



RQF LEVEL 5

TRADE:
INDUSTRIAL
ELECTRICITY

MODULE CODE: ELCRM501

TEACHER'S GUIDE

Module name: ELECTRICAL ROTATING
MACHINES WINDING / REWINDING

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Acronyms

WRERM: Wind and Rewind Electrical Rotating Machine

TSS: Technical Secondary School

Ns: Synchronous Speed

Introduction

Purpose statement

This particular module describes the skills, knowledge and attitude required to wind electrical rotating machines. The electrician will be able to mount/ dismount a rotating machine, prepare the winding diagram and wind accordingly. It applies to electricians working in maintenance.

**Module Code and Title: ELCRM501, ELECTRICAL ROTATING
MACHINES WINDING / REWINDING**

Learning Units:

1. Collect data related to the machine to be wound /rewound.
2. Select tools, equipment and materials.
3. Wind / Rewind Electrical Rotating Machines.
4. Test the wound / rewound machine

LEARNING UNIT 1: COLLECT DATA RELATED TO THE MACHINE TO BE WOUND /REWOUND.



STRUCTURE OF LEARNING UNIT ONE

Learning outcomes:

- 1.1. Interpret machine's nameplate**
- 1.2. Interpret electrical drawing of the rotating machine**
- 1.3. Calculate rotating machine parameters**
- 1.4. Determine winding configurations**

LEARNING OUTCOME 1.1. INTERPRET MACHINE'S NAMEPLATE



Duration: 3hrs



Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Interpret clearly Rotating machine nameplate elements
2. Interpret clearly Rotating machine nameplate manual indication



Resources

Equipment	Tools	Materials
Three phase motor	Set of Screw drivers	Internet manuals
Coil winding machine	Set of Pliers	



Advance preparation:

- Three phase motor
- Motor nameplate



1.1.1. Rotating machine Name plate elements

Three-phase asynchronous squirrel-cage motors (induction motors) are often used in industrial applications because of their low cost, relatively simple manufacturing and robust construction. In all the years since the first induction motor was produced, induction motors have been developed and modified for several reasons. In the last decade according to modern energy efficient society, the development has been oriented into the improvement of induction motor energy-efficiency. This paper presents winding type influence on efficiency of an induction motor considering the mass of used copper.

Ordinary production of induction motors is usually based on standardized stator and rotor laminations which can be bought on the market from several lamination producers. The efficiency of induction motor depends on different factors: producer's technology (purity of squirrel cage material), quality of bearings, quality of lamination materials, construction of housing (additional losses) and type of winding which is inserted into the stator slots.

Moreover, the type of winding can have significant influence on induction motor efficiency.

The tools and materials are quickly and easily obtained and within one day you can begin winding the coils. You only have three more days left to complete the machine and reassemble it in the production line.

➤ ROTATING MACHINE NAMEPLATE ELEMENTS

- Power : kw
- Voltage : volt
- Frequency: Hz
- Speed : rpm
- Connection : star or delta
- Current: Amps
- Power factor

- Serial number
- Insulation class (A-H)
- Manufacture
- Model
- Supplier
- Running condition
- Periodically run
- Continuously run
- weight



Theoretical learning Activity

- Ask trainees to brainstorm about motor nameplate elements



Practical learning Activity

- Trainees in pair identify motor nameplate elements
- Demonstration on motor nameplate elements



Points to Remember (Take home message)

Motor nameplate is always attached on motor housing.



1.1.2. Interpretation of the rotating machine nameplate/ manual indication

Motor parts and their functions

- Stator: for supporting the windings
- Rotor: for driving a machine
- Shaft: hold the rotor
- Bearings: for easy rotor rotation
- End cover: for supporting the rotor
- Fan: for cooling the windings
- End shield: to isolate the fan

- Terminal box: where the wire for the supply and windings are connected
- Bolt and nuts or screws: for holding the end cover to the stator
- Name plate: colure cell the motor (information is available)
- Pulley: for driving a machine
- Base for fixing the motor
- Hook: for lifting the motor (to move up)



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about motor parts and their functions



Practical learning Activity

- ✓ Trainees in pair perform demonstration of the motor parts



Points to Remember (Take home message)

The main parts of three phase motor are stator and rotor

ASSESSMENT

- 1. The following are motor nameplate elements except**
 - Power
 - Air gap
 - Voltage
 - Frequency
 - Speed

Answer: b) Air gap

- 2. The function of bearing in rotating machine is to:**
 - for cooling the windings
 - for driving a machine
 - for easy rotor rotation
 - for supporting the rotor

Answer: c) for easy rotor rotation

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 1.2. INTERPRET ELECTRICAL DRAWING OF THE ROTATING MACHINE



Duration: 2hrs



Learning outcome 2 objectives :

By the end of the learning outcome, the trainees will be able to:

1. Interpret clearly electrical drawing Rotating machine
- 2.



Resources

Equipment	Tools	Materials
Three phase motor	Set of Screw drivers	Internet
Coil winding machine	Set of Pliers	manuals



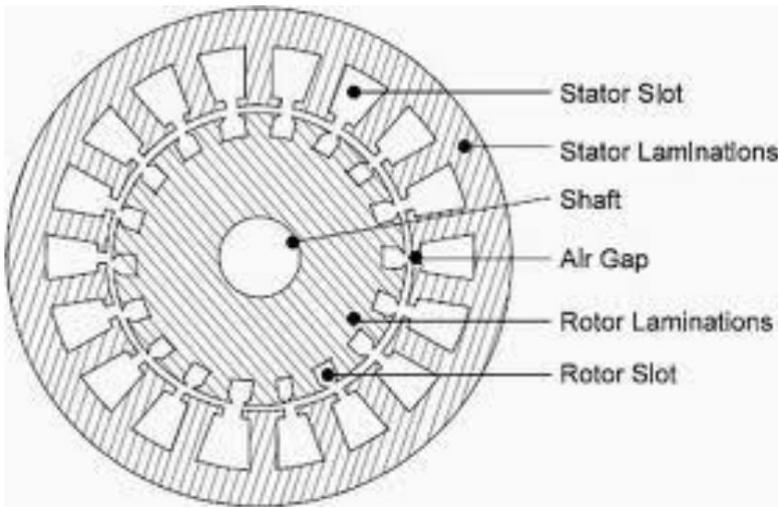
Advance preparation:

- Different diagrams of electrical motor



1.2.1. Construction of the machine

Internal parts of motors (Both of three phase and Single phase motors)



MOTOR WINDING CONNECTIONS

- **STAR CONNECTION**

Star Connection is a connection whereby:

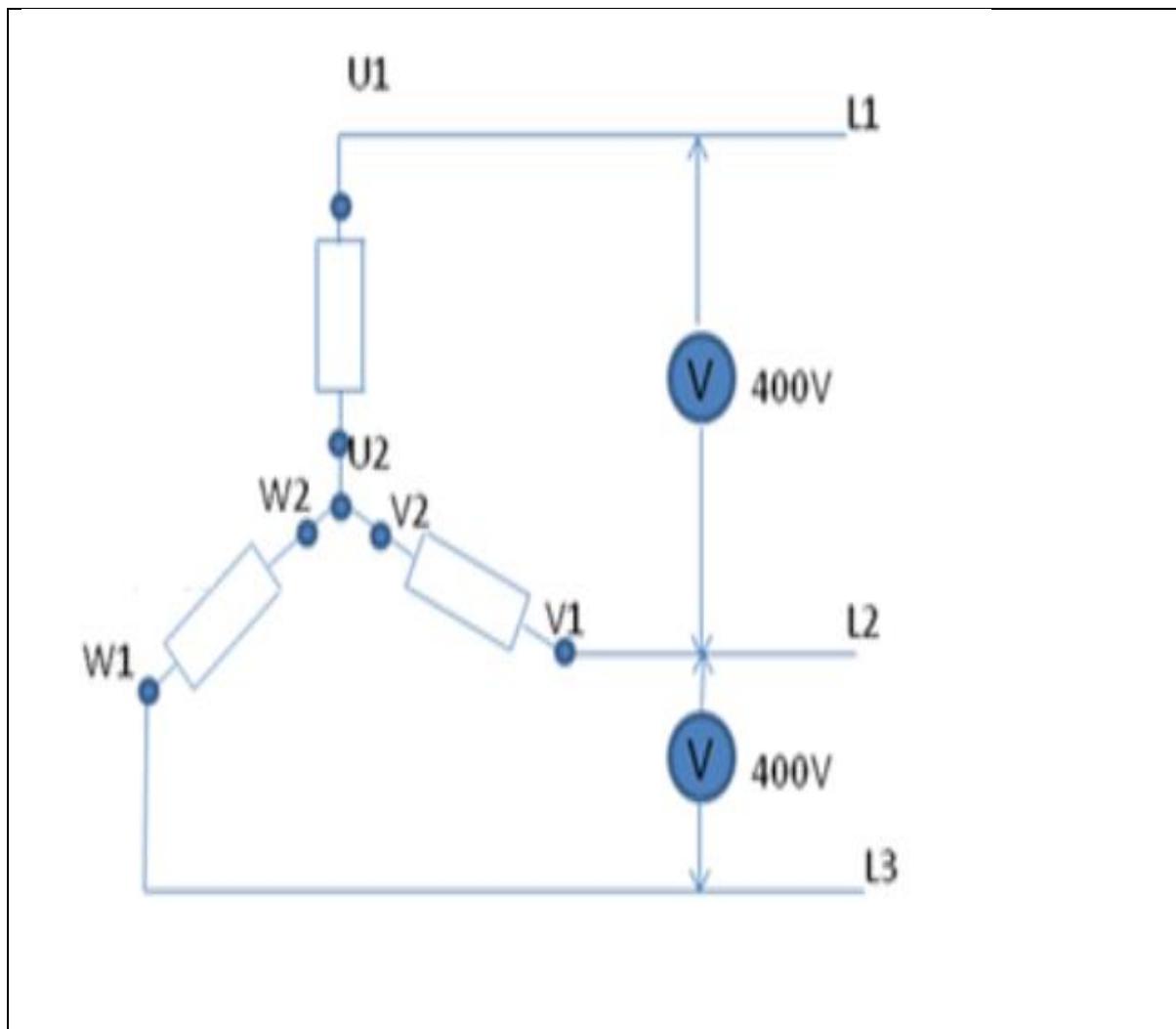
- All the winding ends are connected together
- Supply voltage is connected to the winding starts
- The winding voltages are connected in series

