the efficiency at full load as in Fig 1

Assuming star connection DC resistance/phase = R/2

SOLUTION:

$R_1 + R_2 = 4/15.2 = 0.263\ \Omega$

Resistance/phase = 0.263/2 = 0.1315 Ω

Effective AC resistance $R_s = 1.4\ R_{ph}$

$= 1.4 \text{ x } 0.1315$

$= 0.1841\ \Omega$

$P_{(rot + c)}$ $= P_{NL} - 3I^2_{NL}\ R_s$

$= 340 - 3 \text{ x } 6.2^2 \text{ x } 0.1841$

$= 340 - 21.23$

$= 318.77\ \Omega$ (constant loss)

Copper loss $= 3I^2\ R_e = 430\ \Omega$

Output $= 5 \text{ x } 735.5 = 3677.5\ \Omega$

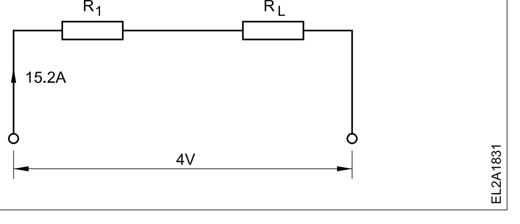
$$\text{Efficiency} = \frac{3677.5}{3677.5 + 318.77 + 430} = \frac{3677.5}{4426.2}$$

= 0.830

% efficiency = 0.830 x 100

i.e. = 83%.

Fig 1



Alternator - Principle - Relation between poles, speed and frequency

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of an alternator**
- **draw and explain the method of production of sine wave voltage by a single loop alternator**
- **describe the relation between frequency, number of poles and synchronous speed.**

Principle of an alternator: An alternator works on the same principle of electromagnetic induction as a DC generator. That is, whenever a conductor moves in a magnetic field so as to cut the lines of force, an emf will be induced in that conductor. Alternatively whenever there is relative motion between the field and the conductor, then, the emf will be induced in the conductor. The amount of induced emf depends upon the rate of change of cutting or linkage of flux.

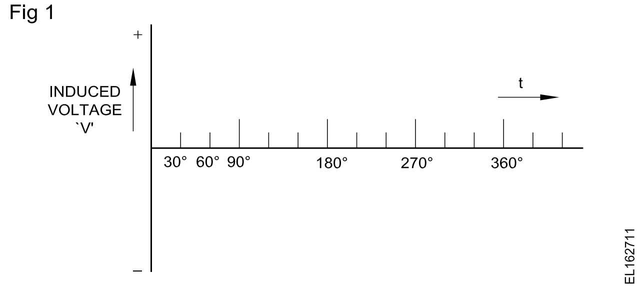
In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armatrue coils can be brought out to the external circuit with the help of slip-rings. Alternatively the stationary conductors in the stator can produce alternating current when subjected to the rotating magnetic field in an alternator.

Production of sine wave voltage by single loop alternator: Fig 2a shows a single loop alternator. As it rotates in the magnetic field, the induced voltage in it varies in its direction and magnitude as follows.

To plot the magnitude and direction of the voltage induced in the wire loop of the AC generator in a graph, the electrical degrees of displacement of the loop are kept in the `X' axis as shown in Fig 1 through 30 electrical degrees. As shown in Fig 2c, three divisions on the `X' axis represent a quarter turn of the loop, and six divisions a half turn. The magnitude of the induced voltage is kept in the `Y' axis to a suitable scale.

The part above the X-axis represents the positive voltage, and the part below it the negative voltage as shown in Fig 1.

Fig 1



The position of the loop at the time of starting is shown in Fig 2a and indicated in Fig 2c as `O' position. At this position, as the loop moves parallel to the main flux, the loop does not cut any lines of force, and hence, there will be no voltage induced. This zero voltage is represented in the graph as the starting point of the curve as shown in Fig 2c. The magnitude of the induced emf is given by the formula E_0 = BLV Sinθ

where

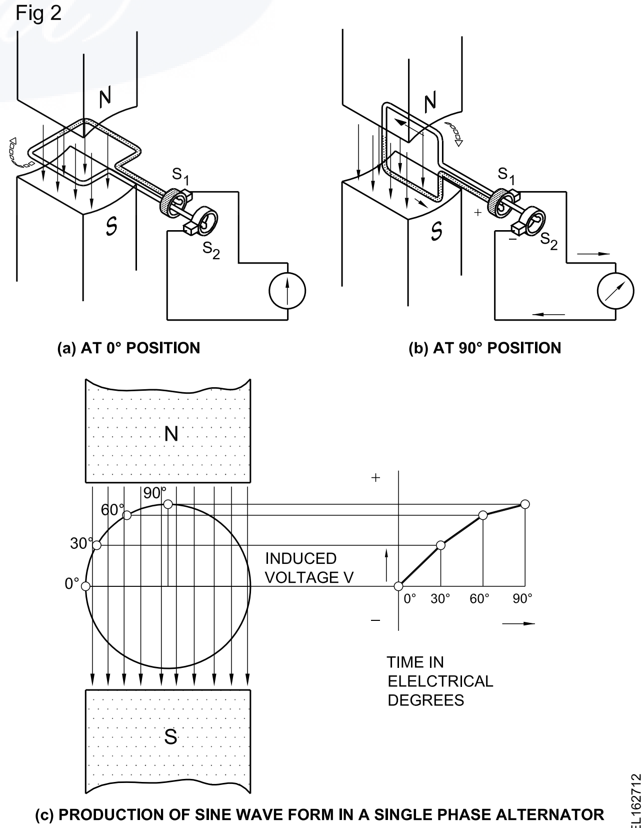
- B is the flux density in weber per square metre,
- L is the length of the conductors in metres,
- V is the velocity of the loop rotation in metres per second and
- θ is the angle at which the conductor cuts the line of force.

As sin θ = 0

E at 0 position is equal to zero. As the loop turns in a clockwise direction at position 30° as shown in Fig 2c, the loop cuts the lines of force and an emf is induced (E_{30}) in the loop whose magnitude will be equal to BLV Sin θ where θ is equal to 30°.

Applying the above formula, we find the emf induced in the loop at 90° position will be maximum as shown in Fig 2c.

Fig 2



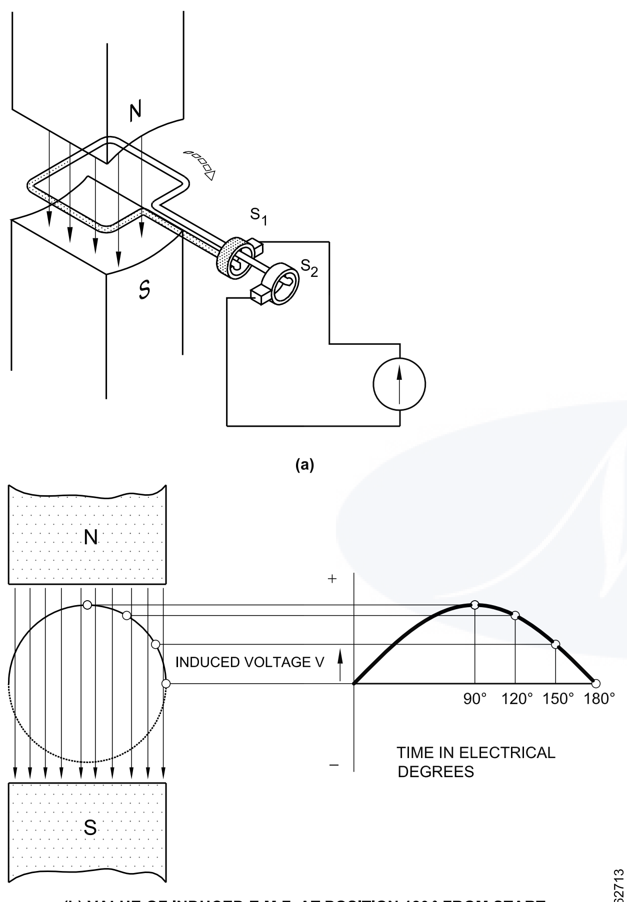
(c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

As the loop turns further towards 180° it is found the number of lines of force which are cut will be reduced to zero value. If the quantity of emf induced at each position is marked by a point and a curve is drawn along the points, the curve will be having a shape as shown in Fig 3b.

During the turn of the loop, from 0 to 180°, the slip ring S_1 will be positive and S_2 will be negative.

However, at 180° position, the loop moves parallel to the lines of force, and hence there is no cutting of flux by the loop and there is no emf induced in the loop as shown in Fig 3b.

Fig 3



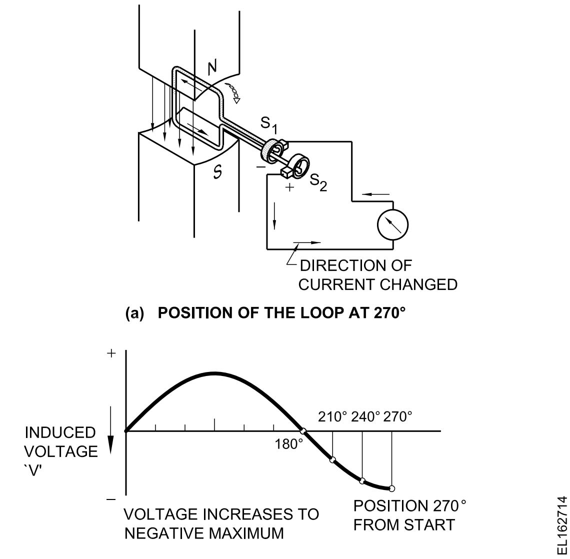
(a)

(b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

Further during the turn of the loop from the position 180° to 270°, the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360°, the slip ring S_2 will be positive and S_1 will be negative as shown in Fig 4a. However, at 270° the voltage induced will be the maximum and will decrease to zero at 360°. Fig 5b shows the variation of the induced voltage in both magnitude and direction during one complete revolution of the loop. This is called a cycle.

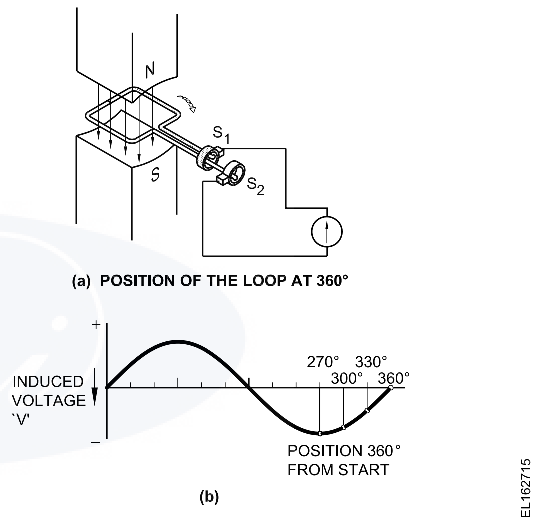
This type of wave-form is called a sine wave as the magnitude and direction of the induced emf, strictly follows the sine law. The number of cycles completed in one second is called a frequency. In our country, we use an AC supply having 50 cycles frequency which is denoted as 50 Hz.

Fig 4



(a) POSITION OF THE LOOP AT 270°

Fig 5



(a) POSITION OF THE LOOP AT 360°

(b)

Relation between frequency, speed and number of poles of alternator: If the alternator has got only two poles, the voltage induced in one revolution of the loop undergoes one cycle. If it has four poles, then one complete rotation of the coil produces two cycles because, whenever it crosses a set of north and south poles, it makes one cycle.

Fig 6 shows the number of cycles which are produced in each revolution of the coil, with 2 poles, 4 poles and 6 poles. It is clear from this that the number of cycles per revolution is directly proportional to the number of poles, `P' divided by two. Therefore the number of cycles produced per second depends on P/2, and the speed in revolutions per second.

Therefore frequency $F = \frac{P}{2} \times 'n'$

where `n' is in r.p.s.

`P' is the number of poles.

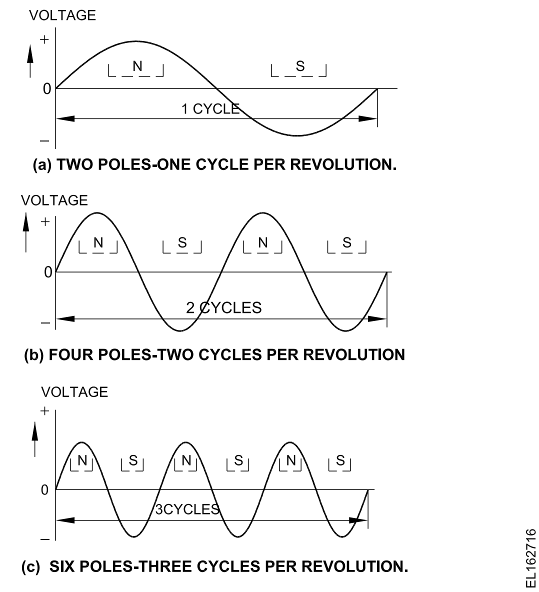
Generally speed is represented in r.p.m.

Then we have requency $F = \frac{PN}{2 \times 60} = \frac{PN}{120}$

where P is number of poles and N is speed in r.p.m.

Accordingly we can state that the frequency of an alternator is directly porportional to the number of poles and speed.

Fig 6



Types and construction of alternators

Objective: At the end of this lesson you shall be able to

• explain the construction, and the various types of alternators.

Types of alternators: DC and AC generators are similar in one important respect, that is, they both generate alternating emf in the armature conductors. The AC generator sends out the electrical energy in the same form of alternating emf to the external load with the help of slip rings.

AC generators, named as alternators, must be driven at a very definite constant speed called synchronous speed, because the frequency of the generated emf is determined by the speed. Due to this reason these machines are called `synchronous alternators or synchronous generators'.

Classification according to the type of rotating part: One way of classifying the alternator is the way in which the rotating part is chosen. In the earlier lessons, we discussed how an alternator can have either stationary or rotating magnetic field poles. Accordingly an alternator having a stationary magnetic field and a moving armature is called a rotating armature type, and an alternator with a stationary armature and moving magnetic field is called a rotating field type. There are definite advantages in using rotating field type alternators.

Advantages of using rotating field type alternators

Only two slip rings are required for a rotating field type alternator whatsoever the number of phases may be.

As the main winding is placed over the stator, more conductors can be housed in the stator because of more internal peripheral area. More conductors result in higher voltage/current production.

As the winding in which the emf is induced is stationary, there is no possibility of breaking or loosening the winding and its joints, due to rotational forces.

There is no sliding contact between the stationary armature and the external (load) circuit, as the supply could be taken direct. Only two slip rings are provided in the rotor for low power low voltage field excitation. Thus less sparking and less possibility of faults.

The main winding being stationary, the conductors can be easily and effectively insulated, and the insulating cost also will be less for higher output voltage (less dielectric strength insulation will be sufficient).

Stationary main conductors need less maintenance.

As the rotar has a field winding which is lighter for the given capacity than in the rotating armature type, the alternator can be driven at a higher speed.

Classification according to the number of phases: Another way of classifying the alternators is based on production of single or 3-phase by the alternator. Accordingly the types are 1) single-phase alternators 2) three-phase alternators.

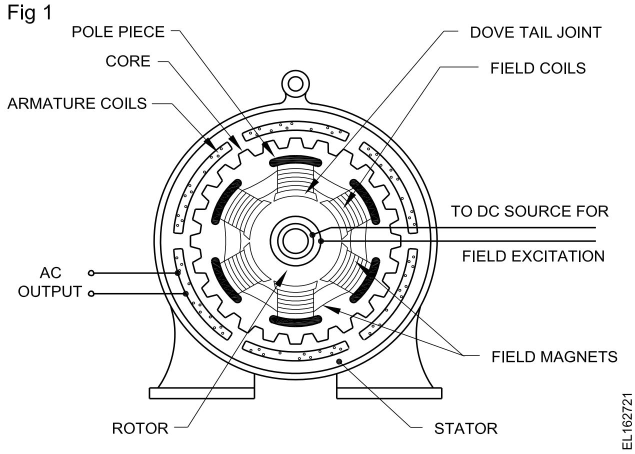
Single-phase alternators: A single-phase alternator is one that provides only one voltage. The armature coils are connected in `series additive'. In other words, the sum of the emf induced in each coil produces the total output voltage. Single phase alternators are usually constructed in small sizes only. They are used as a temporary standby power for construction sites and for permanent installation in remote locations.

Three-phase alternators: This alternator provides two different voltages, namely, phase and line voltages. It has 3 windings placed at 120° to each other, mostly connected in a star having three main terminals U,V,W and neutral `N'.

These alternators are driven by prime movers such as diesel engines, steam turbines, water wheels etc. depending upon the source available.

Construction of alternators: The main parts of a revolving field type alternator are shown in Fig 1.

Fig 1



Stator: It consists of mainly the armature core formed of laminations of steel alloy (silicon steel) having slots on its inner periphery to house the armature conductors. The armature core in the form of a ring is fitted to a frame which may be of cast iron or welded steel plate. The armature core is laminated to reduce the eddy current losses which occur in the stator core when subjected to the cutting of the flux produced by the rotating field poles. The laminations are stamped out in complete rings (for smaller machines) or in segments (for larger machines), and insulated from each other with paper or varnish. The stampings also have holes which make axial and radial ventilating ducts to provide efficient cooling. A general view of the stator with the frame is shown in Fig 2.

Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3(a) and (b) respectively.

The open slots are more commonly used because the coils can be form-wound and pre-insulated before placing in the slots resulting in fast work, less expenditure and good insulation. This type of slots also facilitates easy removal and replacement of defective coils. But this type of slots creates uneven distribution of the flux, thereby producing ripples in the emf wave. The semi-closed type slots are better in this respect but do not permit the use of form-wound coils, thereby complicating the process of winding. Totally closed slots are rarely used, but when used, they need bracing of the winding turns.

Fig 2

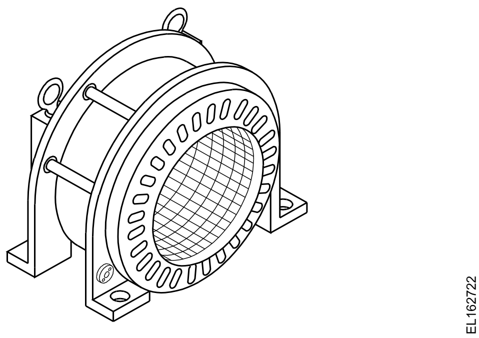
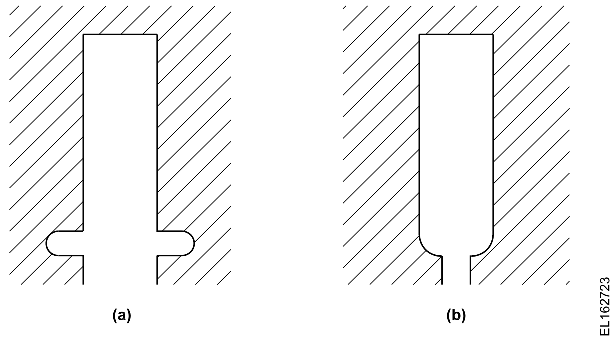


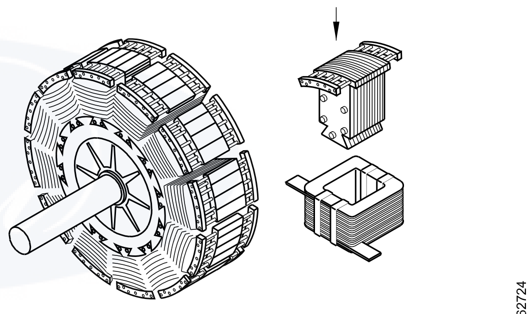
Fig 3



Rotor: This forms the field system, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage DC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted to the same alternator shaft. The exiting current is supplied to the rotor with the help of two slip- rings and brushes. The field poles created by the excitation are alternately north and south.

Rotating field rotors are of two types, namely (i) salient pole type as shown in Fig 4 and (ii) smooth cylindrical type or non-salient pole type, as shown in Fig 5.

Fig 4



SALIENT POLE FIELD STRUCTURE

Salient pole type: This type of rotor is used only for slow and medium speed alternators. This type is less expensive, having more space for the field coils and vast heat dissipating area. This type is not suitable for high speed alternators as the salient poles create a lot of noise while running in addition to the difficulty of obtaining sufficient mechanical strength.

Fig 4 shows the salient pole type rotor in which the riveted steel laminations are fitted to the shaft fitting with the help of a dovetailed joint. Pole faces are curved to have uniform distribution of the flux in the air gap leading to production of sinusoidal wave form of the generated emf. These pole faces are also provided with slots to carry the damper winding to prevent hunting. The field coils are connected in series in such a way as to produce alternate north and south poles, and the field winding ends are connected to the slip rings. The DC excitation source is connected to the brushes which are made to contact the slip rings with the required pressure.

Salient pole type alternators could be identified by their larger diameter, short axial length and low or medium speed of operation.

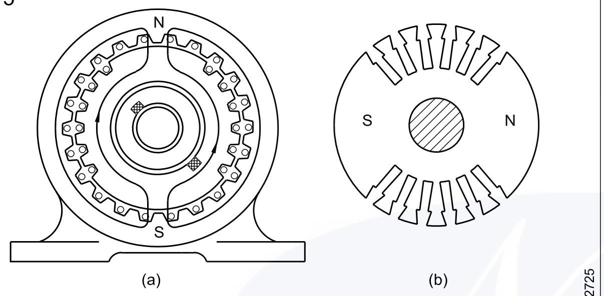
Smooth cylindrical or non-salient pole type rotor: This type is used in very high speed alternators, driven by steam turbines. To have good mechanical strength, the peripheral velocity is lowered by reducing the diameter of the rotor and alternatively with the increased axial length. Such rotors have either two or four poles but run at higher speeds.