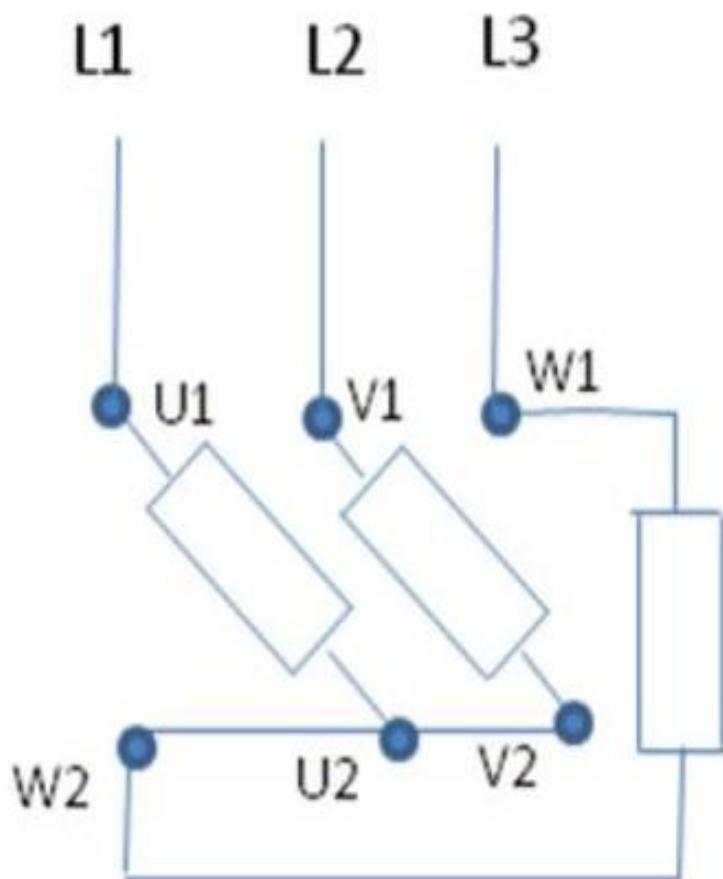
- **DELTA CONNECTION**

Delta connection is a connection whereby :

- The supply voltage is connected to the starts and ends of the windings
- The winding voltage is equal to the line voltage
- Windings are connected in parallel (because if one of them fails the other should work)
- The circuit done through one winding at a time completed
- One motor can be connected into two

STAR CONNECTION



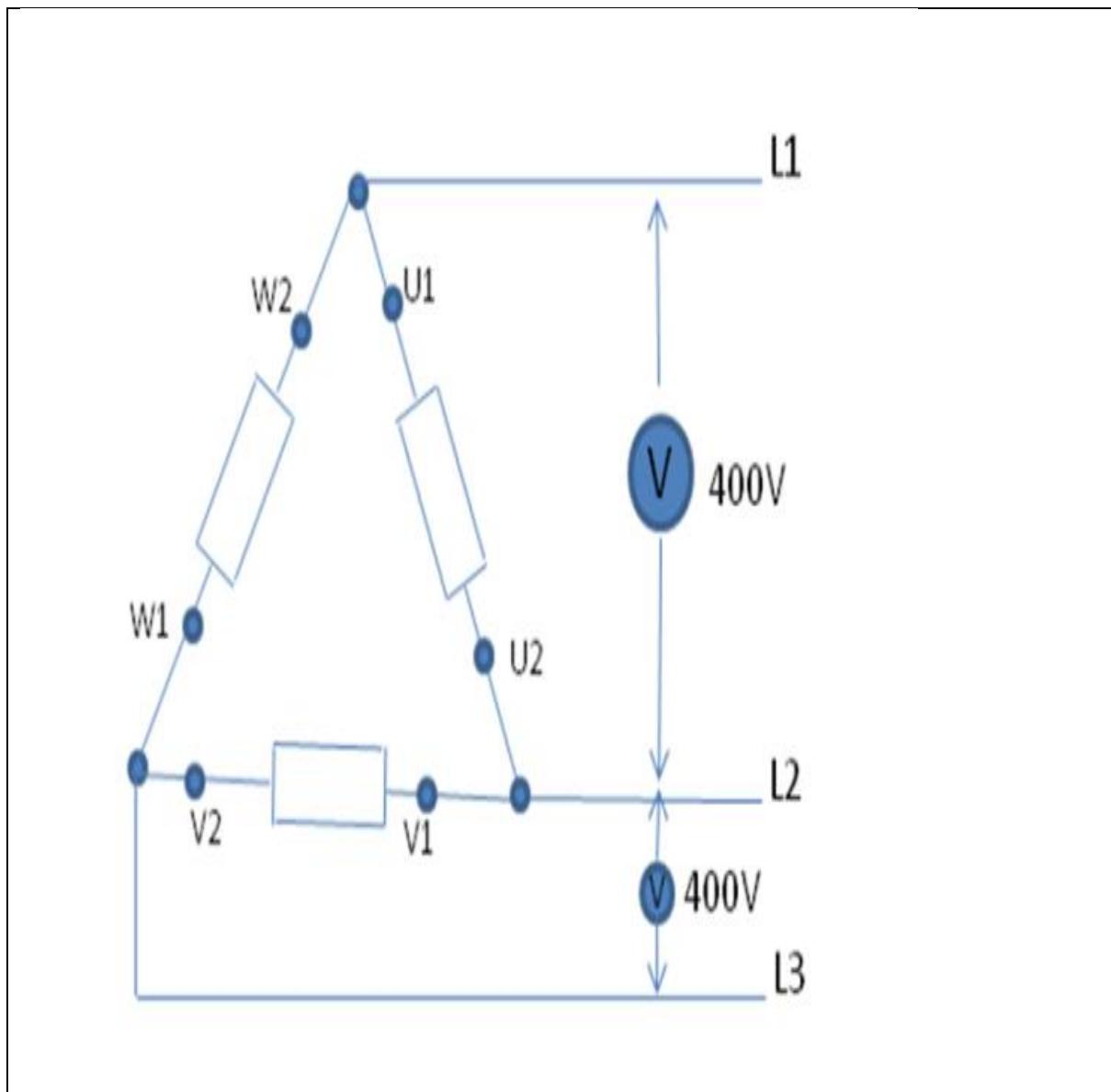


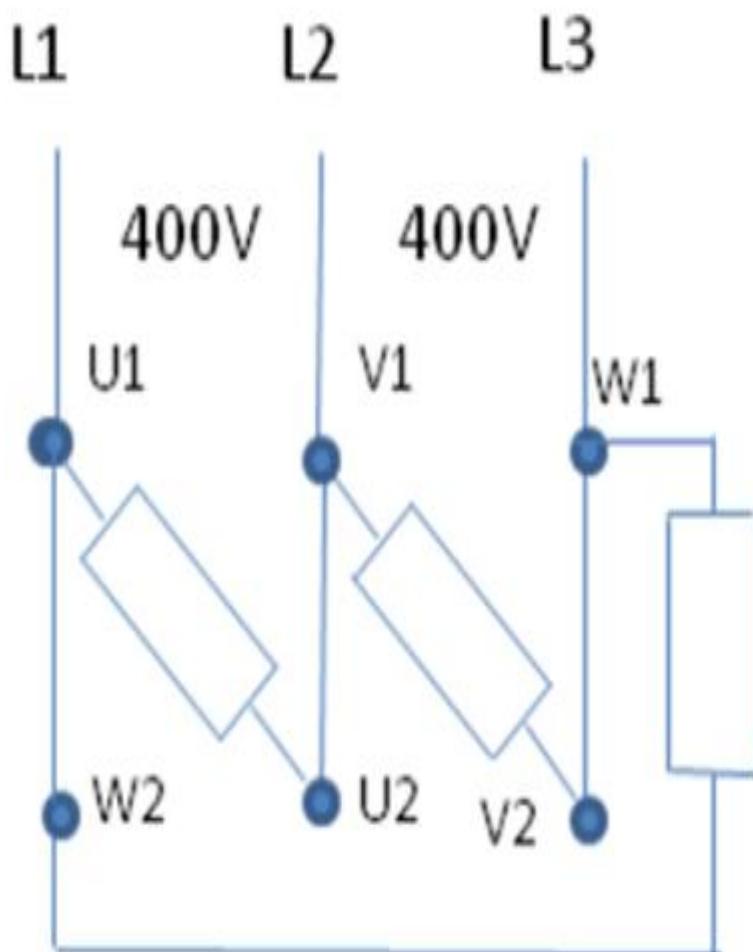
NOTICE

The star connection will be used when the line voltage of the network is identical to that supported by two windings.

Example: A 230V/400V three phase motor will be connected in Star because the line voltage is 400V and each winding supports 230V

Delta connection





NOTICE:

The delta connection will be used when the line voltage of the network is identical to that supported by one winding.

Example: A 400V/690V three phase motor will be connected in delta because the line voltage is 400V and each winding supports this voltage.



1.2.2. Draw and interpret schematic diagram of rotating machine

$$N_s = \frac{1}{P} 120f$$

Where :

N_s : Synchronous speed

P : Number of magnetic poles

F : Frequency

$$\begin{aligned} \text{n of slot} &= 36 \text{ slots} \\ \text{n of slot/pole} &= \frac{36}{2} = 18 \text{ slots} \\ \text{n of slot/pole/phase} &= 18 \text{ slots} / 3 = 6 \text{ slots} \\ \text{n of Coils/group} &= \frac{6 \text{ slots}}{2 \text{ slot/coil}} = 3 \text{ coils} \end{aligned}$$



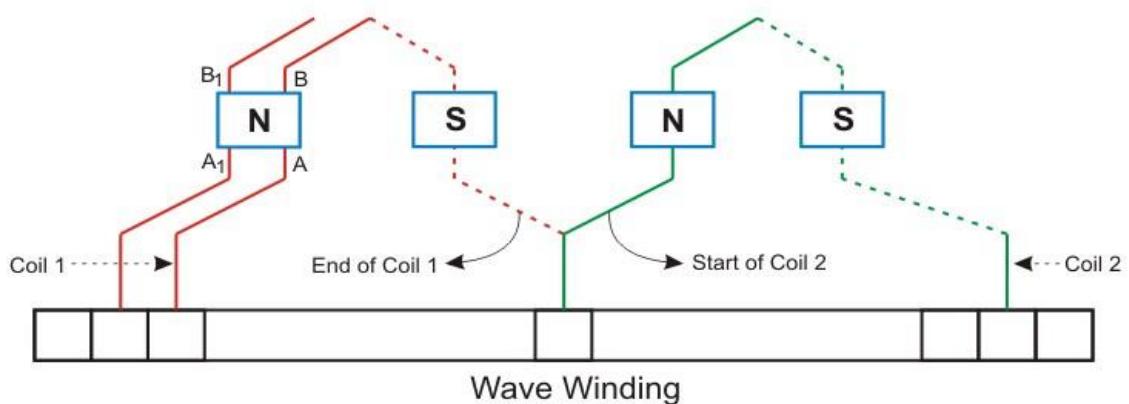
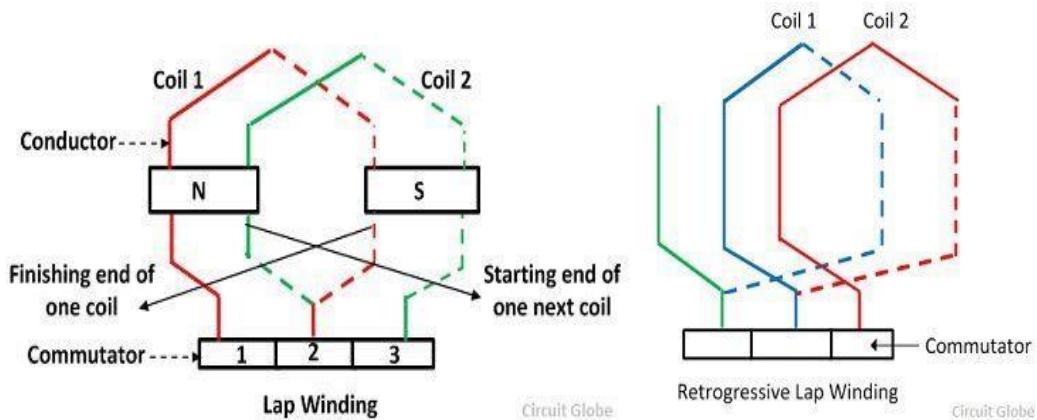
1.2.3. Draw and interpret winding diagram of rotating machine

- **Lap winding**

In lap winding, the conductors are joined in such a way that their parallel paths and poles are equal in number. The end of each armature coil is connected to the adjacent segment on the commutator. The number of brushes in the lap winding is equal to the number of parallel paths, and these brushes are equally divided into negative and positive polarity.

- **Wave winding**

In wave winding, only two parallel paths are provided between the positive and negative brushes. The finishing end of the one armature coil is connected to the starting end of the other armature coil commutator segment at some distance apart.



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about **connections of three phase induction motors**



Practical learning Activity

- ✓ Ask trainees to draw connections of three phase induction motors

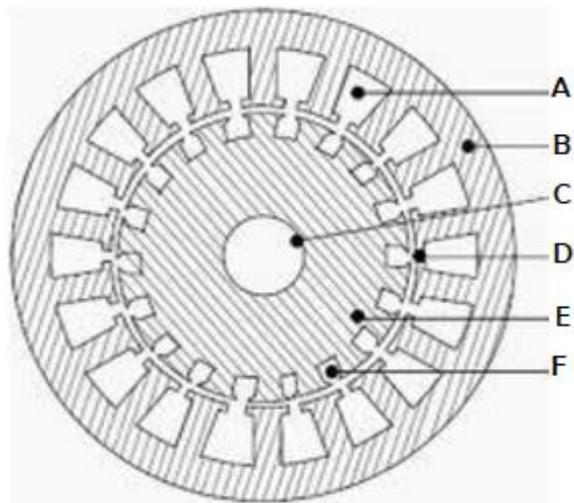


Points to Remember (Take home message)

Three phase induction motors may be coupled either in star or in delta

ASSESSMENT

1. Name the following parts of electrical rotating machine



Answer:

A=Stator slot

B=Stator laminations

C=Shaft

D=Air gap

E=Rotor laminations

F=Rotor slot

2. The formula of how to calculate the synchronous speed of three phase induction motor is:

a) $N_s = \frac{1}{P} 60f$

b) $N_s = \frac{1}{P} 120f$

c) $N_s = \frac{1}{P} 120t$

d) $N_s = \frac{1}{f} 120p$

Answer: b) $N_s = \frac{1}{P} 120f$

3. Answer, True or False

- a) In lap winding, the conductors are joined in such a way that their parallel paths and poles are equal in number.
- b) In wave winding, only two parallel paths are provided between the positive and negative brushes.

Answer:

a) **True**

b) **True**

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 1.3. CALCULATE ROTATING MACHINE PARAMETERS



1.3.1. Compute and analyse rotating machine parameters

Windings

Windings are wires that are laid in coils, usually wrapped around a laminated soft iron magnetic core so as to form magnetic poles when energized with current.