To withstand such speeds, the rotor is made of solid steel forging with longitudinal slots cut as shown in Fig 5a which shows a two-pole rotor with six slots. The winding is in the form of insulated copper strips, held securely in the slots by proper wedges, and bound securely by steel bonds.

One part of the periphery of the rotor in which slots are not made is used as poles as shown in Fig 5b.

Smooth cylindrical pole type alternators could be identified by their shorter diameter, longer axial length and high speed of operation.

Fig 5



NON-SALIENT POLE TYPE FIELD STRUCTURE

Rating of alternators

An electrical machine is usually rated at the load, which it can carry without over heating and damage to insulation. i.e. the rating of electrical machine is governed by the temperature rise caused by internal losses of the machine. The copper loss in the armature (I^2R) depends upon the strength of the armature current and is independent of power factor.

The output in kW is proportional to power factor for the alternator of a given kVA. For example output of 1000 kVA alternator on full load will be 200, 500, 800, 1000 kW at power factor 0.2, 0.5, 0.8, and unity respectively but copper losses in armature will remain the same regardless of power factor.

For the above reasons alternators are usually rated in kVA (kilo Volt Ampere).

Hunting

Hunting is a phenomenon in alternator which is caused by continuous fluctuation in load. When the load on the alternator is frequently changing, then the rotor of the alternator runs unsteadily making a noise of a whistle due to oscillations, or vibrations set up in the rotor. This phenomenon is called as hunting of alternators.

Hunting is prevented by the Damper windings provided in the field pole core.

Generation of 3-phase voltage and general test on alternator

Objectives: At the end of this lesson you shall be able to
- **draw and explain the method of generating 3-phase voltage wave-forms by a 3-phase alternator**
- **explain what is meant by phase sequence**
- **state the method of testing an alternator for continuity insulation and earth connection**
- **state the I.E.E. regulations and B.I.S. recommendations pertaining to earthing of the alternator.**

An AC three-phase system is the most common system used in the present world. It is because of its high efficiency, less cost of material required for the generation, transmission and distribution for a given capacity. The three-phase system supplies power to drive three-phase motors in industry as well as supplying power to single phase motors and lighting loads for both industrial and domestic purposes. Present day electricians may be employed in a generating station or may be employed in a standby power station where three-phase alternators are used. Hence a fairly good knowledge about production of 3-phase voltages, their phase sequence and general testing of alternators is essential.

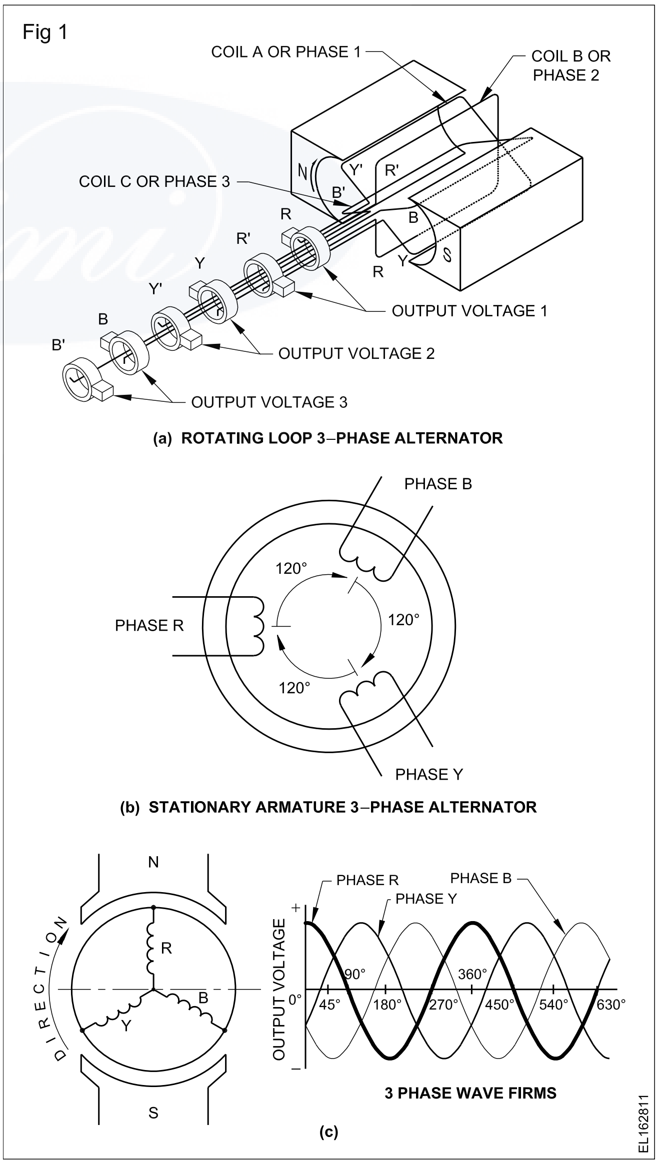
Generation of three-phase voltage: Basically,the principle of a three-phase alternator (generator) is the same as that of a single phase alternator (generator), except that there are three equally spaced coils or windings which produce three output voltages which are out of phase by 120° with each other.

A simple rotating-loop, three-phase generator with its output voltage wave-forms is shown in Fig 1c.

As shown in Fig 1a, three independent loops spaced about 120° apart are made to rotate in a magnetic field with the assumption that the alternator shown is a rotating armature type. As shown in Fig 1a, the three loops are electrically isolated from each other and the ends of the loops are connected to individual slip rings. As the loops are rotating in a uniform magnetic field, they produce sine waves. In a practical alternator, these loops will be replaced by a multi-turn winding element and distributed throughout the rotor slots but spaced apart at 120° electrical degrees from each other. Further, in practice, there will not be six slip rings as shown in Fig 1a but will have either four or three slip rings depending upon whether the three windings are connected in a star or delta respectively.

We also know, as discussed earlier, that the rotating magnetic field type alternators are mostly used. In such cases only two slip rings are required for exciting the field poles with DC supply. Fig 1b shows a stationary, 3-phase armature in which individual loops of each winding are replaced by coils spaced at 120 electrical degrees apart. However, the rotating part having the magnetic poles is not shown.

Fig 1c shows the rotating armature type alternator in which the 3 coils of the three-phases are connected in star which rotates in a two-pole magnetic field. According to Fig 1c, the coil `R' moves under the influence of the `N' pole cutting the flux at right angles, and produces the maximum induced voltage at position `O°' as shown in the graph as per Faraday's Laws of Electromagnetic induction. When the coil `R' moves in a clockwise direction, the emf induces falls to zero at 90 degrees, and then increases to -ve maximum under the influence of the south pole at 180 degrees. Likewise the emf induced in the `R' phase will become zero at 270 degrees and attain +ve maximum at 360 degrees. In the same manner the emf produced by coils `Y' and `B' could be plotted on the same graph. A study of the sine wave-forms produced by the three coils RYB shows that the voltage of coil `R' leads voltage of coil `Y' by 120°, and the voltage of coil `Y' leads voltage of coil `B' by 120°.



Phase sequence: The phase sequence is the order in which the voltages follow one another, i.e. reach their maximum value. The wave-form in Fig 1c shows that the voltage of coil R or phase R reaches its positive maximum value first, earlier than the voltage of coil Y or phase `Y', and after that the voltage of coil B or phase B reaches its positive maximum value. Hence the phase sequence is said to the RYB.

If the rotation of the alternator shown in Fig 1c is changed from clockwise to anticlockwise direction,the phase sequence will be changed as RBY. It is the most important factor for parallel connection of polyphase generators and in polyphase windings. Further the direction of rotation of a 3-phase induction motor depends upon the phase sequence of the 3-phase supply. If the phase sequence of the alternator is changed, all the 3-phase motors, connected to that alternator, will run in the reverse direction though it may not affect lighting and heating loads.

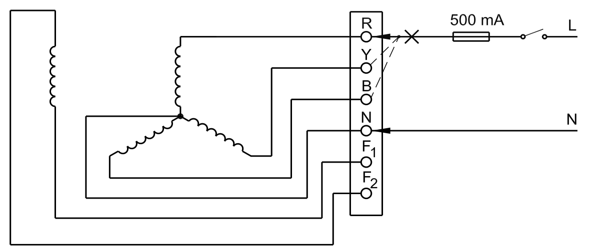
The only difference in the construction of a single phase alternator and that of a 3-phase alternator lies in the main winding. Otherwise both the types of alternators will have similar construction.

General testing of alternator: Alternators are to be periodically checked for their general condition as they will be in service continuously. This comes under preventive maintenance, and avoids unnecessary breakdowns or damage to the machine. The usual checks that are to be carried out on an altenator are:

- continuity check of the windings
- insulation resistance value between windings
- insulation resistance value of the windings to the body
- checking the earth connection of the machine.

Continuity test: The continuity of the windings is checked by the following method as shown in Fig 2.

Fig 2

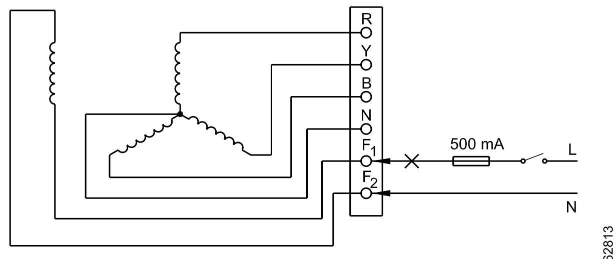


CONTINUITY TEST ON MAIN WINDING OF A 3-PHASE ALTERNATOR

A test lamp is connected in series with one end to the neutral (star point) and the other end to one of the winding terminals (R Y B). If the test lamp glows equally bright on all the terminals RYB then the continuity of the winding is all right. In the same way, as shown in Fig 3, we can test the field leads F1 and F2 for field continuity.

Testing continuity with the test lamp only indicates the continuity in between two terminals but will not indicate any short between the same windings. A more reliable test will be to use an ohmmeter to check the individual resistances of the coils, and compare them to see that similar coils have the same resistance. The readings, when recorded, will be useful for future reference also.

Fig 3

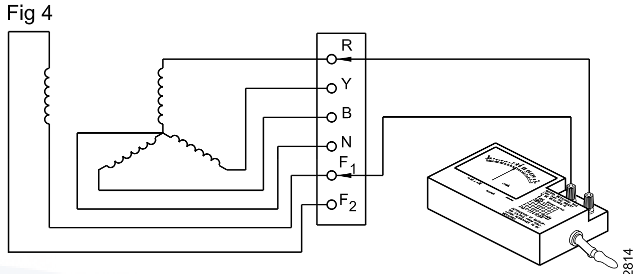


CONTINUITY TEST ON FIELD WINDING OF A 3-PHASE ALTERNATOR

For insulation resistance test

Between windings: As shown in Fig 4, one end of the Megger lead is connected to any one terminal of the RYB and the other is connected to F1 or F2 of the field winding. If the Megger reads one megohm or more, then the insulation resistance is accepted as okay.

Fig 4

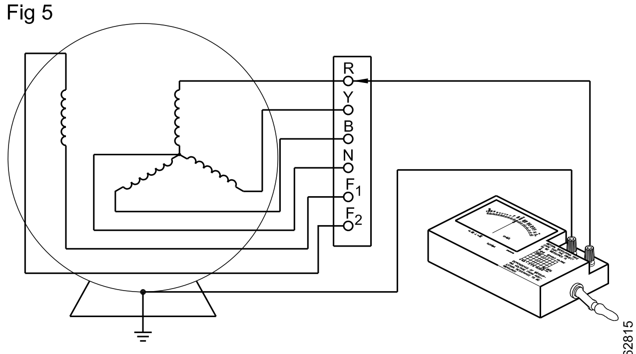


INSULATION TEST BETWEEN WINDINGS

If there is short, between the armature and field windings, the Megger reads zero ohms. If it is weak, it shows less than one megohm.

Testing insulation resistance between body and windings: As shown in Fig 5, one lead of the Megger is connected to one of the leads of the RYB, and the other lead of the Megger is connected to the body. If the insulation between the windings and the frame is all right, the Megger reads more than one megohm.

Fig 5



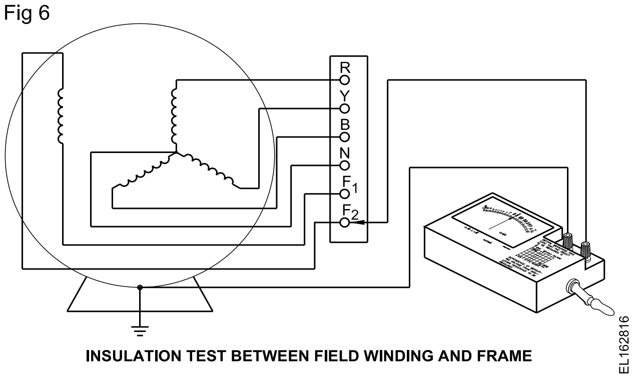
INSULATION TEST BETWEEN MAIN WINDING AND FRAME

The field is tested by connecting one terminal of the Megger to F1 or F2 of the field and the other terminal to the body as shown in Fig 6. If the insulation between the field and the frame is all right, the Megger reads more than one megohm. A lower reading than one megohm shows weak insulation and leakage to the ground.

Caution:

While conducting the insulation resistance test, if the Megger reads zero, then it should be concluded that the insulation of the winding has failed completely and needs thorough checking.

Fig 6



INSULATION TEST BETWEEN FIELD WINDING AND FRAME

> **The permissible insulation resistance should not be less than 1 megohm.**

Earthing of alternators: This consists of two equally important requirements as stated below.

- Earthing of the neutral of the alternator
- Earthing of the alternator frame.

Earthing of neutral: According to B.I.S. 3043-1966, it is recommended to use one of the following methods for earthing the neutral of the alternator.

- Solid earthing
- Resistance earthing
- Reactance earthing
- Arc-suppression coil earthing

The selection and the type of earthing depends to a large extent on the size of the unit, the system voltage protection scheme used, the manufacturer's recommendation and the approval of the electrical inspectorate authority. Trainees are advised to refer to B.I.S.3043-1966 for further details. As earthing of neutral is essential for the operation of protective relays, to maintain proper voltage in the system and for safety reasons, trainees are advised to identify the method of neutral earthing adopted in the available alternator, maintain the continuity of earth connections and keep the earth electrode resistance within the specified value.

Earthing alternator frame: This earthing is essential for the safety of the workers, and to keep the frame of the alternator at zero earth potential. Operation of the earth fault relays or fuses to open the electrical circuits in case of earth faults is fully dependent upon earthing of the frame.

As per I.E. rules No.61, all the electrical equipment/ machines are to be provided with double earthings for safe operation. The condition of earth must be checked periodically, and the earth electrode and the earth conductor resistance must also be measured and recorded at repeated intervals of time. The earth electrode and the earthing conductors should be maintained such that the resistance value is lower than the stipulated value according to the design of the system.

Emf equation of an alternator

Objective: At the end of this lesson you shall be able to
- **explain the emf equation and apply the emf equation to calculate the induced emf in an alternator.**

Equation of induced emf: The emf induced in an alternator depends upon the flux per pole, the number of conductors and speed. The magnitude of the induced emf could be derived as stated below

Let Z = No.of conductors or coil sides in series/ phase in an alternator

P = No.of poles

F = frequency of induced emf in Hz

Ø = flux per pole in webers

k_f = form factor = 1.11 - if emf is assumed to be sinusoidal

N = rotative speed of the rotor in r.p.m.

According to Faraday's Law of Electromagnetic Induction we have the average emf induced in a conductor

= rate of change of flux linkage

$$= \frac{d\varnothing}{dt}$$

$$= \frac{\text{change of total flux}}{\text{time duration in which the flux change takes place}}$$

In one revolution of the rotor (ie in 60/N seconds), each stator conductor is cut by a flux equal to PØ webers.

Hence the change of total flux = dØ = PØ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts} \qquad \text{-------Eq. 1}$$

Substituting the value for in eqn 1

we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120F}{P60} \text{ volts} = 2\varnothing F \text{ volts}$$

If there are Z conductors in series per phase we have the average emf per phase = 2ØFZ volts.

Then r.m.s. value of emf per phase = average value x form factor

$= V_{AV} \times K_F$

$= V_{AV} \times 1.11$

$= 2ØFZ \times 1.11$

$= 2.22ØFZ$ volts.

Alternatively r.m.s. value of emf per phase = 2.22ØF2T volts

= 4.44ØFT volts

where T is the number of coils or turns per phase

and Z = 2T.

This would have been the actual value of the induced voltage if all the coils in a phase were (i)full pitched and (ii) concentrated or bunched in one slot. (In actual practice, the coils of each phase are distributed in several slots under all the poles.) This not being so, the actually available voltage is reduced in the ratio of these two factors which are explained below.

Pitch factor (K_p or K_c.): The voltage generated in a fractional pitch winding is less than the full pitch winding. The factor by which the full pitch voltage is multiplied to get voltage generated in fractional pitch is called pitch factor, and it is always less than one; and denoted as K_p or K_c. Normally this value is given in problems directly; occasionally this value needs to be calculated by a formula $K_p = K_c = \cos \alpha / 2$

where a is the electrical angle by which the coil span falls short of full pitch.

Example: Calculate the pitch factor for a winding having 36 stator slots, 4 poles with a coil span of 1 to 8.

$$\text{For full pitch} = \frac{\text{Number of stator slots}}{\text{Number of slots}} = \frac{36}{4} = 9.$$

Hence winding should start at 1 and end at 10.
In actual practice the coil span is taken as 1 – 8.
Hence actual pitch = 8 – 1 = 7.
Hence the coil span is short pitched by = 9 – 7 = 2.

$$\text{The angle } \alpha = \frac{\text{difference in pitch}}{\text{full pitch}} \times 180°$$

$$= \frac{2}{9} \times 180° = 40°$$

where 180° is the complete angle for full pitch.

$$\text{Pitch factor } K_c = \cos\frac{\alpha}{2} = \cos\frac{40}{2} = \cos 20 = 0.94.$$

Distribution factor (K_d): It is imperative that the conductors of the same phase need to be distributed in the slots instead of being concentrated at one slot. Because of this, the emf generated in different conductors will not be in phase with each other, and hence, cannot be added together to get the total induced emf per phase but to be added vectorially. This has to be taken into account while determining the induced voltage per phase.

Therefore, the factor by which the generated voltage must be multiplied to obtain the correct value is called a distribution factor, denoted by K_d and the value is always less than one. The formula for finding the value of K_d is given below.

$$K_d = \frac{\sin m\,\beta / 2}{m \sin \beta / 2}$$

where m is the number of slots per phase per pole

$$\beta = \frac{180^o}{\text{No. of slots per pole}}$$

Example: A six-pole alternator rotating at 1000 r.p.m. has a single-phase winding housed in three slots per pole; the slots in groups of three being 20° apart. Find the distribution factor.

$$K_d = \frac{\sin m\,\beta / 2}{m \sin \beta / 2}$$

where m = 3 slots per phase per pole

$\beta = 20^0$

$$K_d = \frac{\sin 3 \times 20 / 2}{3 \sin 20 / 2} = \frac{\sin 30°}{3 \sin 10°}$$

$$= \frac{0.5}{3 \times 0.1736} = 0.96$$

Example: A 3-phase, 12-pole, star-connected alternator has 180 slots with 10 conductors per slot, and the conductors of each phase are connected in series. The coil span is 144° (electrical). Find the distribution factor and the pitch factor K_p.

$$K_d = \frac{\sin m\,\beta/2}{m \sin \beta/2}$$

$$m = \frac{180}{3 \times 12} = 5 \text{ slots per phase per pole.}$$

$$\beta = \frac{180°}{\frac{180}{12}} = 12°$$

$$K_d = \frac{\sin 5 \times \frac{12}{2}}{5 \sin \frac{12}{2}} = \frac{\sin 30°}{5 \sin 6°} = \frac{0.5}{5 \times 0.1045} = 0.957$$

$$K_p = \cos\frac{\alpha}{2}$$

= Cos (180-144)/2 = Cos 36/2 = Cos 18° = 0.95.

From the foregoing, it is found that the pitch factor and the distribution factor are to be used to multiply the induced emf to get the actual induced voltage. Thus emf induced in an alternator E_o per phase $4.44\, K_p K_d FØT$ volts.

In the case of a star-connected alternator, the line voltage $= E_L = \sqrt{3}E_P = \sqrt{3}E_0$ and in the case of a delta-connected alternator the line voltage $E_L = E_p = E_o$. However, if the value of either Kd or K_p is not given in the problem it can be assumed to be one.

Example: Calculate the effective voltage in one phase of an alternator, given the following particulars. F=60 Hz, turns/phase T = 240, flux per pole Ø = 0.0208 webber.

Solution: As K_c/K_p and K_d values are not given, we can assume they are equal to one.

Voltage/phase E = 4.44 ØFT volts

= 4.44 x 60 x 0.0208 x 240 volts

= 1329.86 V or 1330 volts.