Power is transferred to the rotor by electromagnetic induction, much like transformer action.

An induction motor resembles a rotating transformer, because the stator (stationary part) is essentially the primary side of the transformer and the rotor (rotating part) is the secondary side

Torque motor

- A torque motor is a specialized form of electric motor which can operate indefinitely while stalled, that is, with the rotor blocked from turning, without incurring damage. In this mode of operation, the motor will apply a steady torque to the load
A common application of a torque motor would be the supply- and take-up reel motors in a tape drive.
- In this application, driven from a low voltage, the characteristics of these motors allow a relatively constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads.
- Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches.

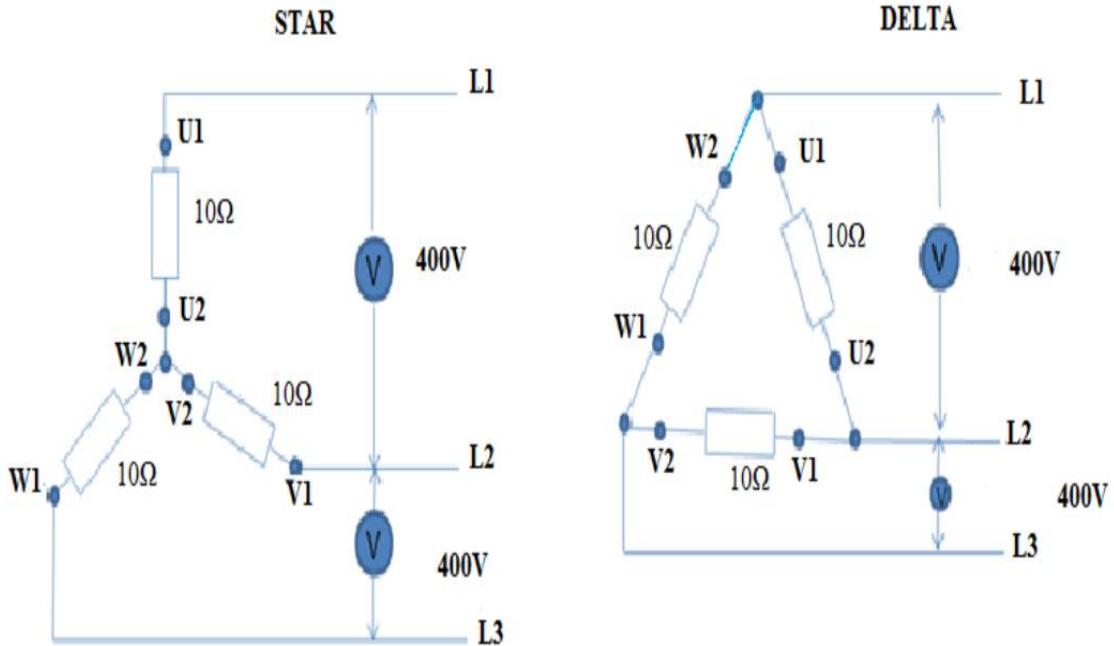
What is the difference between star-delta and Delta-star ?

- Star-delta is an operation of starting a high starting current motor, there is no Delta star starting of a motor exist.
- Delta-star is an indication to indicate the type o connection (DY) according to the line voltage of supply.
- To start motor in star is to minimize the Delta starting current

Motor starting current

- ✓ 0-3kw starting current = 7 times
- ✓ 3-25kw starting current = 4 times
- ✓ 25-250kw starting current =2 times
- ✓ >250 as per manufacture

To prove the proper connection of the motor while installing the motor



Resolution

In STAR Connection

$$I = \frac{V}{R}$$

$$I = \frac{400V}{20\Omega} = 20A$$

Running current is 20A

In DELTA connection

$$I = \frac{V}{R}$$

$$I = \frac{400V}{10\Omega} = 40A$$

Running current is 40A

Starting current is: $20A \times 4 = 80A$

Starting current is: $40A \times 4 = 160A$

The difference between the rotor speed, n_r , and the synchronous speed, n_s , is called the **slip speed**

$$\text{slip speed} = n_s - n_r \text{ rev/s}$$

The ratio $(n_s - n_r)/n_s$ is called the **fractional slip** or just the **slip**, s , and is usually expressed as a percentage. Thus

$$\text{slip, } s = \left(\frac{n_s - n_r}{n_s} \right) \times 100\%$$

Typical values of slip between no load and full load are about 4 to 5% for small motors and 1.5 to 2% for large motors.

Example: A 3-phase, 60 Hz induction motor has 2 poles. If the slip is 2% at a certain load, determine (a) the synchronous speed, (b) the speed of the rotor and (c) the frequency of the induced e.m.f. in the rotor. **solution**

$$(a) \quad f = 60 \text{ Hz}, p = \frac{2}{2} = 1$$

$$\text{Hence synchronous speed, } n_s = \frac{f}{p} = \frac{60}{1} = 60 \text{ rev/s}$$

$$\text{or } 60 \times 60 = 3600 \text{ rev/min}$$

$$(b) \quad \text{Since slip, } s = \left(\frac{n_s - n_r}{n_s} \right) \times 100\%$$

$$2 = \left(\frac{60 - n_r}{60} \right) \times 100$$

$$\text{Hence } \frac{2 \times 60}{100} = 60 - n_r$$

$$\text{i.e. } n_r = 60 - \frac{2 \times 60}{100} = 58.8 \text{ rev/s}$$

i.e. the rotor runs at $58.8 \times 60 = 3528 \text{ rev/min}$

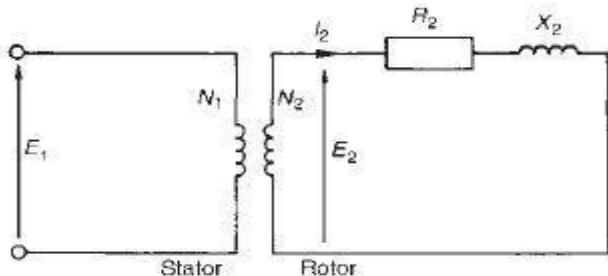
(c) Since the synchronous speed is 60 rev/s and that of the rotor is 58.8 rev/s, the rotating magnetic field cuts the rotor bars at $(60 - 58.8)$, i.e. 1.2 rev/s.

Thus the frequency of the e.m.f.'s induced in the rotor bars is 1.2 Hz

ROTOR E.M.F. AND FREQUENCY

Rotor e.m.f.

When an induction motor is stationary, the stator and rotor windings form the equivalent of a transformer



The rotor e.m.f. at standstill is given by

$$E_2 = \left(\frac{N_2}{N_1} \right) E_1$$

Where E_1 is the supply voltage per phase to the stator. When an induction motor is running, the induced e.m.f. in the rotor is less since the relative movement between conductors and the rotating field is less. The induced e.m.f. is proportional to this movement, hence it must be proportional to the slip, s .

$$\text{Hence when running, rotor e.m.f. per phase} \quad = E_r = sE_2$$

$$= s \left(\frac{N_2}{N_1} \right) E_1$$

Rotor frequency

The rotor e.m.f. is induced by an alternating flux and the rate at which the flux passes the conductors is the slip speed. Thus the frequency of the rotor e.m.f. is given by:

$$f_r = (n_s - n_r)p = \frac{(n_s - n_r)}{n_s}(n_s p)$$

However $\left(\frac{n_s - n_r}{n_s}\right)$ and $n_s p$ is the supply frequency f , hence $f_r = sf$

Example: The frequency of the supply to the stator of an 8- pole induction motor is 50 Hz and the rotor frequency is 3 Hz. Determine (a) the slip, and (b) the rotor speed.

Sol:

$$\text{Hence } 3 = (s)(50)$$

$$\text{from which, slip, } s = \frac{3}{50} = \mathbf{0.06 \text{ or } 6\%}$$

$$(b) \text{ Synchronous speed, } n_s = \frac{f}{p} = \frac{50}{4} = 12.5 \text{ rev/s}$$

$$\text{or } (12.5 \times 60) = 750 \text{ rev/min}$$

$$\text{Slip, } s = \left(\frac{n_s - n_r}{n_s}\right), \text{ hence } 0.06 = \left(\frac{12.5 - n_r}{12.5}\right)$$

$$(0.06)(12.5) = 12.5 - n_r$$

$$\text{and rotor speed, } n_r = 12.5 - (0.06)(12.5)$$

$$= \mathbf{11.75 \text{ rev/s or } 705 \text{ rev/min}}$$

ROTOR IMPEDANCE AND CURRENT

Rotor resistance

The rotor resistance R_2 is unaffected by frequency or slip, and hence remains constant.

Rotor reactance

Rotor reactance varies with the frequency of the rotor current.

At standstill, reactance per phase, $X_2 = 2\pi fL$

When running, reactance per phase, $X_r = 2\pi f_r L = 2(\pi s f)L$ from equation
 $= s(2\pi fL)$

$$X_r = s X_2$$

Rotor copper loss

Power $P = 2\pi n T$, where T is the torque in Newton metres, hence torque
 $T = P/(2\pi n)$

If P_2 is the power input to the rotor from the rotating field and P_m is the mechanical power output (including friction losses)

$$\text{then } T = \frac{P_2}{2\pi n_s} = \frac{P_m}{2\pi n_r}$$

$$\text{from which, } \frac{P_2}{n_s} = \frac{P_m}{n_r} \text{ or } \frac{P_m}{P_2} = \frac{n_r}{n_s}$$

$$\text{Hence } 1 - \frac{P_m}{P_2} = 1 - \frac{n_r}{n_s}$$

$$\frac{P_2 - P_m}{P_2} = \frac{n_s - n_r}{n_s} = s$$

$P_2 - P_m$ is the electrical or copper loss in the rotor, i.e. $P_2 - P_m = I_r^2 R_2$

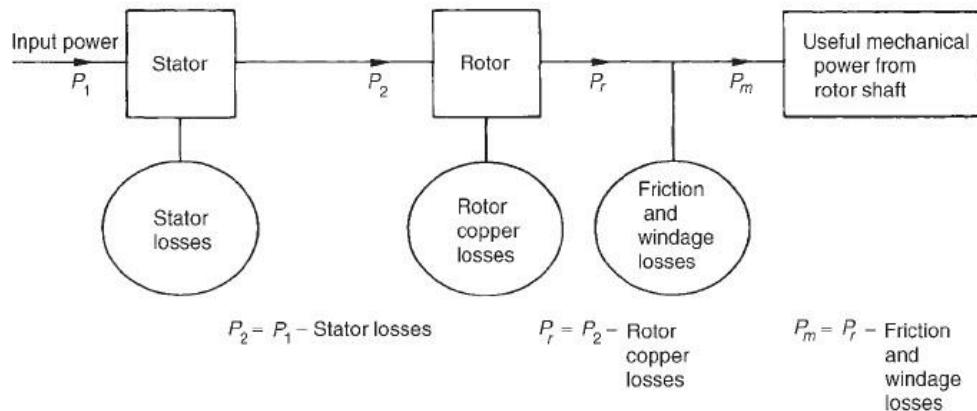
Hence:

$$\text{slip, } s = \frac{\text{rotor copper loss}}{\text{rotor input}} = \frac{I_r^2 R_2}{P_2} \quad \text{or power input to the rotor} \quad P_2 = \frac{I_r^2 R_2}{s}$$

INDUCTION MOTOR LOSSES AND EFFICIENCY

Figure summarizes losses in induction motors. Motor efficiency,

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{P_m}{P_1} \times 100\%$$



Example: The power supplied to a three-phase induction motor is 32 kW and the stator losses are 1200 W. If the slip is 5%, determine (a) the rotor copper loss, (b) the total mechanical power developed by the rotor, (c) the output power of the motor if friction and windage losses are 750 W, and (d) the efficiency of the motor, neglecting rotor iron loss.

(a) Input power to rotor = stator input power - stator losses
 $= 32 \text{ kW} - 1.2 \text{ kW} = 30.8 \text{ kW}$

From equation (22.9), slip = $\frac{\text{rotor copper loss}}{\text{rotor input}}$
 i.e., $\frac{5}{100} = \frac{\text{rotor copper loss}}{30.8}$

from which, rotor copper loss = $(0.05)(30.8) = 1.54 \text{ kW}$

(b) Total mechanical power developed by the rotor

= rotor input power - rotor losses
 $= 30.8 - 1.54 = 29.26 \text{ kW}$

(c) Output power of motor

= power developed by the rotor - friction and windage losses
 $= 29.26 - 0.75 = 28.51 \text{ kW}$

TORQUE EQUATION FOR AN INDUCTION MOTOR

From the equation

$$\text{Torque } T = \frac{P_2}{2\pi n_s} = \left(\frac{1}{2\pi n_s} \right) \left(\frac{I_r^2 R_2}{s} \right)$$

$$I_r = \frac{s(N_2/N_1) E_1}{\sqrt{R_2^2 + (sX_2)^2}} T = \left(\frac{1}{2\pi n_s} \right) \left[\frac{s^2 (N_2/N_1)^2 E_1^2}{R_2^2 + (sX_2)^2} \right]$$

$$T = \left(\frac{1}{2\pi n_s} \right) \left[\frac{s(N_2/N_1)^2 E_1^2 R_2}{R_2^2 + (sX_2)^2} \right]$$

If there are **m** phases then torque,

$$T = \left(\frac{m}{2\pi n_s} \right) \left[\frac{s(N_2/N_1)^2 E_1^2 R_2}{R_2^2 + (sX_2)^2} \right] = k \left(\frac{sE_1^2 R_2}{R_2^2 + (sX_2)^2} \right)$$

$$T = \left[\frac{m (N_2/N_1)^2}{2\pi n_s} \right] \left[\frac{sE_1^2 R_2}{R_2^2 + (sX_2)^2} \right]$$

Where **k** is a constant for a particular

$$\boxed{\text{torque } T \propto \frac{sE_1^2 R_2}{R_2^2 + (sX_2)^2}}$$

Under normal conditions, the supply voltage is usually constant, hence the above $T \propto \frac{sR_2}{R_2^2 + (sX_2)^2} \propto \frac{R_2}{\frac{R_2^2}{s} + sX_2^2}$

The torque will be a maximum when the denominator is a minimum and this occurs when

$$R_2^2/s = sX_2 \quad \text{i.e., when } s = \frac{R_2}{X_2} \text{ or } R_2 = sX_2 = X_r \text{ from equation}$$

Thus **maximum torque** occurs when rotor resistance and rotor reactance are equal, i.e., **R2 = Xr**

Example: A 415 V, three-phase, 50 Hz, 4 pole, star-connected induction motor runs at 24 rev/s on full load. The rotor resistance and reactance per phase are 0.35Ω and 3.5Ω respectively, and the effective rotor-stator turns ratio is 0.85:1. Calculate **(a)** the synchronous speed, **(b)** the slip, **(c)** the full load torque, **(d)** the power output if mechanical

losses amount to 770 W, (e) the maximum torque, (f) the speed at which maximum torque occurs, and (g) the starting torque. **Solution:**

(a) Synchronous speed, $n_s = \frac{f}{p} = \frac{50}{2} = 25$ rev/s or (25×60) (b) Slip, $s = \left(\frac{n_s - n_r}{n_s} \right) = \frac{25 - 24}{25} = 0.04$ or 4%
 $= 1500$ rev/min

(c) Phase voltage, $E_1 = \frac{415}{\sqrt{3}} = 239.6$ volts Full load torque, $T = \left[\frac{m (N_2/N_1)^2}{2\pi n_s} \right] \left[\frac{s E_1^2 R_2}{R_2^2 + (s X_2)^2} \right]$
 $= \left[\frac{3 (0.85)^2}{2\pi (25)} \right] \left[\frac{0.04 (239.6)^2 0.35}{(0.35)^2 + (0.04 \times 3.5)^2} \right]$
 $= (0.01380) \left(\frac{803.71}{0.1421} \right) = 78.05$ Nm

(d) Output power, including friction losses, $P_m = 2\pi n_r T = 2\pi(24)(78.05)$
 $= 11770$ watts

Hence power output = P_m - mechanical losses $= 11770 - 770 = 11000$ W = 11 kW

(e) Maximum torque occurs when $R_2 = X_r = 0.35$ Ω Slip, $s = \frac{R_2}{X_2} = \frac{0.35}{3.5} = 0.1$

Hence maximum torque, $T_m = (0.01380) \left[\frac{s E_1^2 R_2}{R_2^2 + (s X_2)^2} \right] = (0.01380) \left[\frac{0.1 (239.6)^2 0.35}{0.35^2 + 0.35^2} \right]$

$$= (0.01380) \left[\frac{2009.29}{0.245} \right] = 113.18$$
 Nm

(f) For maximum torque, slip $s = 0.1$

Slip, $s = \left(\frac{n_s - n_r}{n_s} \right)$ i.e., $0.1 = \left(\frac{25 - n_r}{25} \right)$ Hence $(0.1)(25) = 25 - n_r$ and $n_r = 25 - (0.1)(25)$