***Example*:** The following information is given in connection with a 3-phase alternator. Slots = 96, poles = 4, r.p.m. = 1500, turns/coil = 16 in single layer, Ø = 2.58 x 10^6 lines. Calculate the voltage generated/phase.

$$F = \frac{PN}{120} = \frac{4 \times 1500}{120} = 50 \text{ Hz.}$$

$$\text{Coils per phase} = \frac{\text{No. of slots}}{\text{No. of phases}} = \frac{96}{3} = 32.$$

Therefore turns/phase = 32 x 16 = 512

= 2.58 x 10^6 lines = 2.58 x 10^6 x 10^{-8} weber

V = 4.44 FØT

= 4.44 x 50 x 512 x 2.58 x 10^6 x 10^{-8} = 2932 volts.

Example: The stator of a 3-phase, 16-pole alternator has 144 slots, and there are 4 conductors per slot connected in two layers, and the conductors of each phase are connected in series. If the speed of the alternator is 375 r.p.m. calculate the emf induced per phase. The resultant flux in the air gap is 5 x 10^{-2} webers per pole, sinusoidally distributed. Assume the coil span as 150° electrical.

Sinusoidal distribution, hence the wave form is sine wave and the emf induced

$E_o = E_p = 4.44\, K_c K_d FØT$ volts

$K_c = \text{Cos} = \text{Cos } (180\text{-}150)/2 = \text{Cos } \frac{30}{2}$

$= \text{Cos } 15 = 0.966$

$$m = \frac{144}{3 \times 16} = 3$$

$$\beta = \frac{180°}{\frac{144}{16}} = \frac{180}{9} = 20°$$

$$K_d = \frac{\text{Sin } 3 \times \frac{20}{2}}{3 \text{ Sin } \frac{20}{2}} = 0.96.$$

Number of slots/phase $= \frac{144}{3} = 48$

Number of conductors/slots = 4

Number of conductors in series per phase = 48 x 4

Number of turns in series per phase $= \frac{48 \times 4}{2} = 96.$

$$\text{Frequency} = \frac{PN}{120} = \frac{16 \times 375}{120} = 50 \text{ Hz.}$$

$E_{ph} = 4.44\, K_c K_d FØT$

= 4.44 x 0.966 x 0.96 x 50 x 5 x 10^{-2} x 96

= 988 volts.

Characteristics and voltage regulation of the alternator

Objectives: At the end of this lesson you shall be able to
- **explain the load characteristic of an alternator and the effect of the P.F. on terminal voltage**
- **explain the regulation of alternators and solve problems therein.**

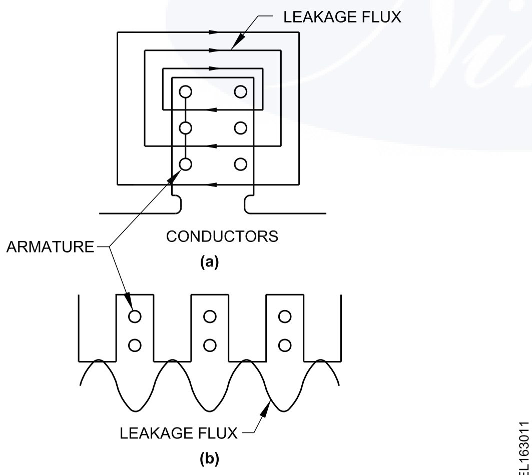
Load characteristic of an alternator: As the load on the alternator is changed, its terminal voltage is also found to change. The reason for this change is due to the voltage drop in the alternator because of

- armature resistance R_a
- armature leakage reactance X_L
- armature reaction which, in turn, depends upon the power factor of the load.

Voltage drop in armature resistance: Resistance of each phase winding of the alternator causes a voltage drop in the alternator, and it is equal to I_pR_a where I_p is the phase current and R_a is the resistance per phase.

Voltage drop in armature leakage reactance: When the flux is set up in the alternator due to the current flow in the armature conductors, some amount of flux strays out rather than crossing the air gap. These fluxes are known as leakage fluxes. Two types of leakage fluxes are shown in Figs 1a and b.

Fig 1



Though the leakage fluxes are independent of saturation, they do depend upon the current and the phase angle between the current and the terminal voltage `V'. These leakage fluxes induce a reactance voltage which is ahead of the current by 90°. Normally the effect of leakage flux is termed as inductive reactance X_L and as a variable quantity. Sometimes the value X_L is named as synchronous reactance to indicate that it refers to working conditions.

Voltage drop due to armature reaction: The armature reaction in an alternator is similar to DC generators. But the load power factor has considerable effect on the armature reaction in the alternators.

The effects of armature reaction have to be considered in three cases, i.e. when load power factor is
- unity
- zero lagging
- zero leading.

At unity P.F. the effect of armature reaction is only cross-magnetising. Hence there will be some distortion of the magnetic field.

But in the case of zero lagging P.F. the effect of armature reaction will be de-magnetising. To compensate this de-magnetising effect, the field excitation current needs to be increased.

On the other hand, the effect of armature reaction due to zero leading P.F. will be magnetising. To compensate the increased induced emf, and to keep the constant value of the terminal voltage due to this additional magnetising effect, the field excitation current has to be decreased.

Effect of armature resistance and reactance in the alternator: The induced emf per phase in an alternator is reduced by the effect of armature resistance, and reactance drops as shown vectorially in Fig 2 where

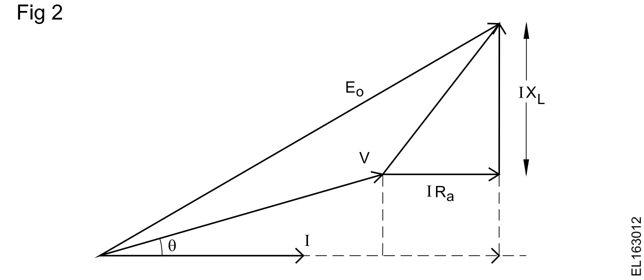
- V is the terminal voltage per phase
- I is the phase current
- θ is the power factor angle between phase current and terminal voltage
- E_o is the induced emf per phase
- R_a is the armature resistance per phase
- X_L is the armature reactance per phase.

The induced emf can be calculated either vectorially or mathematically.

Mathematically the induced emf

$$E = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

Fig 2



For any value of P.F. either lagging or leading, a combination of the effects of cross-magnetising, de-magnetising or magnetising takes place. In all the effects of armature reaction, it is shown vectorially as a force acting in line with the reactance drop as shown in Fig 3 by a vector IX_a.

However this value is not readingly measurable.

On the basis of the above information, it is found that the terminal voltage of an alternator with unity power factor load will fall slightly on load as shown in Fig 4. Also it is found that the terminal voltage falls considerably for an alternator having lagging power factor. On the contrary, with leading P.F. the terminal voltage of the alternator on load increases even beyond the no-load terminal voltage as shown in Fig 4.

Fig 3

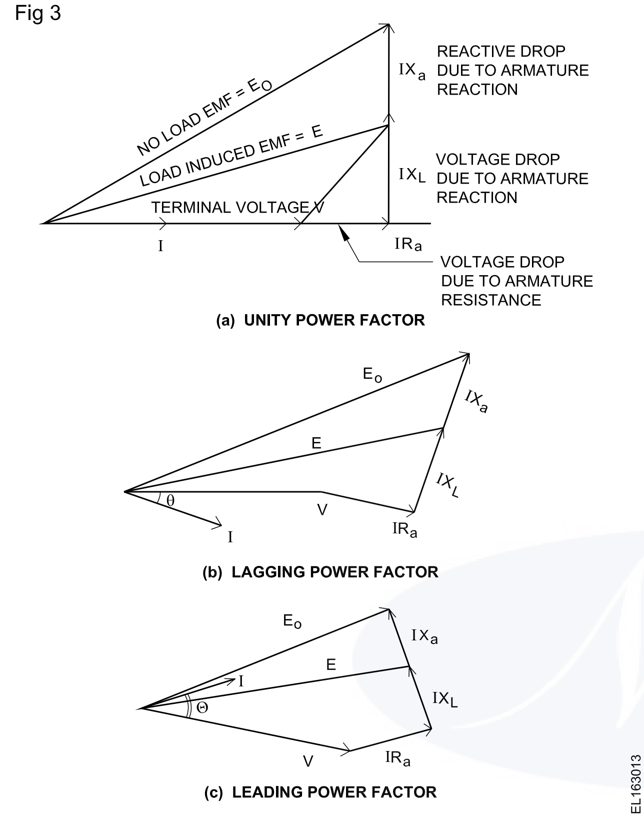
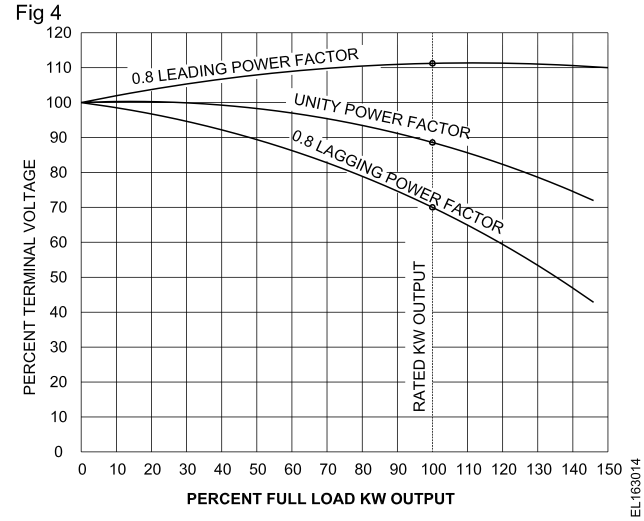


Fig 4



Rating of alternators: As the power factor for a given capacity load determines the load current, and the alternator's capacity is decided on load current, the rating of the alternator is given in kVA or MVA rather than kW or MW in which case the power factor also is to be indicated along with the wattage rating.

Example: A 3-phase, star-connected alternator supplies a load of 5 MW at P.F. 0.85 lagging and at a voltage of 11 kV. Its resistance is 0.2 ohm per phase and the synchronous reactance is 0.4 ohm per phase. Calculate the line value of the emf generated.

Full load current = $I_L = \dfrac{P}{\sqrt{3}E_L \cos\theta}$

$$\frac{5 \times 1000 \times 1000}{\sqrt{3} \times 11000 \times .85} = 309 \text{ Amps.}$$

In star I_L = I_P

IR_a drop = 309x0.2=61.8 V

Ix_L drop = 309 x 0.4 = 123.6 V

Terminal voltage (line)=11000 V

Terminal voltage(phase) $(V_P) = \dfrac{11000}{\sqrt{3}} = 6350\text{V}$

Power factor = 0.85

Power factor angle = $\theta = \cos^{-1}(.85)$

= Cos 31.8°

Sin θ = 0.527.

Drawing the vector, as shown in Fig 5, with the above data, we have

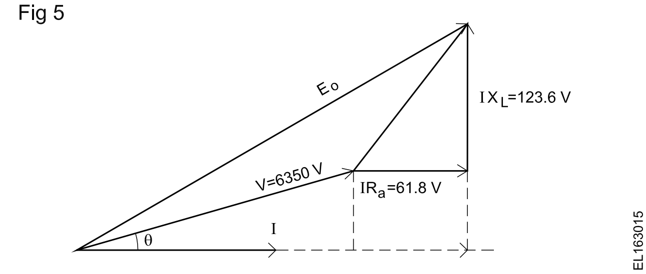
$$E_O = \sqrt{(VP\cos\theta + IR_a)^2 + (VP\sin\theta + IX_L)^2}$$

$$= \sqrt{(6350 \times 0.85 + 61.8)^2 + (6350 \times 0.527 + 123.6)^2}$$

$$= 6468.787 \text{ Volts.}$$

$$\text{Line voltage} = \sqrt{3}E_P = \sqrt{3} \times 6469 = 11204\text{V}$$

Fig 5



The voltage regulation of an alternator: The voltage regulation of an alternator is defined as the rise in voltage when the load is reduced from the full rated value to zero, with the speed and field current remaining constant. It is normally expressed as a percentage of the full load voltage.

% of voltage regulation = $\dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

where V_{NL} - no load voltage of the alternator

V_{FL} - full load voltage of the alternator

The percentage regulation varies considerably, depending on the power factor of the load, and as we have seen for leading P.F. the terminal voltage increases with load, and for lagging P.F. the terminal voltage falls with the load.

Example: When the load is removed from an AC generator, its terminal voltage rises from 640V at full load to 660V at no load. Calculate the voltage regulation.

$$\% \text{ regulation } = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$\frac{660 - 640}{640} \times 100 = 3.1\%$$

Parallel operation methods of alternators and brushless alternator

Objectives: At the end of this exercise you shall be able to
- **state the necessity and conditions for paralleling of alternators**
- **explain the methods of paralleling two 3 phase alternators**
- **state the effect of changes in field excitation and speed on the division of load between parallel operation.**

Necessity for paralleling of two alternators

Whenever the power demand of the load circuit is greater than the power output of a single alternator, the two alternators to be connected in parallel

Conditions for paralleling (synchronising) of two 3 phase alternators

- The phase sequence of both 3 phase alternators must be same. It can be checked byusing phase sequence meters
- The output voltages of the two 3 phase alternators must be same.
- The phase sequence of both the alternators must be same
- The output voltages of the two alternators must be same
- The frequency of the both alternators must be same

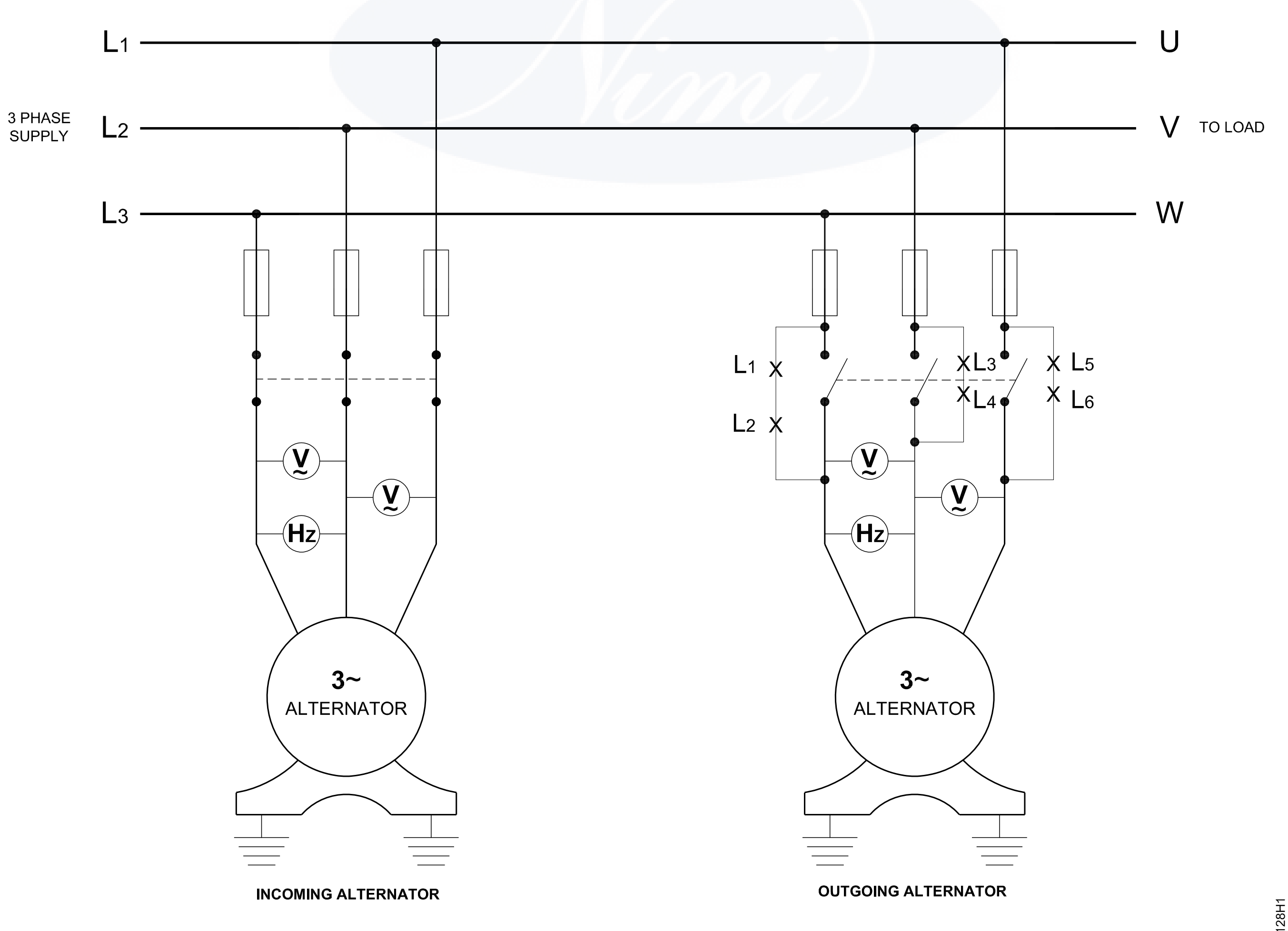
Dark Method

The following describes the method of synchronizing two alternators using the three-dark method

The following describes the method of synchronizing two alternators using the three-dark method.

Fig 1 illustrates a circuit used to parallel two three-phase alternators. Alternator 2 is connected to the load circuit. Alternator 1 is to be paralleled with alternator 2 Three lamps rated at double the output voltage to the load are

Fig 1



PARALLEL OPERATION OF 3 PHASE ALTERNATOR BY DARK LAMP METHOD connected between alternator 2 and the load circuit as shown. When both machines are operating, one of two effects will be observed:

1 The three lamps will light and go out in unison at a rate which depends on the difference in frequency between the two alternators.

2 The three lamps will light and go out at a rate which depends on the difference in frequency between the two machines, but not in unison. In this case, the machines are not connected in the proper phase sequence and are said to be out of phase. To correct this, it's necessary to interchange any two leads to alternator 1. The machines are not paralleled until all lamps light and go out in unison. The lamp method is shown for greater simplicity of operation.

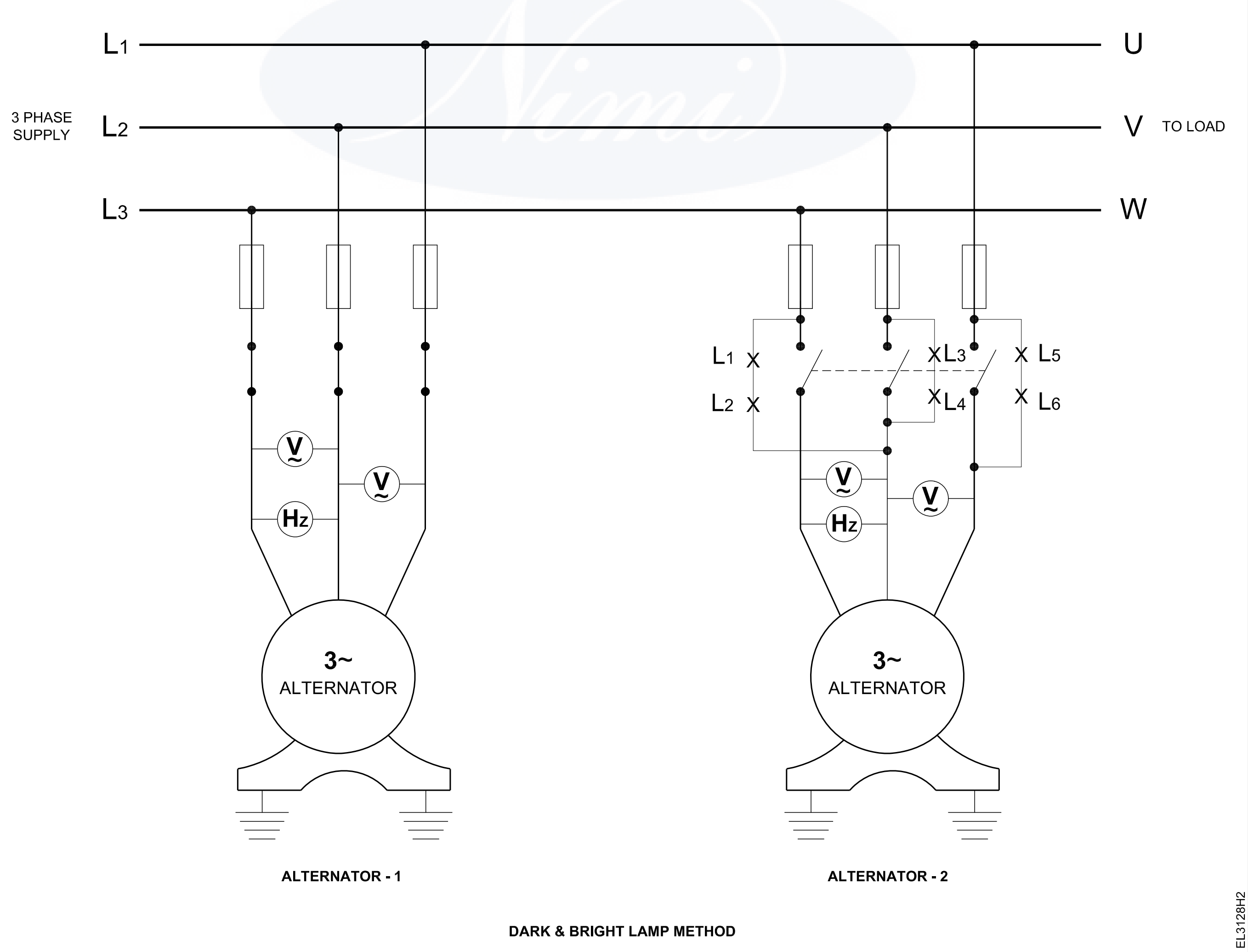
By making slight adjustments in the speed of alternator 1 the frequency of the machines can be equalized so that the synchronizing lamps will light and go out at the lowest possible rate. When the three lamps are out, the instantaneous electrical polarity of the three leads from 1 is the same as that of 2 At this instant, the voltage of 1 is equal to and in phase with that of 2 Now the paralleling switch can be closed at the middle period of the darkness of the lamps so that both alternators supply power to the load. The two alternators are in synchronism, according to the three dark method.