Thus speed at which maximum torque occurs,

(g) At the start, i.e., at standstill, slip $s = 1$

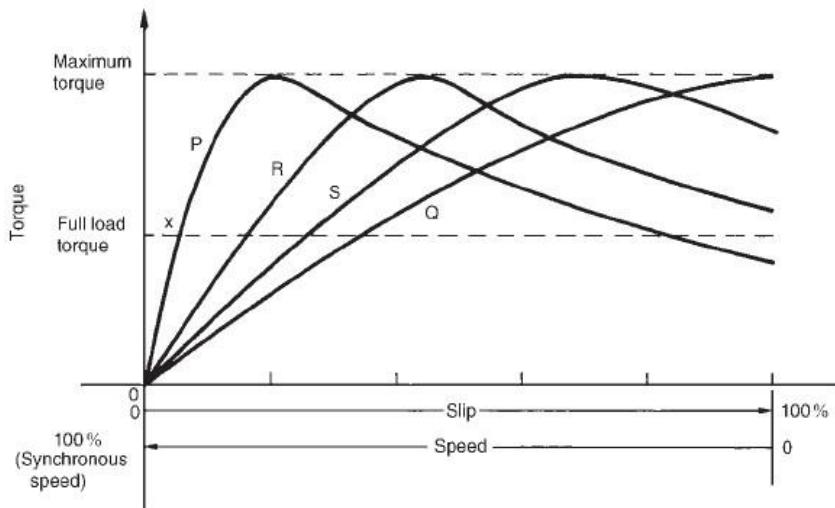
Slip, $s = \left(\frac{n_s - n_r}{n_s} \right)$ i.e., $1 = \left(\frac{25 - n_r}{25} \right)$ Hence $(1)(25) = 25 - n_r$ and $n_r = 25 - (1)(25)$
 $n_r = 25 - 25$
 $n_r = 0$ rev/s or 0 rev/min
Hence starting torque = $\left[\frac{m (N_2/N_1)^2}{2\pi n_s} \right] \left[\frac{E_1^2 R_2}{R_2^2 + X_2^2} \right] = 22.5$ rev/s or 1350 rev/min
 $= (0.01380) \left[\frac{(239.6)^2 0.35}{0.35^2 + 3.5^2} \right] = (0.01380) \left(\frac{20092.86}{12.3725} \right)$ i.e., starting torque = 22.41 N

(Note that the full load torque (from part (c)) is 78.05 Nm but the starting torque is only 22.41 Nm)

Induction motor torque-speed characteristics

From Problem above, parts (c) and (g), it is seen that the normal starting torque may be less than the full load torque. Also, from parts (e) and (f), it is seen that the speed at which maximum torque occurs is determined by the value of the rotor resistance.

At synchronous speed, slip $s=0$ and torque is zero. From these observations, the torque-speed and torque-slip characteristics of an induction motor are as shown in Figure below



The rotor resistance of an induction motor is usually small compared with its reactance (**for example, $R_2 = 0.35\Omega$ and $X_2 = 3.5\Omega$ in the above Problems**), so that maximum torque occurs at a high speed, typically about 80% of synchronous speed.

Curve **P** in Figure above is a typical characteristic for an induction motor. The curve **P** cuts the full-load torque line at point **X**, showing that at full load the slip is about 4–5%. The normal operating conditions are between **0** and **X**, thus it can be seen that for normal operation the speed variation with load is quite small—the induction motor is an almost constant speed machine. Redrawing the speed-torque characteristic between **0** and **X** gives the characteristic shown in Figure below, which is similar to a D.C. shunt motor.

If maximum torque is required at starting then a high resistance rotor is necessary, which gives characteristic **Q**.

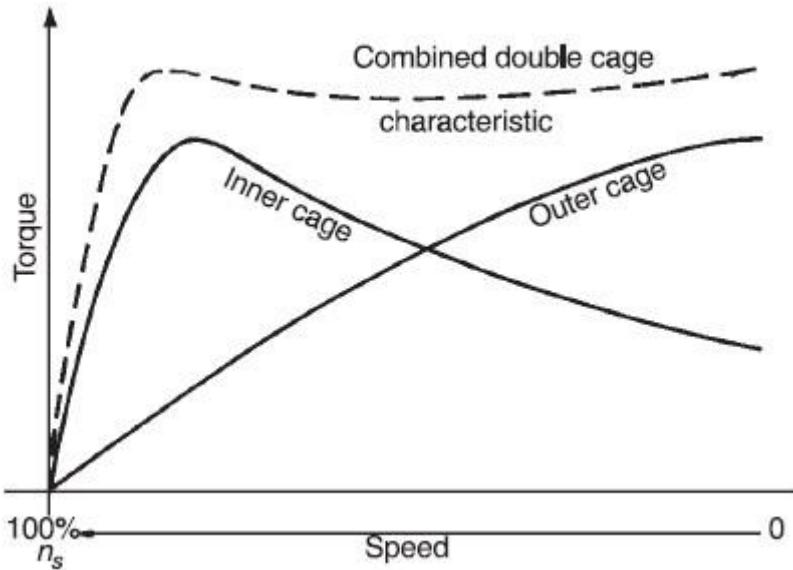
However, as can be seen, the motor has a full load slip of over 30%, which results in a drop in efficiency. Also such a motor has a large speed variation with variations of load. Curves **R** and **S** are characteristics for values of rotor resistances between those of **P** and **Q**. Better starting torque than for curve **P** is obtained, but with lower efficiency and with speed variations under operating conditions.

A squirrel-cage induction motor would normally follow characteristic **P**. This type of machine is highly efficient and about constant-speed under normal running conditions. However, it has a poor starting torque and must be started off-load or very lightly loaded. Also, on starting, the current can be four or five times the normal full load current, due to the motor acting like a transformer with secondary short circuited.

Double cage induction motor

The advantages of squirrel-cage and wound rotor induction motors are combined in the double cage induction motor. This type of induction motor is specially constructed with the rotor having two cages, one inside the other. The outer cage has high resistance conductors so that maximum torque is achieved at or near starting. The inner cage has normal low resistance copper conductors but high reactance since it is embedded deep in the iron core. The torque-speed characteristic of the inner cage is that of a normal induction motor.

At starting, the outer cage produces the torque, but when running the inner cage produces the torque. The combined characteristic of inner and outer cages is shown in Figure below. The double cage induction motor is highly efficient when running.

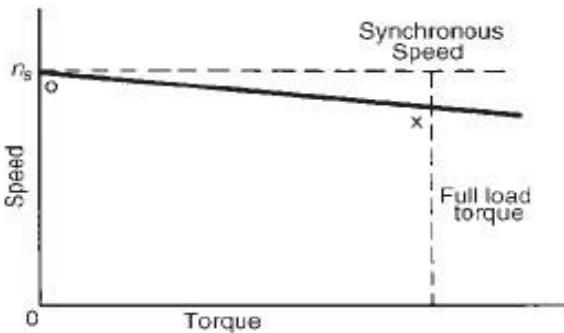


A **wound-rotor induction motor** would follow characteristic P when the slip-rings are short-circuited, which is the normal running condition. However, the slip-rings allow for the addition of resistance to the rotor circuit externally and, as a result, for starting, the motor can have a characteristic similar to curve Q and the high starting current experienced by the cage induction motor can be overcome.

In general, for three-phase induction motors, the power factor is usually between about 0.8 and 0.9 lagging, and the full load efficiency is usually about 80–90%.

From equation $T \propto \frac{sE_1^2R_2}{R_2^2 + (sX_2)^2}$ torque is proportional to the square of the

supply voltage. Any voltage variations therefore would seriously affect the induction motor performance.



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about parameters of electrical rotating machine



Practical learning Activity



Points to Remember (Take home message)

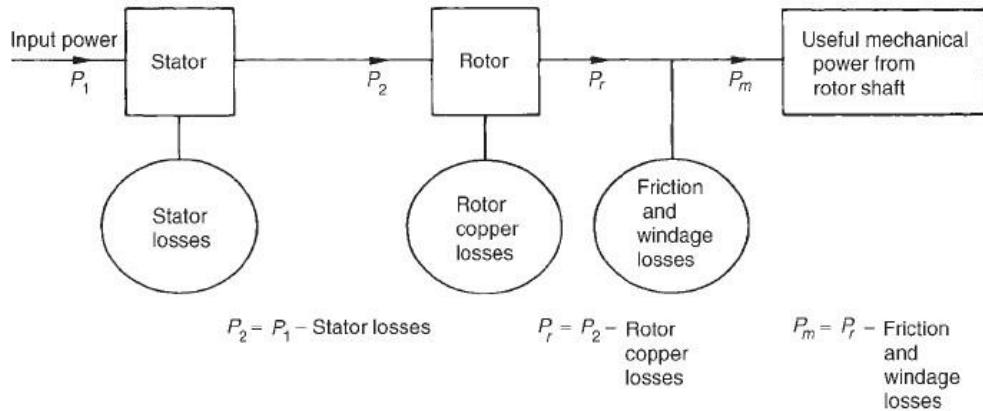
To reduce high starting current, we use electrical starter including stator resistance elimination, auto transformer starting, rotor resistance elimination, star-delta starting,.....