The three dark method has certain disadvantages and is seldom used. A large voltage may be present across an incandescent lamp even though it's dark (burned out). As a result, it's possible to close the paralleling connection while there is still a large voltage and phase difference between the machines. For small capacity machines operating at low speed, the phase difference may not affect the operation of the machines. However, when large capacity units having low armature reactance operate at high speed, a considerable amount of damage may result if there is a large phase difference and an attempt is made to parallel the units.

Two Bright, One Dark Method (Dark and Bright lamp method)

Another method of synchronizing alternators is the two bright, one dark method. In this method, any two connections from the synchronizing lamps are crossed after the alternators are connected and tested for the proper conditions for paralleling phase rotation. (The alternators are tested by the three dark method.) Fig 2 shows the connections for establishing the proper phase rotation by the three dark method. Fig 2 shows the lamp

Fig 2



DARK & BRIGHT LAMP METHOD

connections required to synchronize the alternator by the two bright, one dark method.

When the alternators are synchronized, lamps 1 and 2 are bright and lamp 3 is dark. Since two of the lamps are becoming brighter as one is dimming, it's easier to determine the moment when the paralleling switch can be closed. Furthermore, by observing the sequence of lamp brightness, it's possible to tell whether the speed of the alternator being synchronized is too slow or too fast and can be connected it.

At the moment when the two lamps are full bright and one lamp is full dark, the synchronizing switch can be closed.

Now the both alternator are synchronized and share the load according to their ratings.

Synchroscope

Objectives: At the end of this lesson you shall be able to
- **know various synchroscopes**
- **working principle of synchroscope.**

Synchroscope

A synchroscope is used to determine the correct instant for closing the switch which connects an alternator to the power station busbars. this process of connecting at the correct instant or synchronizing is necessary when an unloaded "incoming" machine is to be connected to the busbars in order to share the load.

The correct instant of synchronizing is when the busbar and the incoming machine voltages

a) are equal in magnitude,
b) are in phase and
c) have the same frequency.

For a 3-phase machine the phase sequence of the two should be the same. This condition is verified by a phase sequence indicator.

The voltages can be checked with the help of a voltmeter. The function of the synchroscope is to indicate the difference in phase and frequency of voltage of the busbar and the incoming machine.

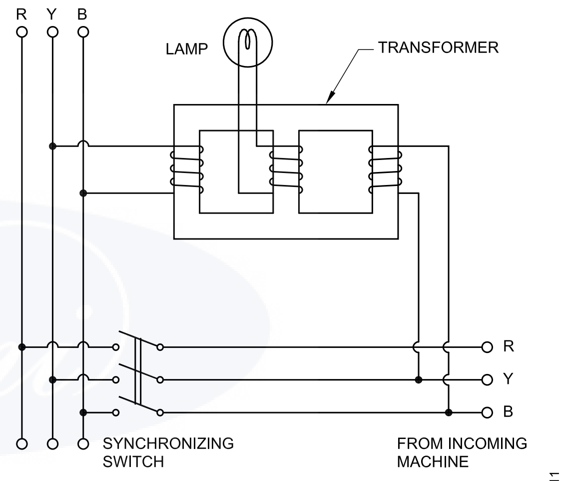
Synchroscopes may either be of the electro-dynamometer type or the moving iron type. Both types are special forms of respective power factor meters.

Electro dynamometer (Weston) type synchroscope.

Fig 1 shows a simple circuit of Weston type synchroscope. it consists of three limbed transformer. The winding one of the outer limbs is excited from busbars and that on the other outer limb by the incoming machine. The winding on the central limb is connected to a lamp.

The windings on the outer limbs produce two fluxes which are forced through the central limb. The resultant flux through the central limb is equal to the phasor sum of these fluxes. This resultant flux induces an emf in the winding of the central limb. The two outer limb windings are so arranged that when the busbar and the incoming

Fig 1



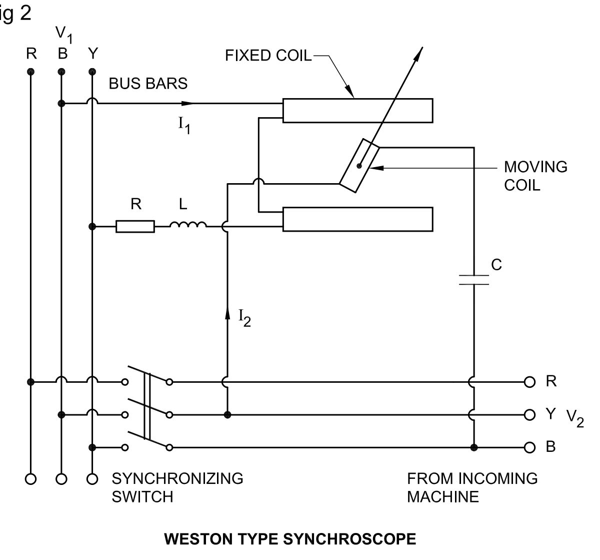
WESTON TYPE SYNCHROSCOPE

machine voltages are in phase, the two fluxes though the central limb are additive and thus emf induced in the central limb winding is maximum. Hence under these conditions the lamp glows with maximum brightness. When the two voltages are 180° out of phase with each other the resultant flux is zero and hence no emf is induced in the central limb winding, with the result the lamp does not glow at all and is dark. If the frequency of the incoming machine is different form that of the busbars, the lamp will be alternately bright and dark or in other words the lamp flickers. The frequency of flickering is equal to the difference in frequencies of the busbar and the incoming machine.

The correct instant of synchronizing is when the lamp is flickering at a very slow rate and is at its maximum brightness.

One of the defect of this simple circuit is that it does not indicate whether the incoming machine is too fast or too slow. This defect can be corrected by introducing an electrodynamometer type instrument into the circuit shown in Fig 2.

Fig 2

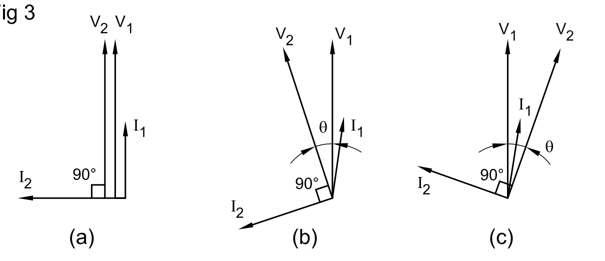


WESTON TYPE SYNCHROSCOPE

The electrodynamometer instrument consists of a fixed coil divided into two parts. The fixed coil is designed to carry a small current and is connected in series with a resistance across the busbars. The moving coil is connected in series with a capacitor across the terminals of the incoming machine. The instrument is provided with control springs which act as current leads for the moving coil. The shadow of the pointer is thrown on an opal glass.

When the two voltages are in phase with each other, current I_1 and I_2 in fixed and moving coils respectively will be in quadrature with each other (Fig 3a) and therefore there will be no torque on the instrument. The control springs are so arranged that the pointer is in vertical position under this condition. Also the lamp is at its maximum brightness and the pointer is silhoueted against the opal glass.

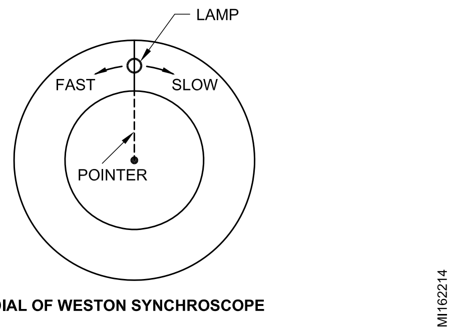
Fig 3



PHASOR DIAGRAMS

If the incoming machine voltage V_2 is leading the busbar voltage V_1 and the incoming machine slightly too slow, the conditions of the circuit will slowly change from those shown in Fig 3 (b) to those shown in Fig 3(c). Then the torque will change from $KI_1I^2 \cos(90° + \theta)$ i.e., from a negative value through zero to a positive value. And during this period lamp will be bright and the pointer will be seen to move from left hand side of dial through the vertical position to the right and side of dial. The dial can thus be marked with directions Fast and Slow as shown in Fig 4.

Fig 4



DIAL OF WESTON SYNCHROSCOPE

During this period when the voltages V_1 and V_2 are 180° out of phase the pointer will move back. But it will not be visible as under these conditions as the lamp is dark.

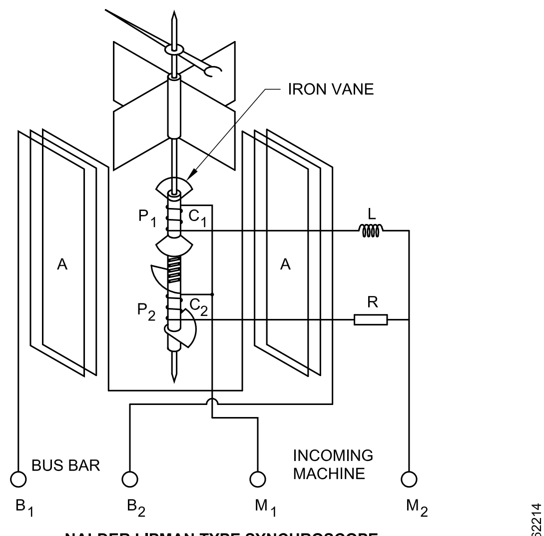
The visible movement of the pointer is therefore a series of traverses on the dial in one direction. If the incoming machine is too fast the visible traverses will be in the other direction. The correct instant of synchronizing is when the pointer is visible at its central position and is moving very slowly.

It may be observed that in order to have an exact quadrature relationship between currents I_1 and I_2 when voltages V_1 and V_2 are in phase, is obtained only if small inductance L is introduced in the fixed coil circuit.

Moving Iron synchroscope:

Fig 5 shows the construction of a moving iron synchroscope which is due to Lipman. It has a fixed coil divided into two parts. This fixed coil A is designed for a small value of current and is connected in series with a resistance across two phases of the busbar. There are two iron cylinders C_1 and C_2 mounted on the spindle. Each iron cylinder is provided with two iron vanes whose axes are 180° out with each other. The iron cylinders are excited by two pressure coils P_1 and P_2 which are connected to two phases of the incoming machine. One of the coils has a series resistance and the other has a series inductance. This is done in order to create an artificial phase difference of 90° between the currents of

Fig 5



NALDER LIPMAN TYPE SYNCHROSCOPE

two pressure coils. There are no control springs. The instrument is provided with a pointer which moves over a dial marked Fast and Slow.

When the frequency of incoming machine is the same as that of busbars, the instrument behaves exactly like the corresponding form of the power factor meter. The deflection of the pointer from the plane of reference is equal to phase difference between the two voltages.

However if the frequencies of the two voltages are different, the pointer rotates continuously at a speed corresponding to difference in frequency of the two voltages. The direction of rotation depends whether the incoming machine is too fast or too slow.

Voltage produced in the exciter armature produce a magnetic field on the main alternator rotor. When this magnetic field cuts the main armature a potential difference procured. Hgere the voltage produced can be regulated by exciter field current (Fig 2).

Brushless alternator

Objectives: At the end of this lesson you shall be able to
- **state the principle and basic theory of brushless alternator**
- **explain the construction of brushless alternator**
- **describe the working of 3 phase brushless alternator**

Principle of brushless alternator

In all alternators, voltage may be generated by rotating a coil wore in the magnetic field or by rotating a magnetic field within a stationary coil wire. To produce voltmeter either the coil is moving or the magnetic field is moving. Either configuration works equally well and both are used separately or in combination depending on mechanical, electrical and other objectives.

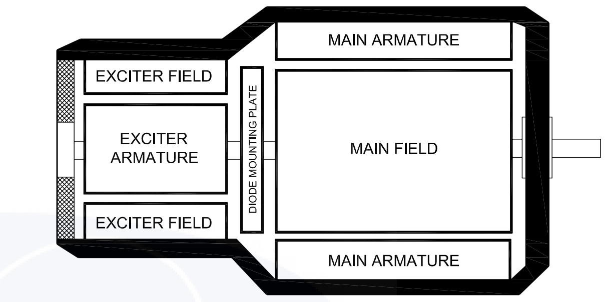
In the case of brushless alternator both combination is used together in one machine.

The stationary part of an alternator is called the stator and the roating part is called the rotor. The coils of wire used to produce a magnetic field are called the field winding and the coils that the power are called the armature winding. Here both armature and field winding used as rotor as well as stator.

Working of brushless alternator

Brushless alternators having two part one is excitation alternator part and another is main alternator part (Fig 1)

Fig 1



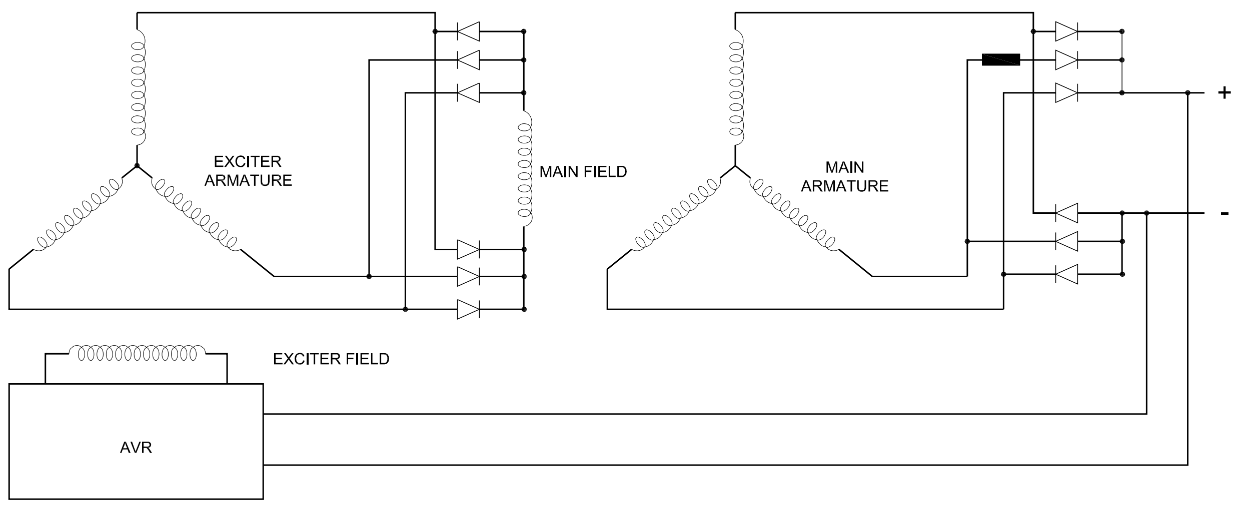
Excitation alternator

The armature is rotor and field winding and field winding is stator. When it starts rotating a voltage is generatred in Exciter armature which gives current the main field to produce magnetic field in main alternator.

Main Alternator

Here main field is rotor and armature is stator so the supply can be taken out directly. No brushes required.

Fig 2



3 PHASE BRUSHLESS ALTERNATOR CIRCUIT DIAGRAM

Basic theory

When an electric current is passed through a coil of wire, a magnetic field is produced (an electromagnet). Conversely, when a magnetic field is moved through a coil of wire, a voltage is induced in the wire. The induced voltage becomes a current when the electrons have some place to go such as into a battery or other load. Both of these actions take place in alternators, motors and generators or dynamos.

Construction

A brushless alternator is composed of two alternators built end-to-end on one shaft. Smaller brushless alternators may look like one unit but the two parts are readily identifiable on the large versions. The larger of the two sections is the main alternator and the smaller one is the exciter. The exciter has stationary field coils and a rotating armature (power coils). The main alternator uses the opposite configuration with a rotating field and stationary armature

Exciter

The exciter field coils are on the stator and its armature is on the rotor. The AC output from the exciter armature is fed through a set of diodes that are also mounted on the rotor to produce a DC voltage. This is fed directly to the field coils of the main alternator, which are also located on the rotor. With this arrangement, brushes and slip rings are not required to feed current to the rotating field coils. This can be contrasted with a simple automotive alternator where brushes and slip rings are used to supply current to the rotating field

Main Alternator

The main alternator has a rotating field as described above and a stationary armature (power generation windings). This is the part that can be confusing so take note that in this case, athe armature is the stator, not the rotor.

With the armature in the stationary portion of the alternator, the high current output does not have to go through brushes and slip rings. Although the electrical design is more complex, it results in a very reliable alternator because the only parts subjects to wear are the bearings.

Three-Phase brushless alternator (Fig 2)

A three phase alternator has a minimum of 3 sets of windings spaced 1200 apart around the stationary armature (stator). As a result, there are 3 outputs from the alternator and they are electrically spaced 1200 out of phase with each other. A multi-pole design will have multiple sets of 3 windings. These sets of windings (poles) are spaced evenly around the circumference of the machine. The more poles there are , the slower the alternator turns for a given voltage and frequency. More poles increase the complexity of the alternator and that in part accounts for the higher price of slower speed versions.

Other than in single-phase power plants, most alternators, including the automotive type, generate 3-phase power. A three-phase AC alternator will not have any diodes in it. If the output is DC, it will probably have 6 diodes to convert the output from the main alternator to DC. This is the configuration used in automotive alternators. A 3-phase brushless alternator may have 4 or 6 diodes on the rotor for the exciter output in addition to the diodes that may be on the stator

There are two ways that 3-phase machines can be wired. One is the delta (triangle) configuration with one wire coming off each "point of triangle". The other is the wye (Y) or star configuration. They have one wire from each branch of the "Y" and in some cases a 4" common wire is added from the centre/centre point of the "Y" (the common connection point between the windings)

Multiple voltage machines will have additional wires to allow them to be configured for the desired system voltage.

Overhauling of AC motors

Objectives: At the end of this lesson you shall be able to
- **explain the reasons for squirrel cage motor overheats while running**
- **list out the types of bearings used in electrical motors**
- **follow the correct procedure to fix the bearing on the shaft**
- **locate the faults in the bearing**
- **follow the correct procedure to increase the life of bearings**
- **follow the correct lubricating procedures**
- **trouble shoot faults like overheating of bearing and noisy operation of motor and rectify them.**

Generally due to the rugged construction of the AC squirrel cage motor, this motor requires less maintenance. However to get trouble-free service and maximum efficiency, this motor needs a scheduled routine maintenance. As found in most of the industries the AC squirrel cage motor is subjected to full load for 24 hours a day and 365 days a year. Therefore the maintenance should be scheduled to have periodic maintenance for a selected area on daily, weekly, monthly, half yearly and yearly periods for increasing the working life of the motor and to reduce the down time.

Suggested maintenance schedule for the AC squirrel cage induction motor is given below.

MAINTENANCE SCHEDULE

The following maintenance schedule is suggested for induction motors as a guide.

Daily maintenance

- Examine earth connections in the motor leads.
- Check motor windings for overheating. (Note that the permissible maximum temperature is above that which can be comfortably felt by hand).
- Examine the control equipment
- In the case of oil ring lubricated machines
  i) examine bearings to see that oil rings are working
  ii) note the temperature of the bearings
  iii) add oil if necessary
  iv) check end play.

Weekly maintenance

- Check belt tension. In case where this is excessive it should immediately be reduced and in the case of sleeve bearing machines, the air gap between the rotor and stator should be checked.
- Blow out windings of protected type motors, insulated in dusty locations.
- Examine the starting equipment for burnt contacts where motor is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, dirt etc. (This can be roughly ascertained on inspection by the colour of the oil).

Monthly maintenance
- Overhaul the controllers
- Inspect and clean the oil circuit breakers
- Renew oil in high speed bearings in damp and dusty locations.
- Wipe brush holders and check the bedding of brushes of slip-ring motors.
- Check the condition of the grease.

Half-yearly maintenance

- Clean the winding of the motors which are subjected to corrosive or other such elements. Also bake and varnish if necessary.
- In the case of slip ring motors check slip rings for grooving or unusual wear.
- Renew grease in ball and roller bearings.
- Drain all oil bearings, wash with kerosene, flush with lubricating oil and refill with clean oil.

Annual maintenance

- Check all high speed bearings and renew if necessary.
- Blow out all windings of motors thoroughly with clean dry air. Make sure that the pressure is not so high as to damage the insulation.
- Clean and varnish dirty and oily windings.
- Overhaul motors that are subject to severe operating conditions.
- In the case of slip ring motors, check the slip ring for pittings and the brush for wear. Badly pitted slip rings and worn out brushes should be replaced.
- Renew switch and fuse contacts if badly pitted.
- Renew oil in starters that are subjected to damp or corrosive elements.
- Check insulation resistance to earth and between phases of motor windings, control gear and wiring.

* Check resistance of earth connections.

* Check air gaps.

CHART - 1

Over Heating of the motor

Sl. No.	Cause	Test	Remedy
1	Too high or low voltage or frequency.	Check the voltage and frequency at the terminal of the motor.	Rectify the cause of low or high voltage or frequency as the case may be.
2	Wrong connection.	Compare the connection with given circuit diagram. Loose joints of rotor bars cause heat.	Reconnect the connection if required.
3	Open circuit in rotor	Check for continuity, short circuit and leakage as stated before.	Re-solder the joints of rotor bars and end rings.
4	Faulty stator winding.		Remove the fault if possible; otherwise rewind the stator winding.
5	Dirt in ventilation ducts.	Inspect ventilation ducts for any dust.	Remove dirt and dust from them if any or dirt in them.
6	Overload.	Check the load and the belt.	Reduce the load or loosen the belt.
7	Unbalanced electrical supply.	Check the voltage for single phasing.	Rectify the single phasing defect.
8	Motor stalled by driven machine or tight bearing.	Check the connection and fuses.	If the defect is with the driven machine repair it. If the problem is with the bearing, investigate and repair.
9	Motor when used for reversing heats up.	Check the manufacturer's instructions.	If required replace the motor designed for this service.