ASSESSMENT

- 1) Draw the power stage of electrical rotating machine (Three phase induction motor)

Answer:

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{P_m}{P_1} \times 100\%$$



(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 1.4. DETERMINE WINDING CONFIGURATIONS



Duration: 2hrs



Learning outcome 4 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Configure three phase motor winding.



Resources

Equipment	Tools	Materials
Three phase motor	Set of Screw drivers	Internet
Coil winding machine	Set of Pliers	manuals

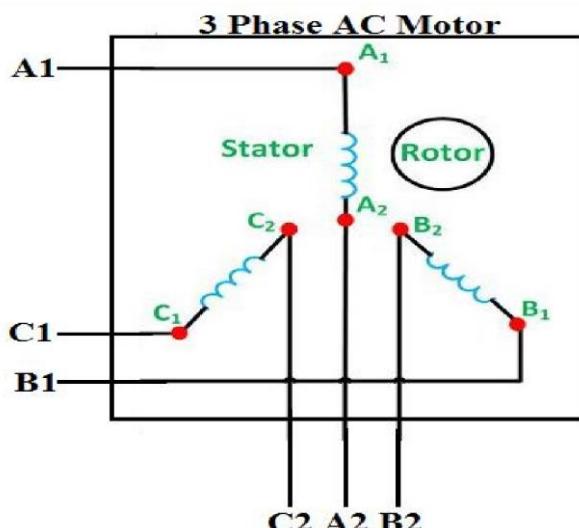


Advance preparation:

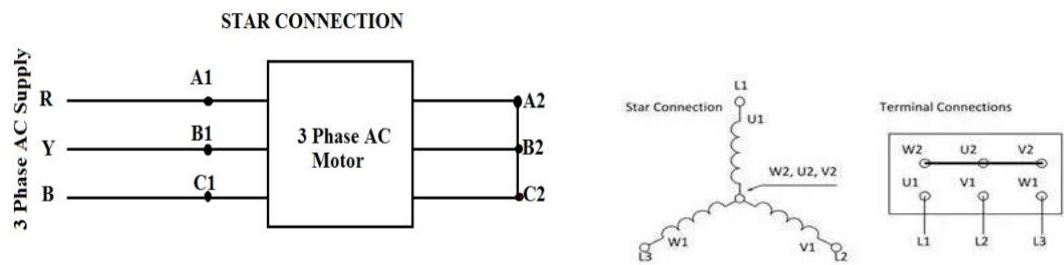


1.4.1. Armature winding for AC machine

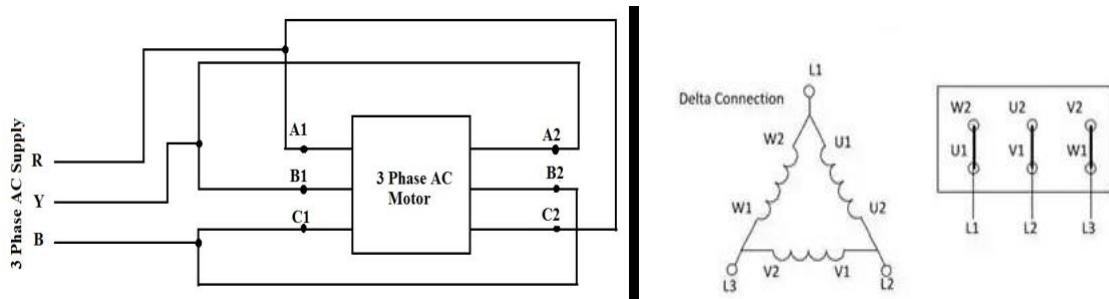
Three phase induction motor have six terminals at the terminal box i.e A1, B1, C1, A2, B2, C2 . i.e,



For star connection:



For delta connection:



Armature winding for AC machines:

❖ AC SINGLE PHASE WINDINGS...

AC Lap Winding : Develop a single phase, single layer AC lap winding for a 4 pole AC machine having 24 slots.

Solution : In single layer winding, the number of coil is equal to half the number of slots on the stator, so that each slot contains only one coil side. Therefore, number of coils, $C = 12$

$$\begin{aligned}\text{the pole pitch} &= \text{Number of slots/Number of Poles} \\ &= 24/6 \\ &= 4\end{aligned}$$

$$\text{slots per pole per phase, } m = 24/4 \times 1 = 6$$

Slots 1 to 6 and 13 to 18 lie under North pole regions N1 and N2 respectively. Similarly slots 7 to 12 and 19 to 24 lie under South pole regions S1 and S2 respectively. In other words, the first pole pair covers slots 1 to 12 and the second pole pair covers slots from 13 to 24.

For full pitch winding, angle between the two sides of the same coil is 180°_{ed} . 180°_{ed} corresponds to 6 slots.

Number of coils(or slots) per pole= 6.

The coil in slot no. 1 is to be connected to coil in slot no. (1 + slots per pole = 1 + 6 =) 7 or back pitch, $Y_b = 7$, ie., if slot no. 1 is at the beginning of the first North Pole, N1, the slot no. 7 will be at the beginning of the first South Pole, S1.

The winding pitch, $Y = +2$ (progressive winding)

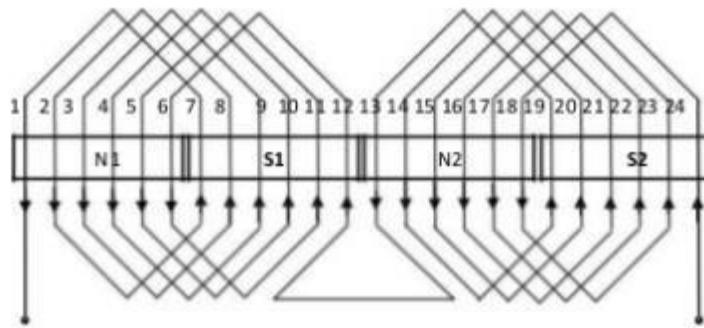
Therefore, the front pitch, $Y_f = Y_b - Y = 5$.

Table 4.1 gives the complete winding table for 4 pole, 24 slot ac machine.

When the winding for one pole pair is completed then last coil side of this pair is connected to the first coil side of the next pole pair, ie., coil in slot no. 12 is connected in series with the coil in slot no. 13. Similarly, the winding for the second pole pair is completed.

To draw the main winding diagram, solid lines of equal length and equal distance equal to number of slots is drawn. Connect the coils as per the Winding Table.

Arbitrarily assume a particular current direction to the coil sides under the pole pairs. For the coil sides under North Pole regions, assume downward current direction and vice versa for the South Pole regions, as shown in Fig..



- ✓ Wave winding
- ✓ Concentric winding
- ✓ Three phase winding
- ✓ Single layer winding

Balanced winding: If the number of coils per pole per phase is same and a whole number then the windings is balanced winding

Unbalanced winding: If the number of coils per pole per phase is not a whole number then the winding is unbalanced winding.

Slot angle: Slot angle = $180^\circ / \text{pole pitch}$ (electrical degrees)

Full pitched winding: The pitch of the coil is equal to full pitch or equal to 180° then the coil is called the full pitched winding.

Short pitched winding or short chorded winding: If the pitch of the coil is less than 180° or less than the full pitch then the coil is called short pitched coil.

Coil span: Coil span is the distance between two coil sides measured in terms of slots. Coil span = winding pitch/slot angle; For full pitched winding $180/\text{slot angle}$

Ex.1: Draw the developed winding diagram of a 3 phase induction motor with 18 slots, 2 poles, singlēlayer, full pitched winding with delta connection.Soln:

No. of slots per pole per phase = $18/(2 \times 3) = 3$
 Pole pitch = no. of conductor / pole = $18/2 = 9$
 Slot angle = $180^\circ / \text{pole pitch} = 180/9 = 20^\circ$

Full pitched winding = coil span = 180°
 Coil span = winding pitch/slot angle = $180/20 = 9$ slots

Winding Table:

Phase 1st pole 2nd pole

$$R 1 + 9 = 10, 11 + 9 = 20 (2) 3 + 9 = 12, 13 + 9 = 22(4)$$

$$B 5 + 9 = 14, 15 + 9 = 24 (6)$$

$$Y 7 + 9 = 16, 17 + 9 = 26 (8), 9 + 9 = 18$$

Connections: $R_s = 1, Y_s = 1$
 $+ 120/\text{slot angle} = 1 + 120/20 = 7; B_s = 1 + 240/\text{slot angle} = 1 + 240/20 = 13$

Winding Diagram

Ex. 4.