Ball or roller bearings

The electric motor is fitted with either a ball (Fig 2) or roller (Fig 3) bearing for easy rotation of the shaft.

As shown in Figs 1 & 2 these bearings have balls or rollers which prevent sliding friction by rolling between the races.

As bearings are used between stationary and revolving machine parts, such bearings have a stationary and a revolving race.

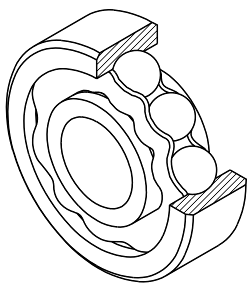
Handling the bearings

Bearings are precision-made of hard, brittle materials.

But the working surfaces of bearings are either honed or very soft. If these surfaces are damaged, the bearings is ruined, therefore:

- handle the bearings carefully to prevent damage
- keep the bearings wrapped until fitted, to keep out dirt
- protect the bearings against corrosion during storage, e.g. steel bearings must be oiled.

Fig 1



SINGLE ROW SNAP RING BALL BEARING

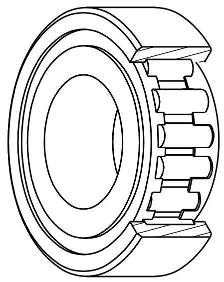
Installing bearings

Before any bearing is fitted:

- clean the journal or housing throughly and the seatings of the locating devices. (Fig 3)
- inspect the surfaces for damage; do not fit the bearings to damaged surfaces.
- then coat the journal or housing with clean, light oil.

Take care to keep the oil clear of slip rings, brushes and the control gear of a motor.

Fig 2

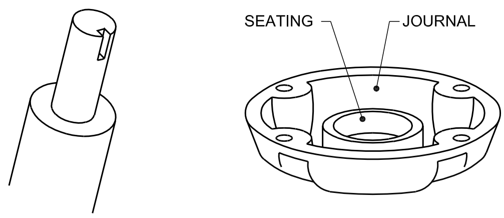


CYLINDRICAL ROLLER BEARING

While fitting the bearing to the shaft sufficient force has to be applied on the bearing. During the process for avoiding damage to the bearings follow the procedure given below.

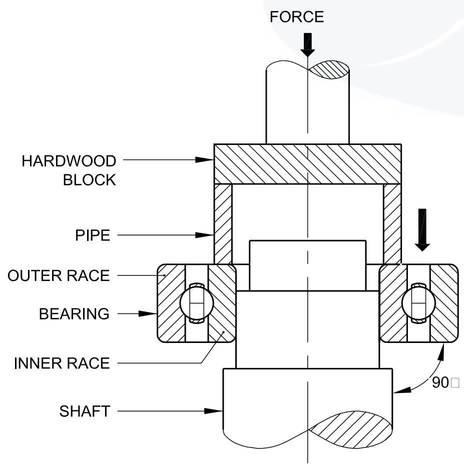
a) Force through arbor press.

Fig 3



Apply force through an arbor press to the inner race which is in contact with the housing as shown in Fig 4 by using a pipe and solid block of wood.

Fig 4



This is the best method, since the bearing can more easily be kept square to its seating.

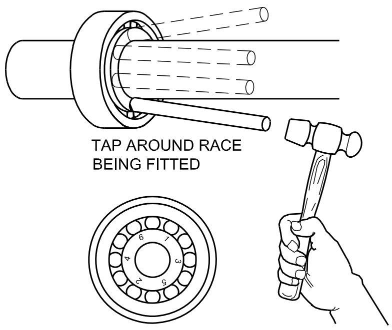
b) Tapping bearings into place using a drift. (Fig 5)

NOTE:

Bearings should only be tapped into place when they cannot be pressed into position. Decide which is the most appropriate method.

Tap evenly around the race being fitted. Take care to keep the bearing square to seating. the method is useful when the seating is in an awkward situation. Take care to prevent foreign matter from entering the bearing.

Fig 5



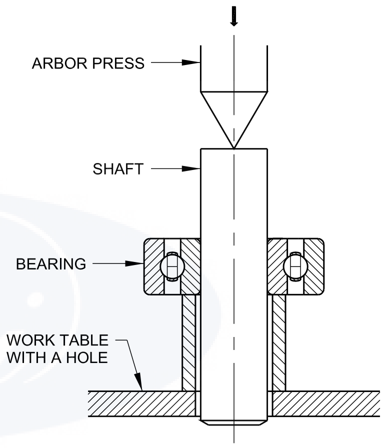
Tap the bearing home gently, stopping frequently to check that it is square.

Bearing removal techniques

a) Using an arbor press. (Fig 6)

Decide which is the best way to set the job up on the press. Apply the force evenly to remove the bearing.

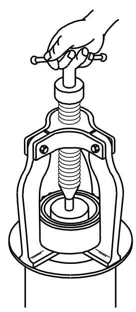
Fig 6



b) Using bearing puller. (Fig 7)

When using bearing pullers take care to keep the bearing square to the shaft. Screw-pullers are suitable for most purposes; take care to keep the puller square when turning the screw.

Fig 7



Locating faults in bearings

For checking any bearing, it should be cleaned well.

Ball bearings

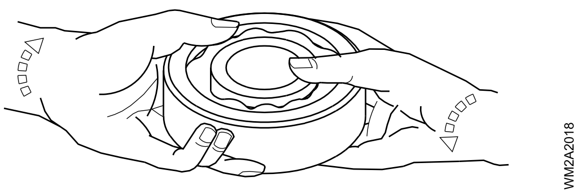
Normally the ball bearings cannot be readily dismantled for close examination.

Wear

Check the wear of the ball bearing by holding the inner ring between the thumb and fore finger of one hand and holding the outer ring with the other. Holding the ball bearing twist the rings to and fro as indicated in Fig 8.

Any sign of movement indicates wear and the bearing needs be replaced with a ball bearing of the same specification.

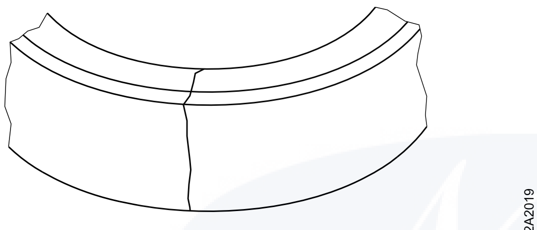
Fig 8



Break

Check the bearing for broken inner and outer rings which also indicate poor fitting, excessive load or wrong choice of bearing. (Fig 9)

Fig 9

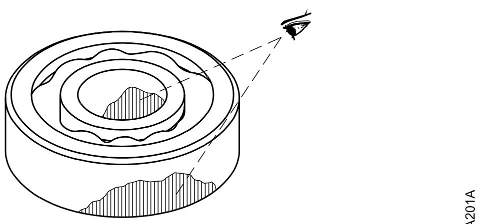


BROKEN RACES

Stains

Check the inner bore and the outer surface for the characteristic brown and black stains on a generally smooth and bright surface. (Fig 10). These marks indicate that movement has been taking place between the bearing, shaft and the housing due to poor fitting.

Fig 10



STAINS IN FITTING SURFACES

Roller bearing

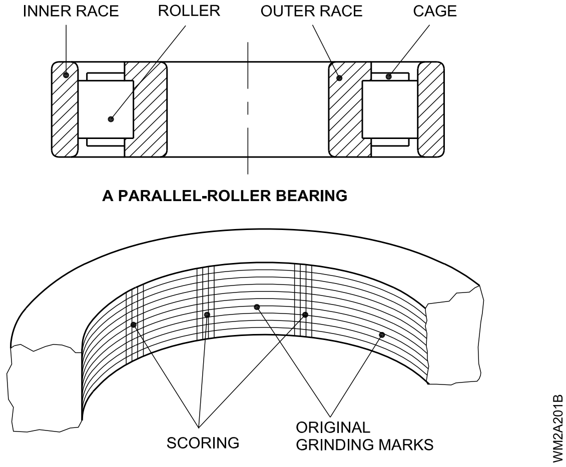
After cleaning the bearing remove the inner ring and roller assembly from the outer ring.

Check the inner surface of the outer ring. The surface should be smooth and polished with no marks of roughness or indentations.

The presence of score marks across the track at intervals corresponding to the pitch of the rollers as shown in Fig 11 indicates faulty initial fitting.

These roller bearings with score mark indicates excessive wear and will produce noise.

Fig 11

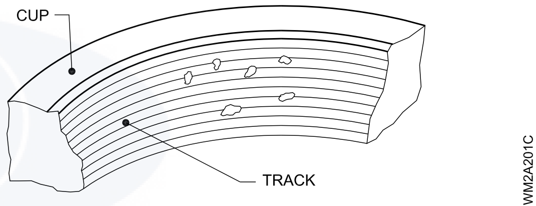


Rough patches on the track as shown in Fig 12 indicates the wear caused by out-of-balanced vibration or fatigue effects. The hard surface flakes off.

Check the general wear of the bearing by using both the hands as describe for ball bearings.

General wear sometimes causes a loss of brightness of the track, the shine being replaced by a dull surface.

Fig 12



Heavy general wear may produce a distinct groove around the track.

Static electrical discharges may also cause blackened surface pitting of bearing on certain machines. Where this suspected check the rotor earthing arrangements.

General pitting may be due to rusting caused by inadequate lubrication or damp service conditions.

Examine the cage rings for signs of wear somewhere around the inner circumference. Localized wear of a brass ring may be accompanied by a brassy discoloration of the track, as the minute particles of brass are ground into the surface.

A worn out ring indicates a worn out bearing. Replace it.

Lubrication

Many times it is detected that the mechanical faults found in the motor are due to imperfect lubrication. A thorough knowledge about lubrication is required for the service technician. Most of the motor manufacturers recommend certain type and grade of lubricant for efficient operation of the motor. It is recommended that the same type and grade should be used to get optimum efficiency of the motor and the specified grade of lubricant should be notified on the motors for guidance.

There are several methods of lubricating motors. Small motors with sleeve bearings have oil holes with spring covers. These motors should be oiled periodically with a good grade of mineral oil as recommended by the manufacturer.

The bearings of larger motors often provided with an oil which fits loosely in a slot in the bearing. The oil ring picks up the oil from a survivor located directly under the ring. Under normal operating conditions the oil should be replaced in the motor at least once in a year. More frequent oil replacement may be necessary in motors operating under adverse conditions. In all cases, avoid excessive oil can cause deterioration of the insulation of windings.

Many motors are lubricated with grease. Periodic replacement of the grease should be done whenever a general overhaul is indicated, or sooner if the motor is operated under severe operating conditions.

Grease can be removed by using a light mineral oil heated to 165°F or a solvent. Any grease-removing solvent should be used in a well-ventilated work area.

Bearing troubles and the possible remedies are given in Chart 2.

CHART - 2

Bearing problems

Sl. No.	Cause	Test	Remedy
1	Too much or too little grease inbearings or unsuitable grade.	Remove grease cups and covers. Check grade and quantity of grease.	Replace grease of paper grade and quantity in bearings.
2	Loose or damage bearings.	Remove the bearing and check the condition of bearings.	Replace new bearing if old ones are damaged.
3	Bearing is loose in its housing.	Remove grease cups and end covers. Check fitting of outer race of bearing in housing.	Put shim in housing if loose. If the housing is too loose send for filling of material and turning in a lathe in the workshop.
4	Loose inner race of bearing on shaft.	Remove the rotor and check fitting of inner race of the bearing on shaft.	Send rotor to repair shop for filling the material on the shaft if necessary and fine machine the area.
5	Wrong size of bearings.	Remove end covers and check number and make of bearing and check for size.	Replace bearing as recommended by the manufacturer by using correct sized bearing.
6	Wrong fitting of new bearings.	Open end covers and inspect any friction on rotor or stator.	Refit bearing properly.
7	Too high a tension on driving belt.	Inspect tension on belt. It should be as directed by the manufacturer.	Realign the coupling system properly.
8	Wrong alignment of mechanical (or belt) coupling.	Check alignment with a spirit level or dial test indicator. In case of belt coupling use a thread for checking the alignment.	Realign the coupling system properly
9	Bent shaft	Check the shaft with a dial test indicator.	If found bent slightly straight it on a a lathe with the help of a turner or replace the shaft.
10	Motor tilted too far causing end thrust.	Check the motor level with the help of a spirit level.	Level the motor, reduce the tilt and realign if necessary.

CHART - 3

Vibration and noise in motors

Sl. No.	Cause	Test	Remedy
1	Loose foundation bolts or nuts.	Inspect nuts of foundation for loose fittings.	Tighten the Foundation nuts.
2	Wrong alignment of of coupling.	Check alignment with a spirit level or dial test indicator.	Realign the coupling system.
3	Faulty magnetic circuit of stator or rotor.	Measure the current in each phase and they should be equal. Check also per-phase resistance and between the windings and the frame.	Repair fault if possible or rewind the motor.
4	Motor running on single phase.	Stop the motor, try to start. (It will not start on single phase). Check for open in one of the lines or circuits.	Rectify the supply.
5	Noisy ball bearing.	Check the lubrication for correct grade and low noise in the bearing.	If found, replace the lubricant or replace the bearing.
6	Loose punching or loose rotor on shaft.	Check the parts visually.	Tighten all the holding bolts.
7	Rotor rubbing on the stator.	Check for rubbing marks on the stator and rotor.	If found, realign the shaft to centre it or replace the bearings.
8	Improper fitting of end-covers.	Measure the air gap at four different points for uneven position of rotor covers.	Open the screws of the side covers and then tighten one by one. If trouble still persists, remove the end cover, shift for next position and tighten the screws again.
9	Foreign material in air gap.	Examine the air-gap	File or clean out air gap.
10	Loose fan or bearings.	Check looseness of the fan screw or bearings.	Tighten the fan screw or refit new bearings if necessary.
11	Slackness in bearing on shaft or in housing.	Remove the bearings and inspect the inner looseness of the race on shaft and outer race in the housing.	Send the motor to the repair shop for removing the looseness of the shaft and housing, if any.
12	Improper fitting of bearings.	Remove the bearings and inspect the inner looseness of the race on the shaft and outer race in the housing.	Refit the bearings on the shaft housing.
13	Minor bend in shaft.	Check for alignment on the lathe.	Remove the bend or replace the shaft, if required.

D.O.L. starter for single phase motor (push-button)

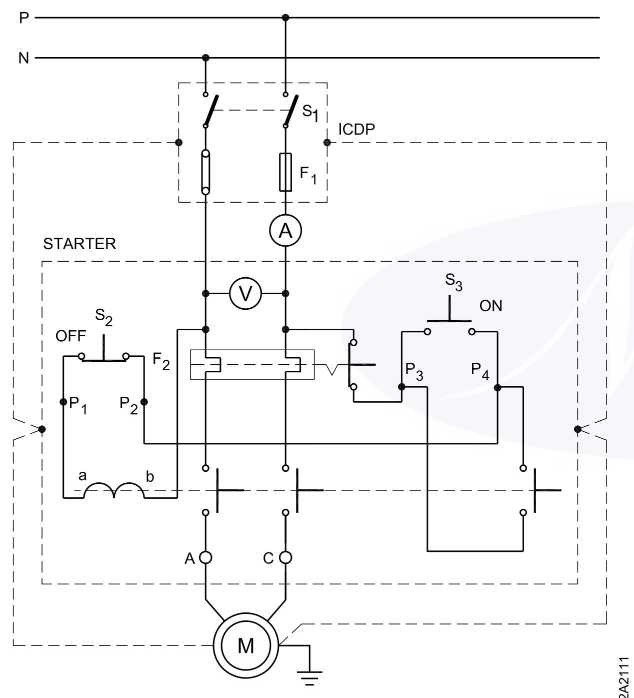
Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation

A push-button type, direct on-line starter which is in common use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

Fig 1



D.O.L STARTER FOR SINGLE PHASE MOTOR

There is no difference between the complete contactor circuit explained in previous exercise and the D.O.L. starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 240V and is to be connected across as shown in Fig 1. Further the overload relay can be situated between IC switch and contactor, or between the contactor ad motor as shown in Fig 1, depending up on the starter design.

Specification of D.O.L. starters

While giving specification, the following datas are to be given.

D.O.L. Starter

Phase - single or three.

Voltage 230 or 415V

Current rating 10, 16, 32, 40, 63, 125 0r 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230, 240 volts.

Number of main contacts 2,3 or 4 which are normally open.

Number of auxiliary contacts 1, 1 NC.

Push-button - one ‘ON’ and one ‘OFF’ buttons.

Overload from setting from —amp to —amp. Enclosure metal sheet or PVC.

Applications

In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 2 HP squirrel cage induction motor and up to 1.5 kW double cage rotor motors.

Necessity of back-up fuses

Motor starters must never be used without back-up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses when it is used in the motor circuit it will operate at a faster rate and open the circuit. Hence H.R.C. diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, the back-up fuses melt and open the circuit quickly. A reference table is given for indicating fuse ratings for different motor ratings.

It is recommended that the use of semi-enclosed, rewirable, tinned copper fuses may be avoided as for as possible.

Fuse ratings table

Sl. No.	Motor ratings 240V single phase			Relay range	Normal back-up fuse recommended
	hp	kW	Full load current in amps		
1	0.05	0.04		0.25 - 0.4	2A
2	0.125	0.11		1.0 - 1.6	6A
3	0.5	0.18	2.0	1.5 - 2.5	6A
4	0.5	0.4	3.6	2.5 - 4.0	10A
5	0.75	0.55		4.0 - 6.5	15A
6	1.0	0.75	7.5	6.0 - 10	20 A
7	2.0	1.5	9.5	9.0 - 14.0	25 A

The given full load current supply in the case of single phase, capacitor starter type motors.

Capacitor-start induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain the principle of capacitor start induction run single phase motor**
- **explain how to reverse the direction of rotation of the motor.**

One of the method of producing rotating magnetic field is by split phasing. This could be done by providing a second set of winding in the starter called the starting windings. This winding should be kept physically and electrically 90° degrees from the main winding and should carry a current out of phase from the main windings. This out of phase current could be achieved by making the reactance of the starting winding different from the main windings.

In order to reverse the direction of rotation of all the types of single phase motors the direction of current either the starting or the main windings terminals to be inter changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarites of main field flux and the starting winding flux. Therefore reversing the polarity of all of the fields will reverse the torque. This can be achieved by a change over switch. A three phase change over switch can be used by modifying the connection.

Capacitor motor starter is very similar to the split phase motor, except the starting winding has a few more turns, and consists of heavier wire than the starting winding of a split-phase motor. There is also a large capacity electrolytic capacitor connected in series with the starting winding. The capacitor and starting winding will cut off the circuit as soon as the motor reaches approximately 70% of its full load speed. It has a high starting torque. For this reason it requires little maintenance. By reversing either of the starting or running winding leads the direction of rotation can be changed. They are usually designed to operate on two voltages (Dual voltage). In this the running winding there are two sections, so that it may be connected in parallel for 115V, and in series for 230V main. Capacitor start and capacitor run is the same as the capacitor start motor except that it has an extra capacitor (oil type) connected in the starting windings.

Capacitor-start, capacitor-run motor

Objectives : At the end of this lesson you shall be able to
- **distinguish between the single and two-value (capacitor-start, capacitor-run) motors**
- **draw the schematic diagram of a permanent capacitor motor, state its characteristic and uses**
- **draw the schematic diagram of a capacitor-start, capacitor-run motor, state its characteristic and uses.**

Capacitor-start, capacitor-run motors are of two types.

– Permanent capacitor motor (Single value capacitor motor)

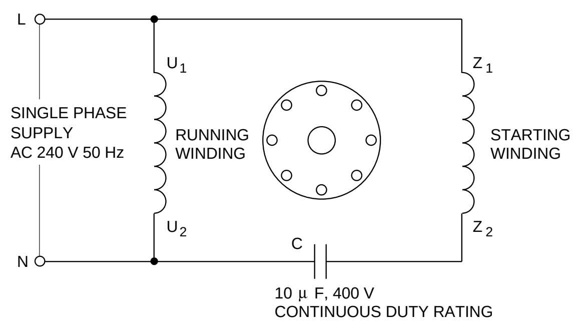
– Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor

This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high and at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the starting winding and remains so throughout the operation. These capacitors should be of oil type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low which in turn brings down the starting torque to about 50 to 80% of the full load torque.

Fig 1



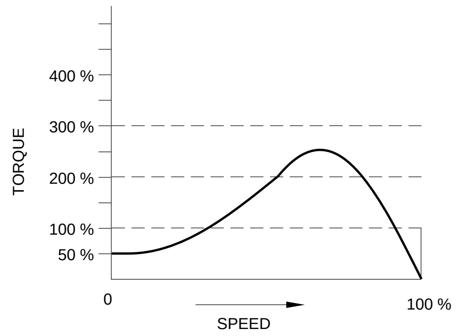
CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction motor with low starting torque but with higher power factor during starting as well as during running.

This motor is most suitable for drives which require lower torque during start, easy changes in direction of rotation, stable load operation and higher power factor during operation.

Examples - fans, induction regulators, furnace control and arc-welding controls. This motor is cheaper than capacitor-start, induction-run motor of the same rating.

Fig 2



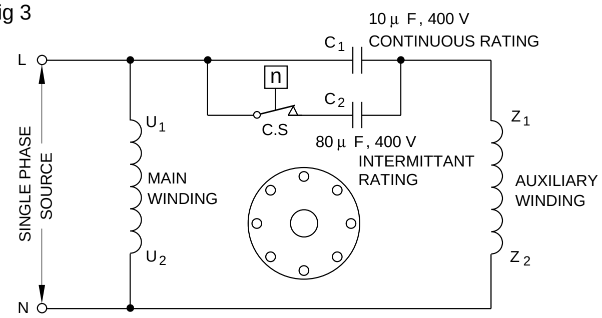
TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

Capacitor-start, capacitor-run motor

As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque and their power factor during starting is high. However, their running torque is not good and their power factor while running is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting whereas a smaller capacitor of oil filled (continuous duty) type is used for running by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start, induction motor with the exception, the capacitor C_1 is always in the circuit altering the running performance to a great extent.

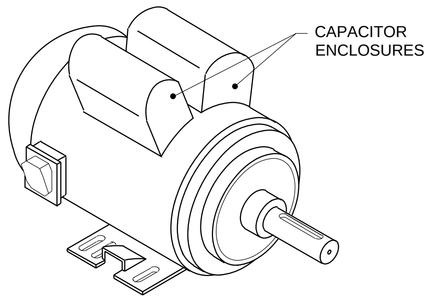
Fig 3



SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

The starting capacitor which is of short duty rating will be disconnected from the starting winding with the help of a centrifugal switch when the starting speed attains about 75% of the rated speed.

Fig 4



CAPACITOR-START CAPACITOR-RUN MOTOR

Characteristics

The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

1 Starting torque is 300% of the full load torque.

2 Starting current is low, say 2 to 3 times of the running current.

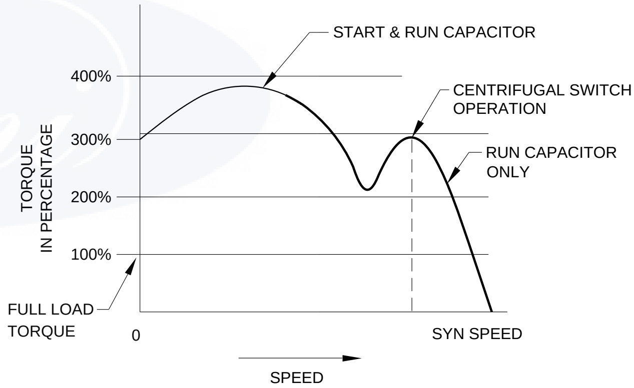
3 Starting and running P.F. are good.

4 Highly efficient running.

5 Extremely noiseless operation.

6 Can be loaded up to 125% of the full load capacity.

Fig 5



TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

The effect of a running capacitor is to make the motor perform like a two-phase motor, particularly at one value of load. It is not possible to duplicate two-phase motor performance at all load values with a single value of capacitance, as different values of capacitance would be required for each different load; hence, we settle for one capacitor only.

APPLICATION

These motors are used for compressors, refrigerators and air conditioners etc. where the duty demands higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction-run motors of the same capacity.

Universal motor

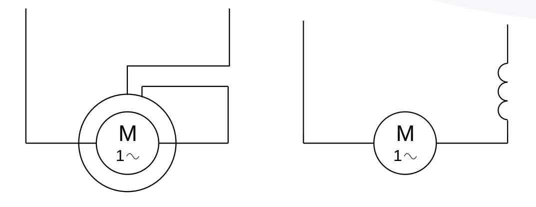
Objectives: At the end of this lesson you shall be able to
- **compare a universal motor with a DC series motor with respect to its construction**
- **explain the characteristic and application of a universal motor**
- **explain the method of changing the direction of rotation**
- **describe the methods of controlling the speed of a universal motor.**

Comparison between a universal motor and a DC series motor

A universal motor is one which operates both on AC and DC supply. It develops more horsepower per kg. weight than any other AC motor, mainly due to its high speed. The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it requires suitable modification in the construction, winding and brush grade to achieve sparkless commutation and reduced heating, when operated on AC supply due to increased inductance and armature reaction.

A universal motor could be defined as a series wound or a compensated series motor designed to operate at approximately the same speed and output on either direct current or single phase alternating current of a frequency not greater than 50 Hz and of approximately the same RMS voltage. A universal motor is also named as AC single phase series motor and Fig 1 shows the multi-line representation according to BIS 2032 Part IV.

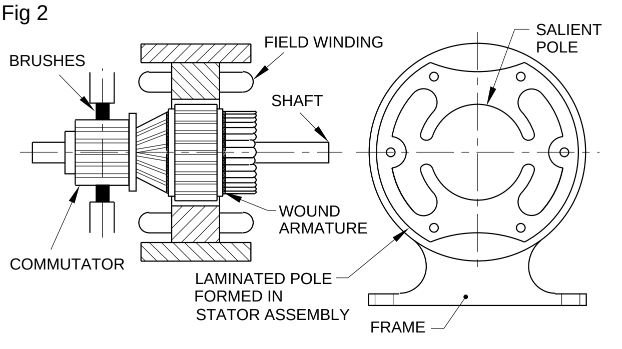
Fig 1



MULTIPLE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 2.

Fig 2



PARTS OF A UNIVERSAL MOTOR

The increased sparking at the brush position in AC operation is reduced by the following means:

a Providing compensating winding to neutralize the armature MMF. These compensating windings are either short circuited windings or windings connected in series with the armature.

b Providing commutating interpoles in the stator and connecting the inter-pole winding in series with the armature winding.

c Providing high contact resistance brushes to reduce sparking at brush positions.

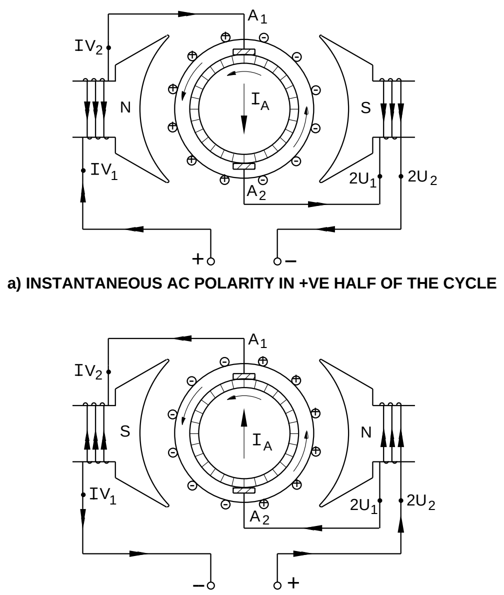
The table given below indicates the differences between an universal motor and a DC series motor

Universal motor	DC series motor
1 Can run on AC and DC supplies.	Can run smoothly on DC. However, when connected to AC supply it produces heavy sparks at brush positions and becomes hot due to armature reaction and rough commutation.
2 Compensating winding is a must for large machines.	Does not require compensating winding.
3 Inter-poles provided in large machiines.	Does not require inter-poles normally.
4 High resistance grade brushes are necessary.	Normal grade brushes will suffice.
5 Air gap is kept to the minimum.	Normal air gap is maintained.

Operation

A universal motor works on the same principle as a DC motor i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operates on AC or DC supply. Fig 3 shows the operation of a universal motor on AC supply. In AC operation both field and armature currents change their polarities resulting in unidirectional torque.

Fig 3



a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE

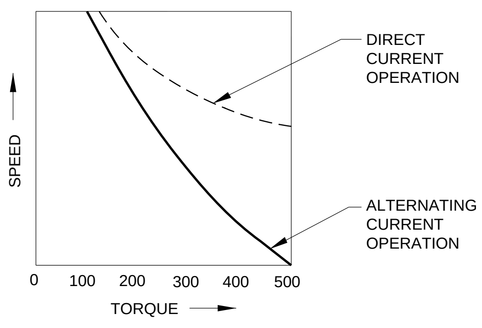
b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

Characteristic and application

The speed of a universal motor is inversely proportional to the load i.e. speed is low at full load and high on no-load. The speed reaches dangerously high value due to low field flux at no load. In fact the no-load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no load thereby avoiding high speeds.

Fig 4 shows the typical torque- speed characteristic of a universal motor for both AC and DC operations. This motor develops about 450 percent of full load torque at starting - as such higher than any other type of single phase motor.

Fig 4



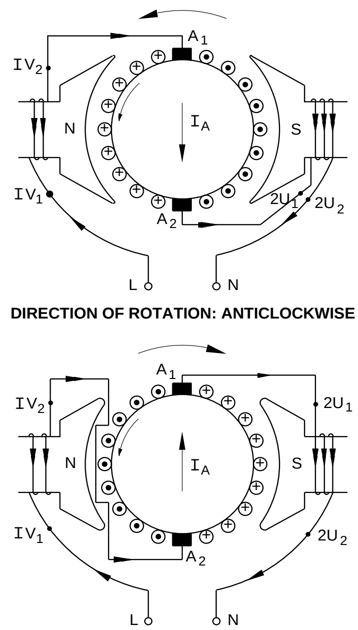
TORQUE-SPEED CHARACTERISTIC OF A UNIVERSAL MOTOR

Universal motors are used in vacuum cleaners, food mixers, portable drills and domestic sewing machines.

Change of rotation

Direction of rotation of a universal motor can be reversed by reversing the flow of current through either the armature or the field windings. It is easy to interchange the leads at the brush-holders as shown in Fig 5.

Fig 5



DIRECTION OF ROTATION: ANTICLOCKWISE

DIRECTION OF ROTATION: CLOCKWISE BY CHANGING ARMATURE TERMINALS

However, when the armature terminals are interchanged in a universal motor having compensating winding, care should be taken to interchange the compensating winding also to avoid heavy sparking while running.

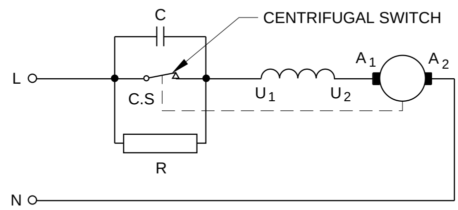
Speed control of universal motor

The following methods are adopted to control the speed of a universal motor.

- Series resistance or applied voltage control
- Tapped field method
- Centrifugal switch method

  A centrifugal mechanism, adjusted by an external lever, is connected in series with the motor as shown by Fig 6.

Fig 6



CENTRIFUGAL SWITCH MECHANISM FOR SPEED CONTROL

If the speed reaches beyond a certain value, according to the lever setting, the centrifugal device opens the contacts and inserts the resistance R in the circuit, which causes the motor speed to decrease. When the motor speed falls and reaches a predetermined value, the centrifugal switch contact closes, the motor gets reconnected to the supply and the speed rises. Some advanced type of food mixers employ this sort of speed control. A capacitor is used across the centrifugal switch to reduce the switching spark and to suppress the radio interference. Apart from the above methods of speed control, a thyristor is also used in certain food mixers to control the speed electronically.

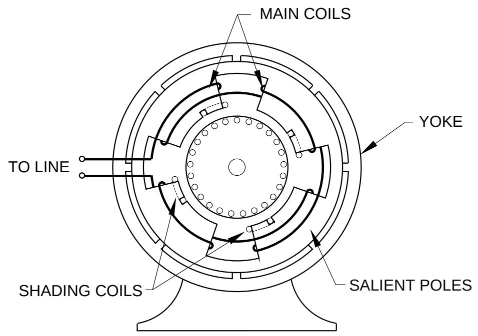
The shaded pole motor and repulsion motor

Objectives : At the end of this lesson you shall be able to
- **explain with a diagram the parts of a shaded pole motor and their functions**
- **explain the principle of working of the shaded pole motor**
- **explain the characteristic of the shaded pole motor and its application.**

Shaded pole motor (construction)

The motor consists of a yoke with salient poles as shown in Fig 1 and it has a squirrel cage type rotor.

Fig 1

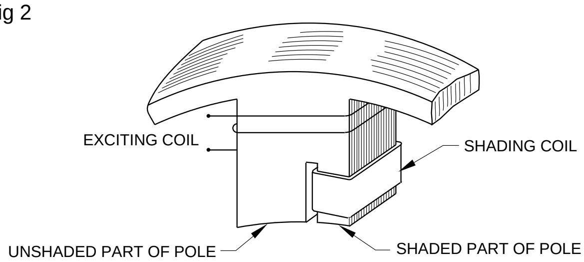


A SINGLE-PHASE MOTOR WITH SHADING COILS FOR STARTING

Construction of a shaded pole

A shaded pole made up of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole. Around the smaller portion of the pole, a short circuited copper ring is placed which is called the shading coil and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig 2.

Fig 2



A TYPICAL SHADED-POLE CONSTRUCTION

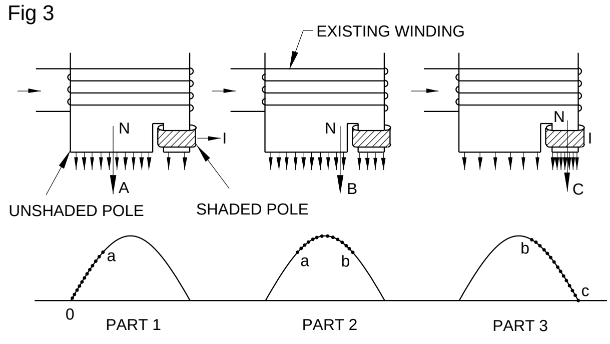
Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is given to the exciting coil the magnetic axis shifts from the unshaded part of the pole to the shaded part as explained in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole. This magnetic axis which is moving, cuts the rotor conductors, and hence, a rotational torque is developed in the rotor. Due to this torque, the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

Shifting of the magnetic flux from the unshaded part to the shaded part could be explained as stated below.

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron core it will have high inductance.

When the exciting winding is connected to an AC supply a sine wave current passes through it. Let us consider the positive half cycle of the AC current as shown in Fig 3. When the current raises from 'zero' to point 'a', the change in current is very rapid (fast), hence induces an emf in the shading coil by the principle of Faraday's laws of electromagnetic induction. The induced emf in the shading coil produces a current which in turn produces a flux which is in opposite direction to the main flux in accordance with Lenz's law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig 3 in the same form of flux arrows. This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow (longer one) in part 1 of Fig 3. On the other hand as shown in Part 2 of Fig 3 when current rises from point 'a' to 'b' the change in current is slow, the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shaded portion. This makes the magnetic axis to be shifted to the centre of the whole pole as shown by the arrow in part 2 of Fig 3.

Fig 3



CHANGE OF MAGNETIC AXIS SHOWN FROM POSITION A TO C

In the next instant, as shown in part 3 of Fig 3, when the current falls from 'b' to 'c', the change in current is fast and its value of change is from maximum to minimum. Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the centre of the shaded part as shown by the arrow in part 3 of Fig 3.

From the above explanation it is clear that the magnetic axis shifts from the unshaded part to the shaded part which is more or less physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing the direction. Two such types are shown in Fig 4. In a) the double set of shading coils method is shown and in b) the double set of exciting winding method is shown.

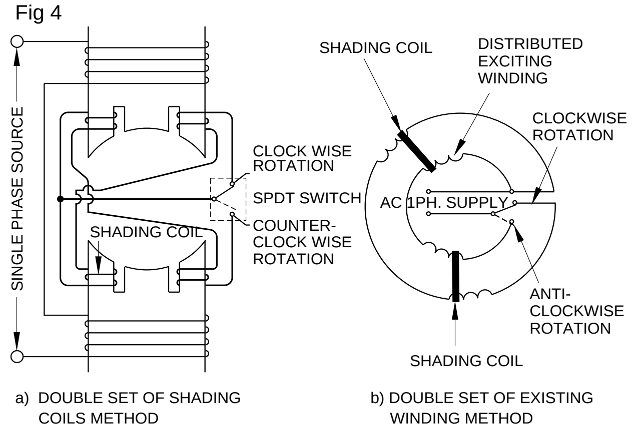
Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motors as stated below:

– low starting torque

– very little overload capacity

– low efficiency.

Fig 4



METHODS FOR REVERSING SHADED-POLE MOTORS-TWO-POLE CONSTRUCTION

The efficiency varies from 5% to 35% only in these motors.

Because of its low starting torque, the shaded pole motor is generally used for small table fans, toys, instruments, hair dryers, advertising display systems and electric clocks etc.

Repulsion motor

Objectives: At the end of this lesson you shall be able to
- **explain with diagrams the principle, working, types and construction of the repulsion motor**
- **explain the characteristic and application of the repulsion motor.**

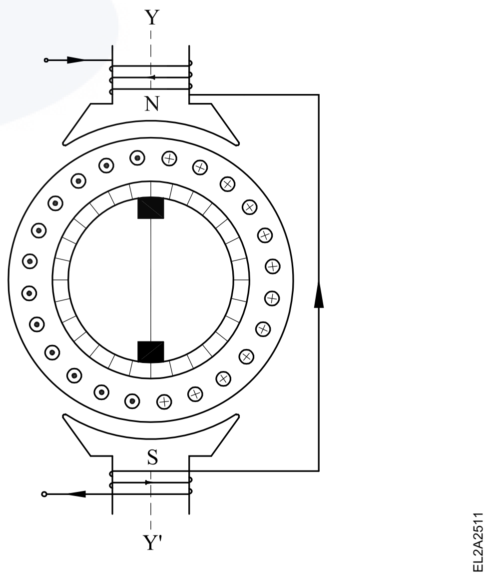
Repulsion Motor

Repulsion motors, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, abilitiy to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

The repulsion principle : The principle of torque production in a repulsion motor could be explained as follows. Fig 1 shows a two-pole motor with its magnetic axis vertical. An armature, having a commutator which is short-circuited through the brushes, is placed in the magnetic field. When the stator winding is connected to an AC supply, it produces an alternating magnetic field. Assume that at an instant, a north pole at the top and a south pole at the bottom are produced by this alternating magnetic field. Because of this a voltage will be induced in all the rotor conductors by the transformer action. The direction of current in the conductors will be in accordance with Lenz's law such that they create a north pole at the top just below the stator north pole, and a south pole at the bottom just at the top of the stator south pole to oppose the induction action. Hence the stator poles and the rotor poles will oppose each other in the same line. There will, therefore, be no torque developed due to the abscence of the tangential component of the torque.

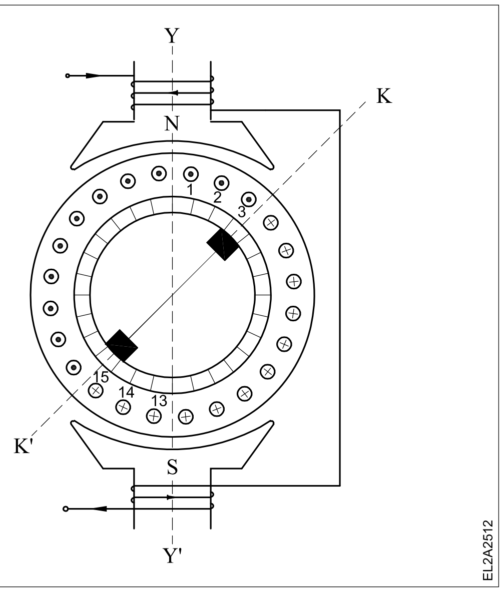
Let us assume that the short-circuited brush-axis is moved to a position as in Fig 2. Due to the present brush position, the magnetic axis of the armature is no longer co-linear with respect to the vertical axis of the main poles.

Fig 1



It will now be along the axis `KK' with north and south poles shifted around by an angle `A°' depending upon the shifting of the brushes. In this position, the direction of current in the conductors 1,2,3 and 13,14,15 is reversed, and hence, the armature becomes an electromagnet having the north (N) and south (S) poles in the `KK' axis just at an angle of `A°' from the main magnetic axis. Now there is a condition that the rotor north pole will be repelled by the main north pole, and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion

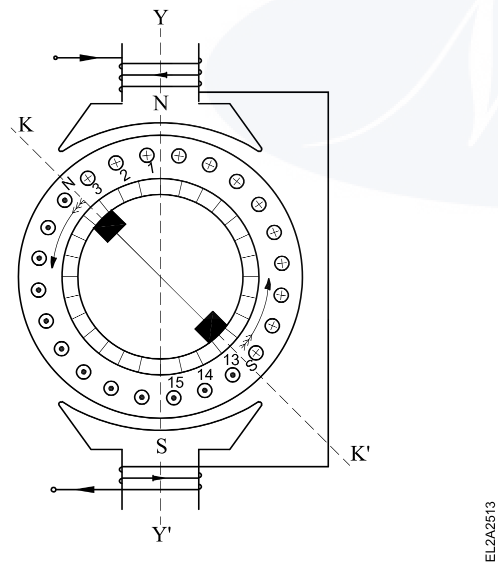
Fig 2



action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this motor is named as repulsion motor.

Direction of rotation : To change the D.O.R. of this motor, the brush-axis needs, to be shifted from the right side as shown in Fig 2 to the left side of the main axis in a counter-clockwise direction as shown in Fig 3.

Fig 3



This working principle applies equally well for all types of repulsion motors having distributed windings in the stator.

Types of repulsion motors : There are four types of induction motors as stated below.

– Repulsion motor

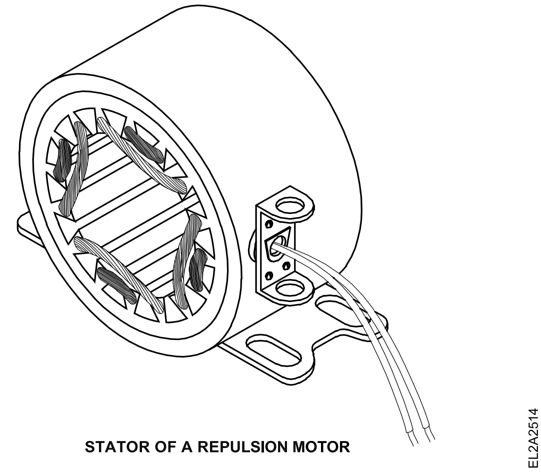
– Compensated-repulsion motor

– Repulsion-start, induction-run motor

– Repulsion-induction motor

Construction : The construction of stators is the same in all the types, except for certain variation in the compensated-repulsion motor. In general, for all types of repulsion motors the stator winding is of the distributed, non-salient pole type, housed in the slots of the stator, and only two terminals as shown in Fig 4 are brought out. It is wound for four, six or eight poles. The rotor for each type of motor is different, and will be explained under each type.

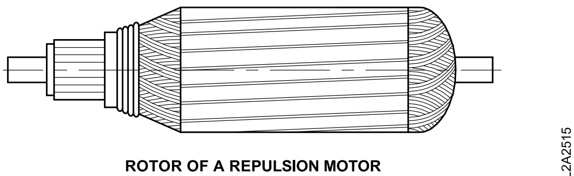
Fig 4



STATOR OF A REPULSION MOTOR

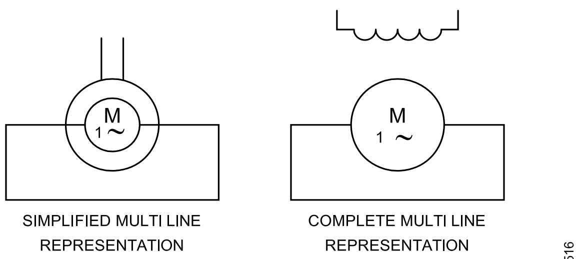
Repulsion motor : The general construction of the repulsion motor is similar to the one explained under the `Repulsive principle'. However the rotor of the repulsion motor is like a DC armature that is as shown in Fig 5, having a distributed lap or wave-winding. The commutator may be similar to the DC armature, that is axial type, having commutator bars in parallel to the shaft or radial or vertical bars on which brushes ride horizontally. The shorted brush position can be changed by a lever attached to the rocker-arm. The B.I.S. symbol for the repulsion motor is shown in Fig 6.

Fig 5



ROTOR OF A REPULSION MOTOR

Fig 6

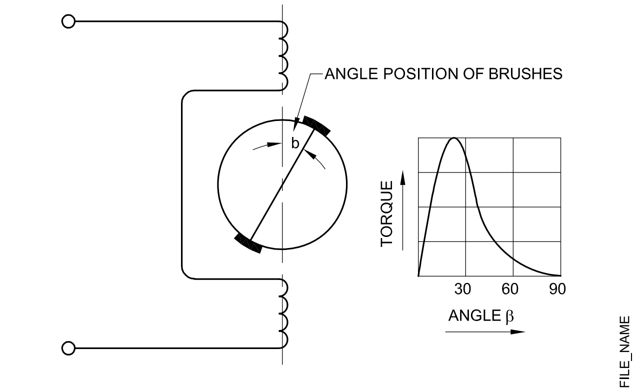


REPULSION MOTOR

As explained earlier, the torque developed in a repulsion motor will depend upon the amount of brush-shaft as shown in Fig 7, whereas the direction of shift decides the direction of rotation. Further, the speed also depends upon the amount of brush-shift and the magnitude of the load.

The torque speed characteristic of the motor is shown in Fig 9.

Fig 7

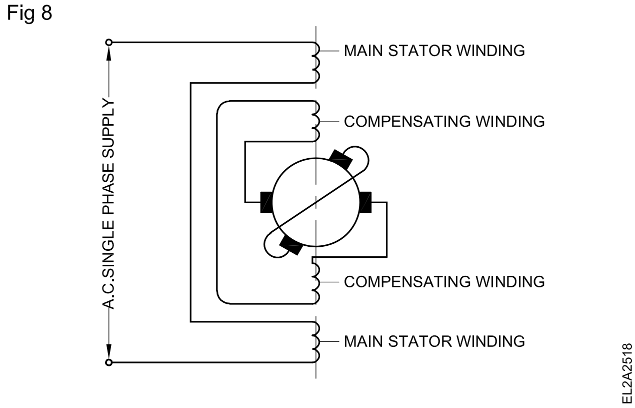


Relationship between the torque and brush-position angle in a repulsion motor

Though the starting torque varies from 250 to 400 percent of the full load torque, the speed will be dangerously high during light loads. This is due to the fact that the speed of the repulsion motor does not depend on frequency or number of poles but depends upon the repulsion principle. Further, there is a tendency of sparking in the brushes at heavy loads, and the P.F. will be poor at low speeds. Hence, the conventional repulsion motor is not much used and the other three improved types are popular.

Compensated repulsion motor : The rotor of the compensated repulsion motor is similar to that of the repulsion motor, except that there is another set of brushes placed in the middle position between the usual short circuited brushes. On the other hand, the stator has an additional winding, called the compensatory winding as shown in Fig 8.

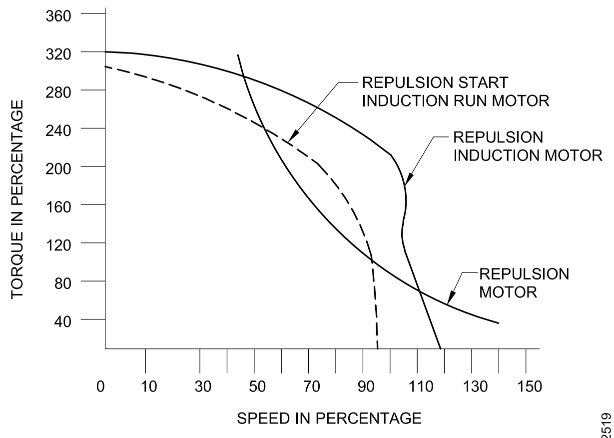
Fig 8



necklace-type shorting mechanism, activated by a centrifugal force which short circuits the entire commutator. From then on, this motor works as an induction motor with a short-circuited rotor (armature). After the commutator is short-circuited, in some machines, there is a special mechanism to lift the brushes to avoid wear and tear of the brushes and the commutator.

The torque speed characteristic of this motor is shown in Fig 9.

Fig 9



SPEED LOAD CHARACTERISTIC OF REPULSION MOTOR

Repulsion-induction motor : The rotor of this motor has a squirrel cage winding deep inside the rotor, in addition to the usual winding. The brushes are short-circuited, and they continuously ride over the commutator. Generally the starting torque is developed in the wound part of the rotor, while the running torque is developed in the squirrel cage winding. The speed torque characteristic is shown in Fig 9. This develops a little less torque, say about 300% of the full load torque, and can start with a load and run smoothly on no load. This motor has its starting characteristic similar to DC compound motor, and running characteristic similar to an induction motor.

APPLICATION : In these motors the average starting torque varies from 300-400 percent of the full load torque, and these motors are preferred in places where the starting period is of comparatively long duration, due to heavy load. These motors are used in refrigerators, air-compressors, coil winders, pertrol pumps, machine tools, mixing machines, lifts and hoists, due to their excellent starting torque, ability to withstand sustained overloads, good speed regulation and easy method of reversal of direction of rotation.

The purpose of the compensating winding is to improve the power factor and to have better speed regulation. This compensating winding is housed in the inner slots of the stator and connected in series with the armature.

Repulsion-start, induction-run motor : The rotor of this motor is similar to that of a repulsion motor but the commutator and the brush mechanism are entirely different. This motor starts like a repulsion motor, and after attaining about 75% of the rated speed, there is a

Panels for electrical work

Objectives: At the end of this lesson you shall be able to
- **state the difference between the panel board and switch board**
- **state the relevant rules and regulations and N.E. code pertaining to erection and wiring of the panel board**
- **estimate the accessories and materials required for the panel board fabrication**
- **explain the method of fabricating the panel board**
- **explain the method of installing panel boards and wiring**
- **explain the method of earthing of the panel board**
- **explain the method of terminating and harnessing the cable**
- **explain the method of testing the m.g. set panel wiring.**

Differences between panel and switch boards: A panel board contains a single panel or a group of panel units designed for assembly in the form of a single panel that includes bus-bars, protective devices and control switches. The control gear panel boards may also include instruments, regulators, circuit breakers and motor starters etc.

In a panel board, the interior assemblies are designed to be placed in a cabinet or cut out box placed in or against a wall or partition and accessible only from the front.

On the other hand a switch board consists of a large single panel, frame or assembly of switch gears, with or without instruments, but the term switch board does not apply to a group of local switches in the final circuit. Unlike panel boards, switch boards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. However the terms, panel board and switch board, are used normally without much discrimination.

Panel board and assembly: A panel may consist of the following equipment.

a) Bus bar

b) Main power isolator

c) Power transformer

d) Switches and fuses

e) Motor starter unit

f) Capacitor banks

g) Electronic controls

h) Relays

i) Meters/instruments

j) Annunciators

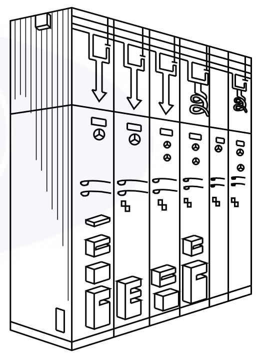
k) Signal lamps/indicating systems etc.

Each of these pieces of equipments are normally housed in a separate enclosure, with controls and relays usually being grouped in an instrument cabinet.

Modern equipment can be mounted in identical, gangable, plug-in type enclosures. Whereas a number of identical panel boards arranged in a row gives good appearance, it also leads to confusion unless the switch gears, fuses, control equipment and connected instruments are marked legibily about their area of control. Normally name identification plates are made and riveted in the panel for correct identification.

Further the panel boards can have single line diagrams either painted or made in plates and then riveted on panel to show the routes and connections to the control gear. The general arrangement is shown in Fig 1.

Fig 1



Relevant rules and regulations as per I.E.: At this stage it is necessary to study certain I.E. rules, which are given below pertaining to panels/switch boards.

Extracts from indian electricity rules - 1956

Rule 29 Construction,installation,protection,operation and maintenance of electric supply lines and apparatus.

All electric supply lines and apparatus should be of sufficient strength and size for the work they may be required to do and should be constructed, installed and protected in accordance with I.S. specifications.

Rule 30 Service lines and apparatus on consumer's premises.

1 The supplier shall ensure that all electric supply lines, wires and fittings and apparatus belonging to him or under his control, which are on the consumer's premises are in safe condition and in all respects fit for supplying energy and the supplier shall take due precautions to avoid danger arising on such premises from such supply lines, fittings and apparatus.

2 The consumer shall ensure that the installation under his control is maintained in a safe conditions.

Rule 31 Cut out on consumer's premises.

The supplier shall provide a suitable cut out in each conductor of every service line other than an earthed or earthed neutral conductor in an accessible position and on consumer's premises. Such cutout shall be contained within an adequately enclosed fire proof receptacle and each consumer shall be provided with an independent cutout at the point of junction to the common service.

Rule 32 Identification of earthed and earthed neutral conductors and position of switches and cut-outs therein.

1 The earthed conductor shall be provided with an indication of permanent nature at the point of commencement of supply.

2 No cut-out, link or switch other than a linked switch shall be provided on the earthed conductor, except a link for testing purposes.

Rule 33 Earthed terminal on consumer's premises.

1 The supplier shall provide and maintain on the consumer's premises, a suitable earthed terminal for consumer's use and in case of medium, high or extra-high voltage, the consumer shall provide his own additional earthing electrode.

Rule 35 Caution notices.

The owner of every medium, high and extra-high voltage installations shall affix permanently caution notices in Hindi,English and local language of the district on poles, motors or transformers etc. Also, all supports of high and extra high voltage overhead lines shall have caution notices.

Low voltage	: upto 250V
Medium voltage	: 250 to 650V
High voltage	: 650 to 33 kV
Extra high voltage	: Above 33 kV

Rule 44 Instructions for restoration of persons suffering from electric shock.

Shock treatment charts in English, Hindi and local language for the restoration of persons suffering from electric shock shall be affixed in conspicuous position. The authorised persons on duty should be familiar with the instructions in shock treatment.

Rule 45 Precautions to be adopted by consumers, owners, electrical contractors, electrical workmen and suppliers.

All electrical installation work shall be carried out only by licensed electrical contractors and under the supervision of a person holding a certificate of competency issued by the state or Central Government.

Rule 46 Periodical inspection and testing of consumer's installation.

1 Every installation, already connected to the supply system, should be periodically inspected and tested at intervals not exceeding five years either by the inspector or by the supplier as may be directed by the State Government.

Rule 49 Leakage of current in consumer's premises.

The supply can be disconnected, after giving 48 hours notice in writing by the inspector to the consumer, if the leakage exceeds 1/5000th part of the maximum current and shall not give supply until the inspector is satisfied that the cause of the leakage has been removed.

Rule 50 Supply to consumers.

The supplier shall not commence or continue to give supply of energy to any consumer unless:

a A linked switch or a circuit breaker of requisite capacity to carry the current is placed at the point of commencement of supply.

b Every distinct circuit is protected against excess energy by a cut-out or circuit breaker.

c The supply of energy to each motor or other apparatus is controlled by a suitable linked switch or a circuit breaker of requisite capacity placed in an accessible position.

Rule 51 Provisions applicable to medium high or extra voltage installations.

1 In case of medium, high or extra-high voltage, all cables shall be completely enclosed in mechanically strong metal casing, or metallic covering, which is electrically and mechanically continuous and adequately protected against mechanical damage, unless the said conductors are accessible only to an authorised person or are installed and protected to the satisfaction of the inspector, so as to prevent danger.

2 All metal parts (work) must be earthed.

3 Every main switch board and panel board shall comply with the following provisions:

   a A clear space of not less than 91.44 cm in width shall be provided in front of the switch board.

   b If there are any attachments of bare connections at the back of the switch board, the space (if any) behind the switch board shall be neither less than 22.86 cm nor more than 76.2 cm in width, measured from the farthest outstanding part of any attachment or conductor.

   c If the space behind the switch board exceeds 75 cm in width, there shall be a passage way from either end of the switch board clear to a height of 1.829 m.

Rule 54 Declared voltage of supply consumer.

The voltage at the point of commencement of supply shall not vary more than 5 per cent in case of low or medium voltage or by more than 12 1/2 per cent in case of high or extra high voltage except with the written consent of the consumer or previous sanction of the State Government.

Rule 61 a) Connection with earth

The following provisions shall apply to the connection with earth of systems at low voltages in cases where the voltage normally exceeds125 volts and of systems at medium voltage.

1 The neutral conductor of a three-phase four wire system and the middle conductor of a two-phase three wire system shall be earthed by not less than two separate and distinct connections with earth both at the generating station and at the sub-station.

2 It may also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which may be at consumer's premises.

3 In the case of concentric cables, the external conductor shall be earthed by two separate and distinct earths.

4 In a direct current three-wire system, the middle conductor shall be earthed at the generating station. Only the current from the middle conductor to earth shall be continuously recorded by means of a recording ammeter and if any time the current exceeds 1/1000th part of the maximum supply current, immediate steps shall be taken to improve the insulation of the system.

5 In case of D.C. system, no impedance other than that required, solely for the operation of switch gear or instruments, cut-outs or circuit breakers shall be inserted. Results of all leakage currents shall be recorded by the supplier.

6 No earth connection shall be made with water main normally except with the consent of the owner and the inspector.

Rule 61(b).

1 The frame of every generator, stationary motor, transformer etc. using energy at medium voltage shall be earthed with two separate and distinct earths.

2 All metal casings of any system or apparatus shall be connected with earth and shall be so joined as to have good electrical and mechanical connection throughout their whole length.

3 Test the earthing system for electrical resistance before energisation.

4 All earthing systems belonging to the supplier shall in addition be tested for electrical resistance on a dry day during the dry season not less than once every two years. A record shall be kept of all such tests.

Extracts form of N.E. Code

Erection of panel board/distribution board: Fixed-type metal boards **-** These shall consist of an angle or channel iron frame fixed on the wall or on the floor and supported on the wall at the top if necessary. There shall be a clear distance of 1m in front of the switchboard. If there are any attachments of bare connections at the back of the switchboard, Rule 51(1)(c) of Indian Electricity Rules, 1956 shall apply.

Such types of boards are particularly suitable for large switchboards for mounting a large number of switchgears or a higher capacity metal-clad switchgear or both.

Arrangement of apparatus: Equipment which is on the front of a switchboard shall be so arranged that inadvertent personal contact with live parts is unlikely during the manipulation of switches, changing of fuses and other similar operations.

No apparatus shall project beyond any edge of the panel. No fuse body shall be mounted within 2.5 cm of any edge of the panel and no hole other than the holes by means of which the panel is fixed shall be drilled closer than 1.3 cm from any edge of the panel.

The various live parts, unless they are effectively screened by substantial barriers of non-hygroscopic, non-flammable insulating material, shall be so spaced that an arc cannot maintain between such parts and earth.

Identification and marking: Marking on a panel board wherever necessary shall be done as given in Table 1.

The arrangement of the gear shall be such that they shall be readily accessible, and their connections to all instruments and apparatus shall also be easily identifiable.

In every case in which switches and fuses are fitted on the same pole, these fuses shall be so arranged that the fuses are not live when their respective switches are in the off position.

No fuses other than the fuses in the instrument circuit shall be fixed on the back of or behind a switchboard panel or frame.

Wiring of panel/distribution board: All connections between pieces of apparatus or between the apparatus and terminals on a board shall be neatly arranged in a definite sequence, following the arrangements of the apparatus mounted thereon, avoiding unnecessary crossings.

Cables shall be connected to a terminal only by soldered or welded or crimped lugs using suitable sleeves, lugs or ferrules unless the terminal is of such a form that it is possible to clamp them securely without the cutting away of the cable strands. The cables in each circuit shall be bunched together.

All bare conductors shall be rigidly fixed in such a manner that a clearance of atleast 2.5 cm is maintained between the conductors of opposite polarity or phase and between the conductors and any material other than the insulating material.

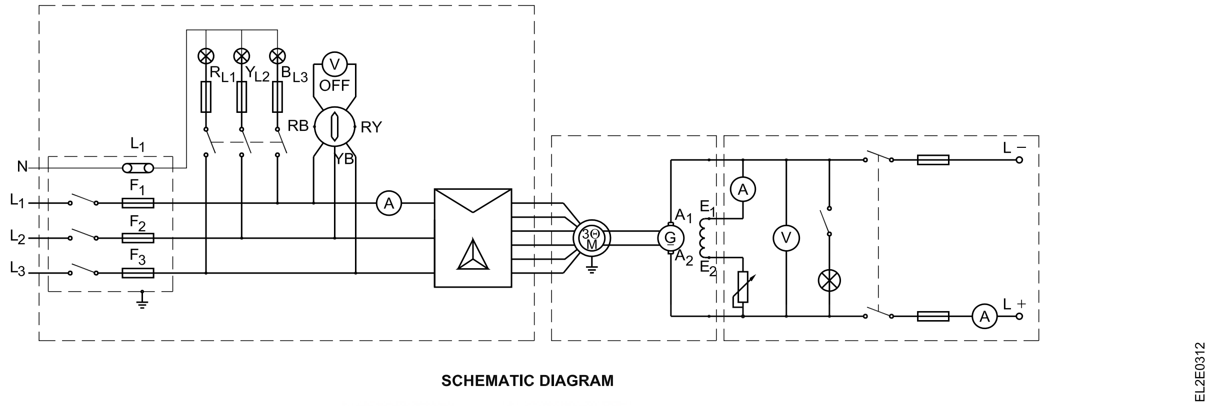
If required, a pilot lamp shall be fixed and connected through an independent single-pole switch and fuse to the bus-bars of the board.

Panel design and estimation: Estimation of accessories and material required for a panel board can only be done after the following requirements are met

1 Decision on type of machine, and coupling if any.
2 Decision on the capacity of machines.
3 Application of the machines.
4 A list of complete control equipment depending on the application.
5 Type of protection for the equipment.
6 Type of wiring to be used taking into account functional and environmental requirement.
7 Selection of place of installation.
8 Type of foundation taking into account soil condition weight of machine, duty cycle and speed of rotation.
9 Type of panel metal or laminated boards.
10 Location of panel and type of cable harnessing.

Based on the above requirement, the technician has to draw the schematic diagram of connection of the electrical machines incorporating all necessary control gears, safety devices like fuses etc. and measuring equipment. The schematic diagram has to checked thoroughly and revised taking into consideration the relevant I.E. rules. For example Fig 2 shows such a schematic diagram. Once the schematic diagram is finalised a list of accessories could be prepared.

Fig 2



SCHEMATIC DIAGRAM

TABLE 1
Alpha-numeric Notation, Graphical symbols and Colours

Designation of conductors		**Identification by**		
		Alphanumeric notation	Graphical symbol	Colour
Supply AC system	Phase 1 Phase 2 Phase 3 Neutral	L_1 L_2 L_3 N		Red Yellow Blue Black
Apparatus AC system	Phase 1 Phase 2 Phase 3 Neutral	U V W N		Yellow Blue Black
Supply DC system	Positive Negative Midwire	L+ L- M		Red Blue Black
Supply AC system (single phase)	Phase Neutral	L N		Red Black
Protective	Conductor	PE		Green & yellow
Earth		E		No colour other than the colour of the bare conductor.
Noiseless(clean earth)		TE		Under consideration.
Frame or chasis		MM		
Equipotential terminal		CC		

Determination of panel size by templates: The next step is to determine the actual panel size. For this take the measurement of the actual accessories to be fitted in the panel.

Consider the following conditions of the component layout.

1 Surface component devices shall be kept in symmetry as far as possible (up/down, left/right).

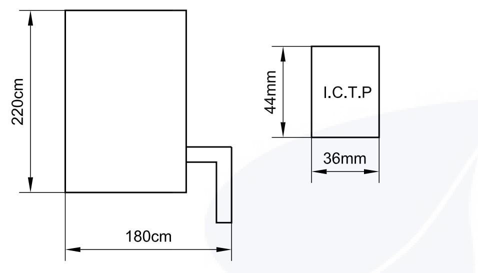
2 The circuit group shall be clearly identified for easy operation.

3 Install wiring for easy recognition.

4 Keep such devices sufficiently apart from other devices or wires that generate arc or heat.

Prepare templates for all the accessories to a convenient reduced scale from a thick card board. An example is shown in Fig 3 which shows the scale used 1/5th of the actual size. While taking measurements, the length and width only are required. Height need not be measured. Take care to see that even the projected handle or larger shafts/handles of the equipment are included in the length and width measurement.

Fig 3



Write the respective name of the accessories on each template.Fix a suitable size drawing paper on a drawing board. Based on the schematic diagram, place the templates on the drawing paper allowing space between the accessories for operational convenience as shown in Fig 4.

While arranging, see that dials and controls are provided so that they are easy to read and operate respectively. Arrange the accessories to satisfy the aesthetic sense, safety requirements and operational convenience. After you are completely satisfied with the placement of the accessories, bearing a width equal to the width of supporting structure like the angle iron frame, draw the length and breadth required for the panel as shown in Fig 4. Take the measurement of the length and width of the panel from the drawing board and multiply with the reciprocal of the reduced scale to get the acutal panel measurement. For example the panel size as per the drawing is 600 mm x 300 mm and the reduced scale is 1/5 th the actual.

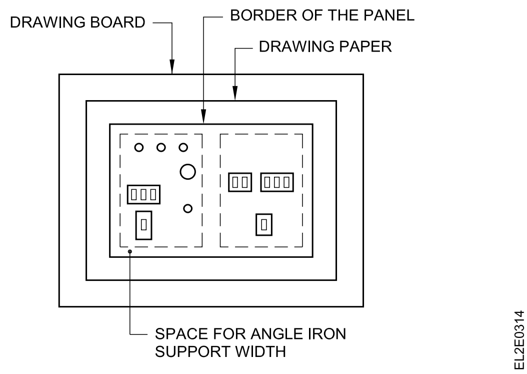
The actual panel length= 600 x 5 = 3000mm or 300cm.

Width = 300 x 5 = 1500 mm or 150 cm.

Draw the layout diagram of the panel to the reduced scale showing the position of all accessories. Measurement should indicate actual panel measurements.

At this stage decide whether metal sheet or laminated boards are to be used for the panel.

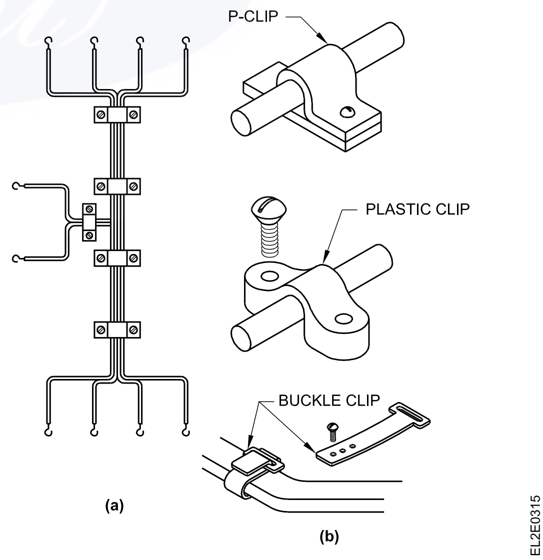
Fig 4



Now decide the size of angle iron and whether additional intermediate supports are required taking into account the length and breadth of the panel and weight of the accessories. In case such additional supports need to be used, the accepted template model need certain modifications to avoid the placement of accessories on the supporting flats or angle irons. If necessary readjust the templates to suit the requirements. Further the type of cables to be used for incoming outgoing and control wiring are to be decided.

Based on this, decide on how the cable harnessing will be done at the back of the panel board. You may use P.V.C. straps or metal bands to harness the cables. Such arrangements are shown in Figs 5a and 5b. In case the metal straps to be used the same can be fitted to the back side of the panel by the use of machine studs. For this the panel board needs to be threaded at pre-selected cable routes.

Fig 5



Apart from this, the type of fastener to be used to mount the accessories is to be decided. Either machine has bolts and nuts or machine studs which could be used in metal panels. But in laminated boards only nut and bolts should be used. Depending on this, drill bits and taps are to be procured from stores.

Lastly the type of panel mounts are to be decided. Panels could either be fitted to the wall or supported by legs to rest on the workshop floor. Such arrangements are shown in Figs 6a, 6b & 6c and Fig 7a & 7b.

While installing the panel boards, a clear space not less than 91.44 cm in width, shall have to be provided in front of the panel board. Further, the space in the back of the panel should not be less than 22.86 cm or more than 76.2 cm in width, measured from the farthest part of any attachment or conductor. In case the back side width exceeds 75 cm there should be a passage in the backside of the panel having a clear height of 1.829 metres according to I.E. rule No.51.

Based on the above requirements prepare a complete list of materials and tools required for the job.

Fig 6

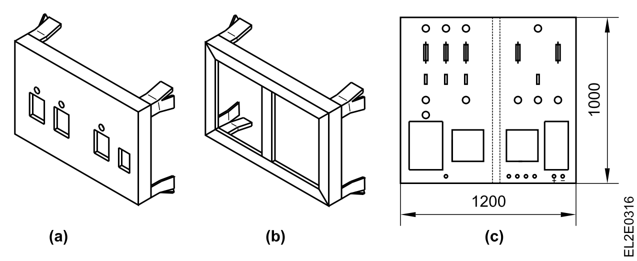
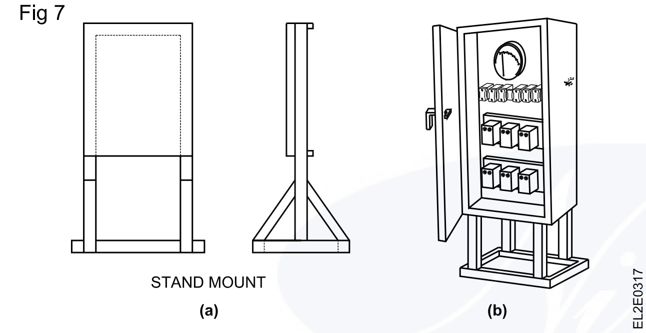


Fig 7



Method of fabricating panel board: According to the panel measurement, cut the angle irons to the required size and form 45^o angle joints. Weld the pieces together in such away the surface is even and the corners are perfect. Grind or file the surface to make it uniform. Mark and cut a M.S. sheet of 3 mm thickness or a laminated board of 10 mm thickness Make holes correspondingly in the frame and fix the metal/laminated sheet to the frame.

Lay the metal/laminated sheet horizontally and mark the position of the fixing holes of the accessories according to the layout diagram shown in Fig 4. Mark the cable entry points and drill suitable size holes in the panel sheet.

Mount the accessories on the panel sheet. Use spring washers for fixing the metal accessories as shown in Fig 8. Use flat washers for moulded equipment as shown in Fig 9. Use craft paper in between the porcelain equipment and the panel as shown in Fig 10. When fixing the equipment on a panel care should be taken to extend atleast two threads of the bolt beyond the nut as shown in Fig 11. Use flat washers and spring washers in between the panel and the nuts. For fixing the terminals of supply in the metal panels use insulated washers. Preferably use decorative bolts for equipment mounted on the panel face. These are shown in Fig 11. Exercise special care to see the equipment fitted maintains horizontal and vertical positions aligned with the edges of the panel.

Fig 8

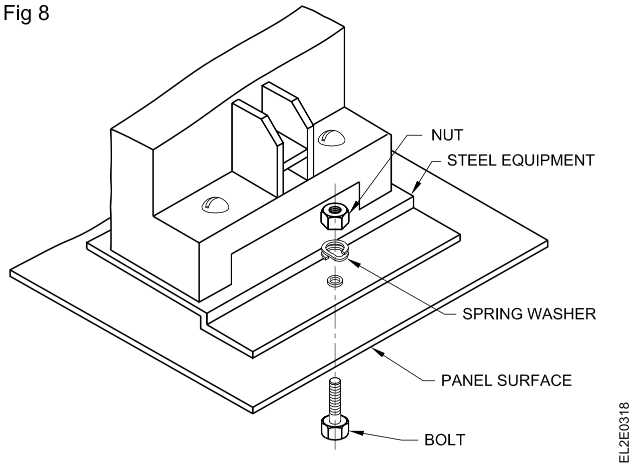


Fig 9

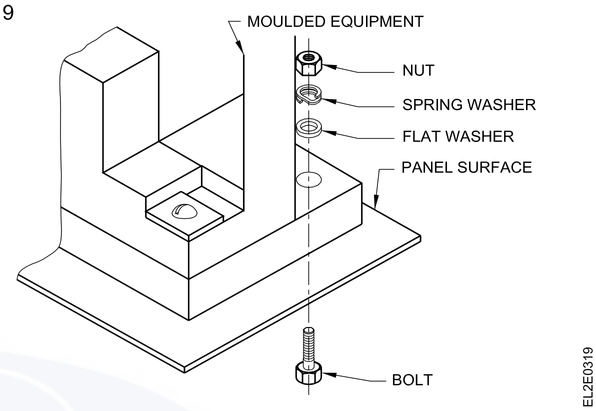


Fig 10

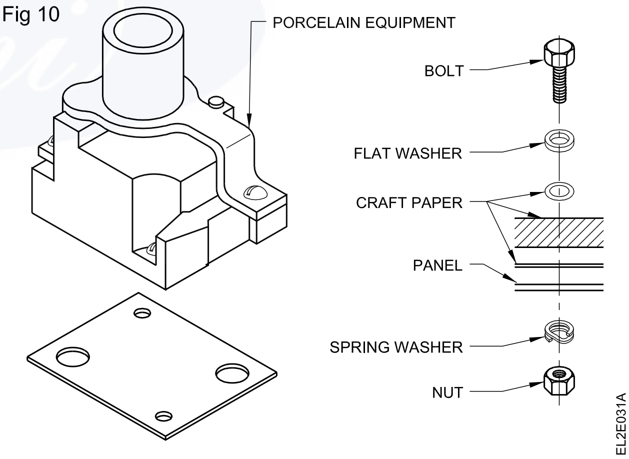
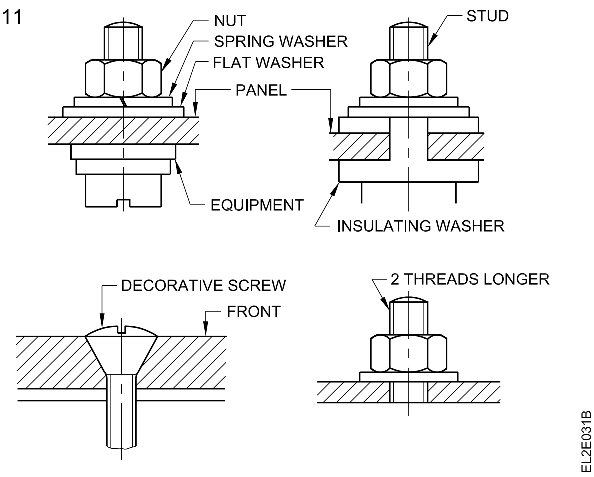


Fig 11



Installation of panel board and conduit: Depending upon the location and weight of the panel with the accessories, the panel could either be mounted in a wall or made to stand on the floor with the help of a metal stand as shown in Figs 6 and 7 respectively.

Care should be taken to see the panel when grouted to the wall is stable and strong. A minimum depth of 200 mm should be maintained for shell panels while heavy panels require more than 300 mm depth in the walls. Grouting should be made with cement, stone and sand mixture of good proportion to rest on the legs. While making the panel special care is to be taken to see that the panel is completely balanced along with the accessories.

At this stage the metal panel sheet and the supporting angle irons need to be painted first with a metal primer and then with a good quality synthetic enamel paint of grey colour. Allow the paint to dry before refixing the accessories on the panel.

The conduit run from the machine to the panel should satisfy I.E. rules and I.S. recommendations.

Method of earthing: Two separate earthing terminals should be made available on the panel. Two distinct earth continuity conductors should run from the machine to the panel and to the main earth electrodes. Use a solid copper or aluminium bar to bond each item of equipment to the earth terminal as shown in Fig 12 or alternatively cables could be used as bonding conductors to earth the equipment as shown in Fig 13.

Fig 12

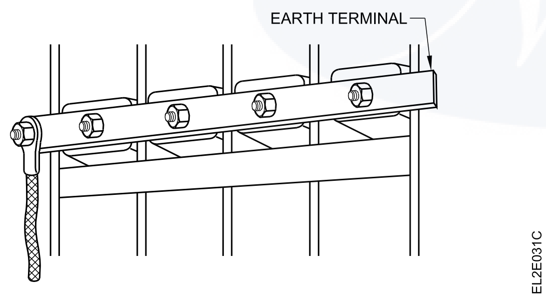
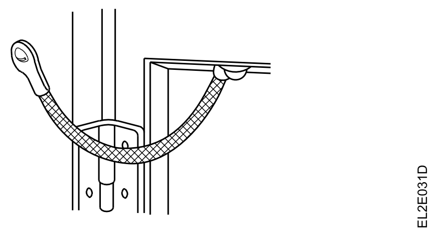


Fig 13



Termination of cables: The rear panel wiring could be done using terminal blocks or directly connecting the cables to the accessories. Fig 14 shows the terminal block arrangements. While terminating the cables at the terminal block the following points need to be observed.

1 Do not remove too much insulation such that bare wire is visible outside the terminal.

2 Do not remove too less cable insulation such that the insulation is caught between the terminal and its base.

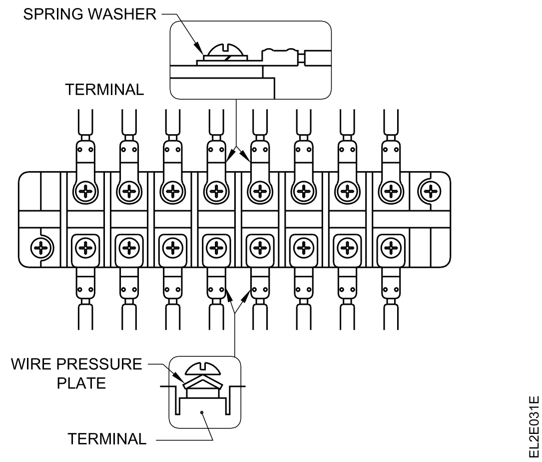
3 Insert the wire fully.

4 The element wires should not stick out.

5 Do not let the wire end to stick out.

6 Always twist the wire before connecting.

Fig 14



Cables harnessing: Fig 15 shows the above mentioned defects in the serial order. While harnessing the cable, the cable run should be straight for 20 to 40 mm from the terminals as shown in Fig 16. Preferably either solid or stranded coppercables should be used for panel wiring and their sizes should depend upon the circuit currents.

Fig 15

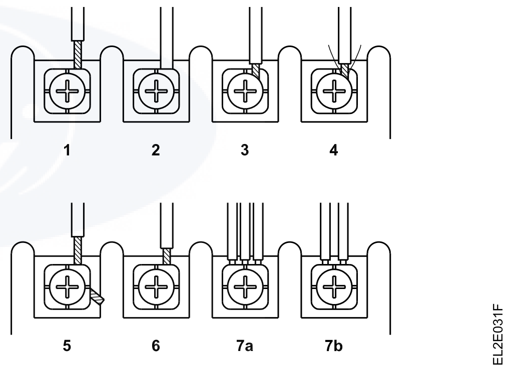
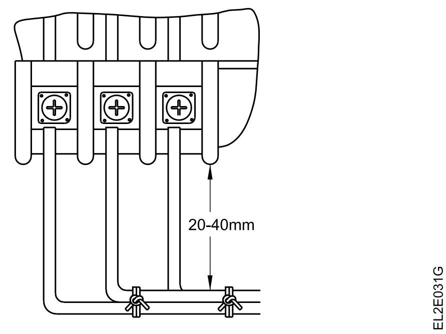
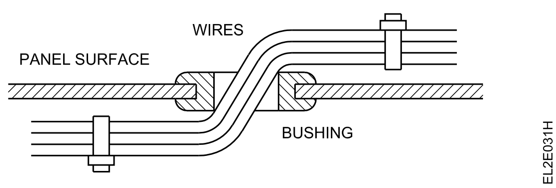


Fig 16



While taking the cables through the panel sheet either rubber or PVC bushed should be used as shown in Fig 17.

Fig 17

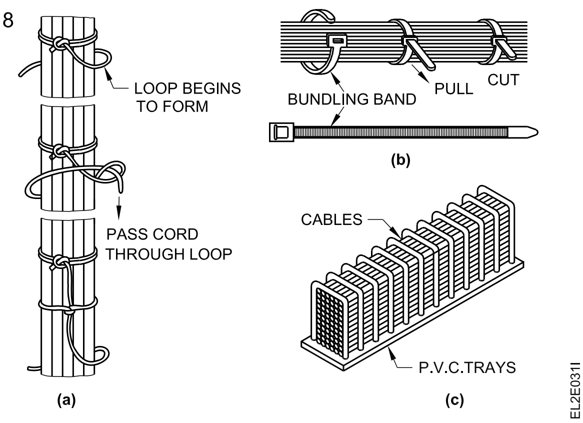


Cables in the rear panel should be bunched straight using any one of the method shown in Fig 18a or 18b.

Fig 18a shows the use of twine or P.V.C. wire whereas 18b shows the use of P.V.C. bundling band, and Fig 18c shows the use of PVC trays which are sometime called PVC casings.

For easy identification of cables, during harnessing and well before terminations, use cable identification markers of similar numbers/alphabets on both ends of the cable. The size of these markers should suit the size of the cables used.

Fig 18



Cables can be held tight along with the panel with the help of P.V.C. saddles as shown in Fig 19. Alternatively the cables could be bundled together with the use of P.V.C. bands as shown in Fig 20.

Fig 19

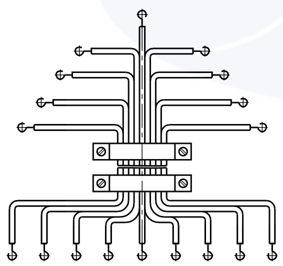


Fig 20

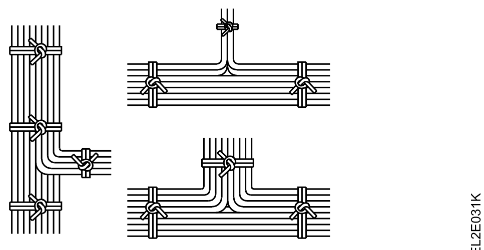
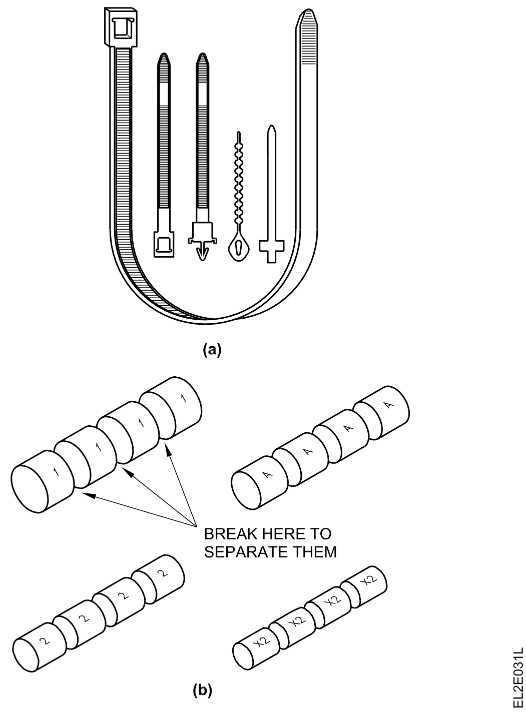


Fig 21a shows various types of nylon bands used for cable harnessing and Fig 21b shows the cable identification markers of various types.

Fig 21



While harnessing cables, it is recommended to use separate bundles of cables for power and control wiring to avoid transfer of heat from power cables to control cables.

Testing of panel board: The panel wiring needs to be tested for

- continuity of power cables
- continuity of control cables
- proper working of the switches, safety equipment indicators and control gears
- insulation resistance of power and control wiring
- effectiveness of the earth connection
- load performance of the connected machine through the panel control circuit.

The information given here is prepared with a view to helping the instructor and trainees to fabricate the panel boards whenever necessary in the institute and also to repair the old ones. This experience will ultimately help the trainees to erect panel boards independently for agriculture pump sets and industrial motor drives after they complete the course in the institute.