Design and draw the developed winding diagram of an alternator with following details: N poles = 4 no. of phases = 3, No. of slots = 24, single layer wave winding, delta connected.

Soln:

No. of poles = 4; No. of conductors = 24; Pole pitch = $24/4 = 6$; no of slots/pole /phase = $24/(4 \times 3) = 2$
 No. of coils = $24/2 = 12$ Slot angle = $180/\text{pole pitch} = 180/6 = 30^\circ$

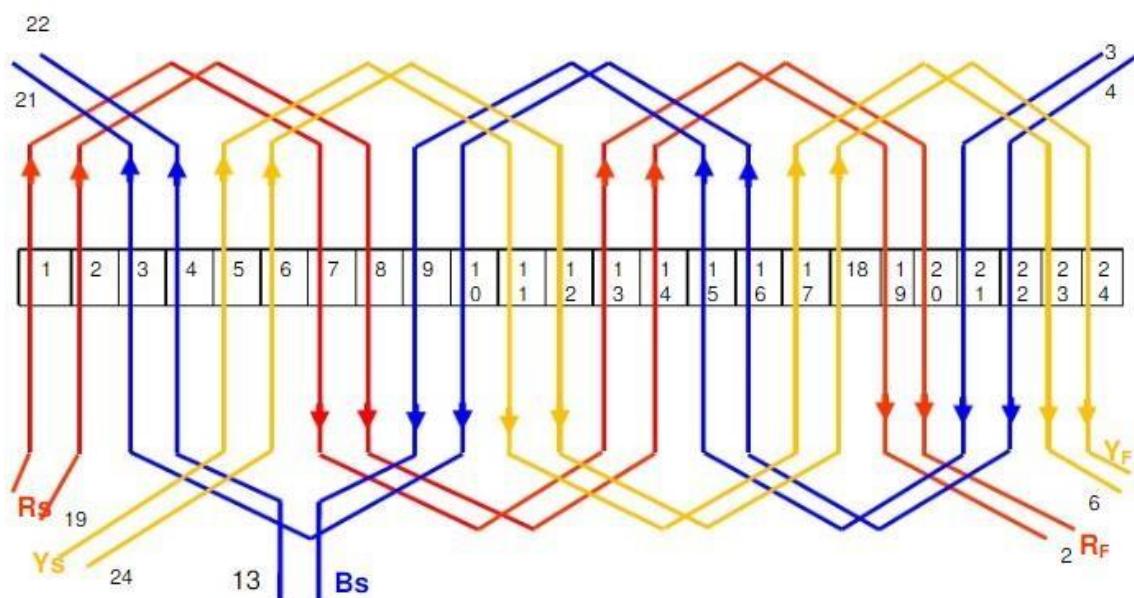
Winding pitch = $180 - (\text{slot angle}) = 180 - 30 = 150$ Hence coil span = 180
 $/ 30 = 6$ slots
 $Y_b = 6$ and $Y_f = 6$
 Connections: $R_s = 1, Y_s = 1 + 120/30 = 5; B_s = 1 + 240/30 = 13$
 Winding

Table: Phase R 1 + 6 = 7 7 + 6 = 13 13 + 6 = 19 19 + 6 = 25 (1)(1 + 1) + 6 = 8 8 + 6 = 14 14

$$20 B 9 + 6 = 15 15 + 6 = 21 21 + 6 = 27 (3) 3 + 6 = 9 10 + 6 = 16 16 + 6 = 22$$

$$22 + 6 = 28$$

$$(4) Y 5 + 6 = 11 11 + 6 = 17 17 + 6 = 23 23 + 6 = 29 (5) 6 + 6 = 12 12 + 6 = 18 18 + 6 = 24$$



✓ Double layer winding

Design and draw the developed winding diagram of an AC motor with following details:
No of poles= 4 no. of phases = 3, No. of slots = 24, double layer wave winding, star connected.

Soln:

No. of poles = 4; No. of conductors = 24; Pole pitch = $24/4 = 6$; no of slots/pole /phase = $2(4 \times 3) = 2$
No. of coils = $24/2 = 12$ Slot angle = $180/\text{pole pitch} = 180/6 = 30^\circ$

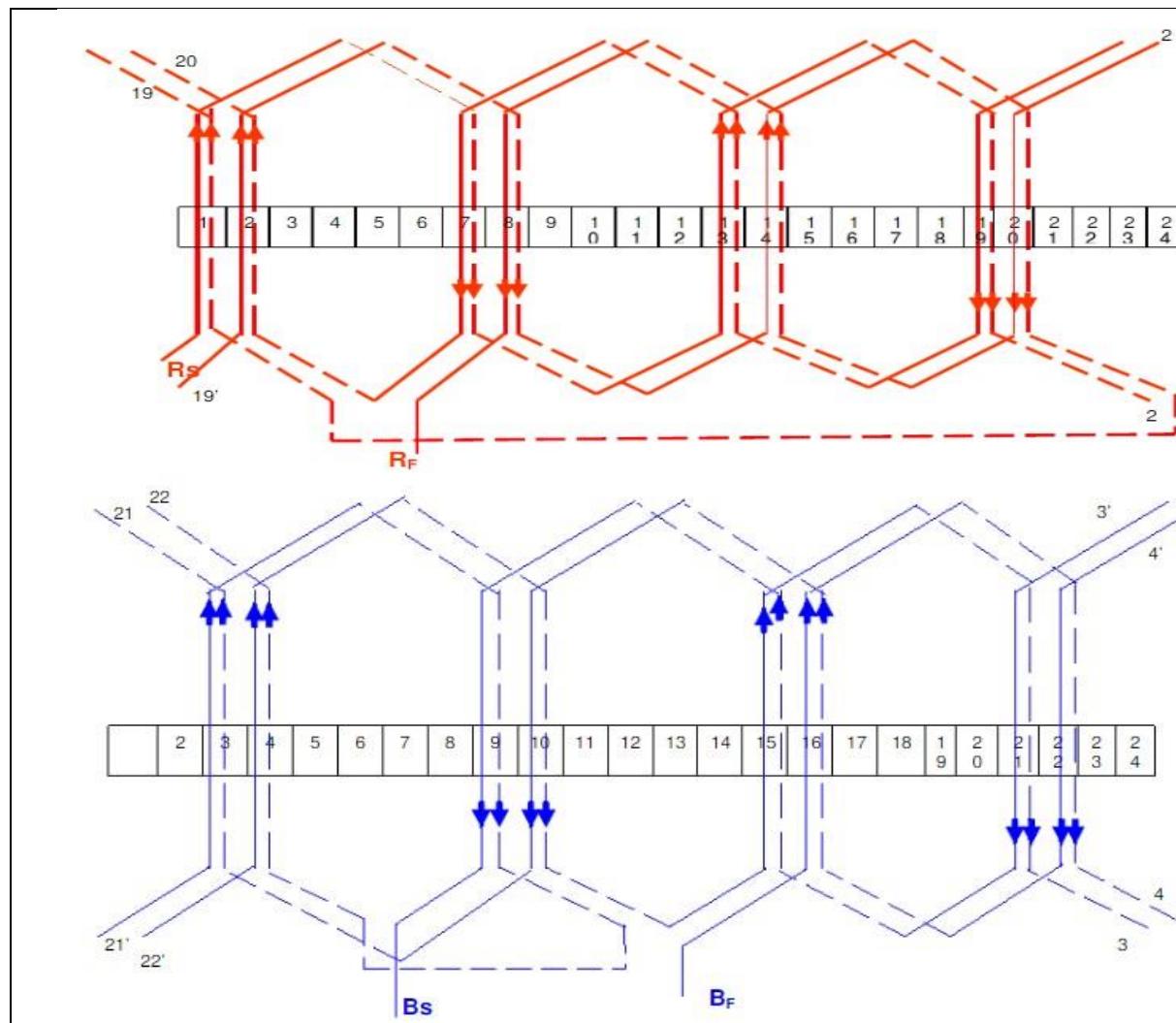
Winding pitch = $180 - (\text{slot angle}) = 180 - 30 = 150$ Hence coil span = 180

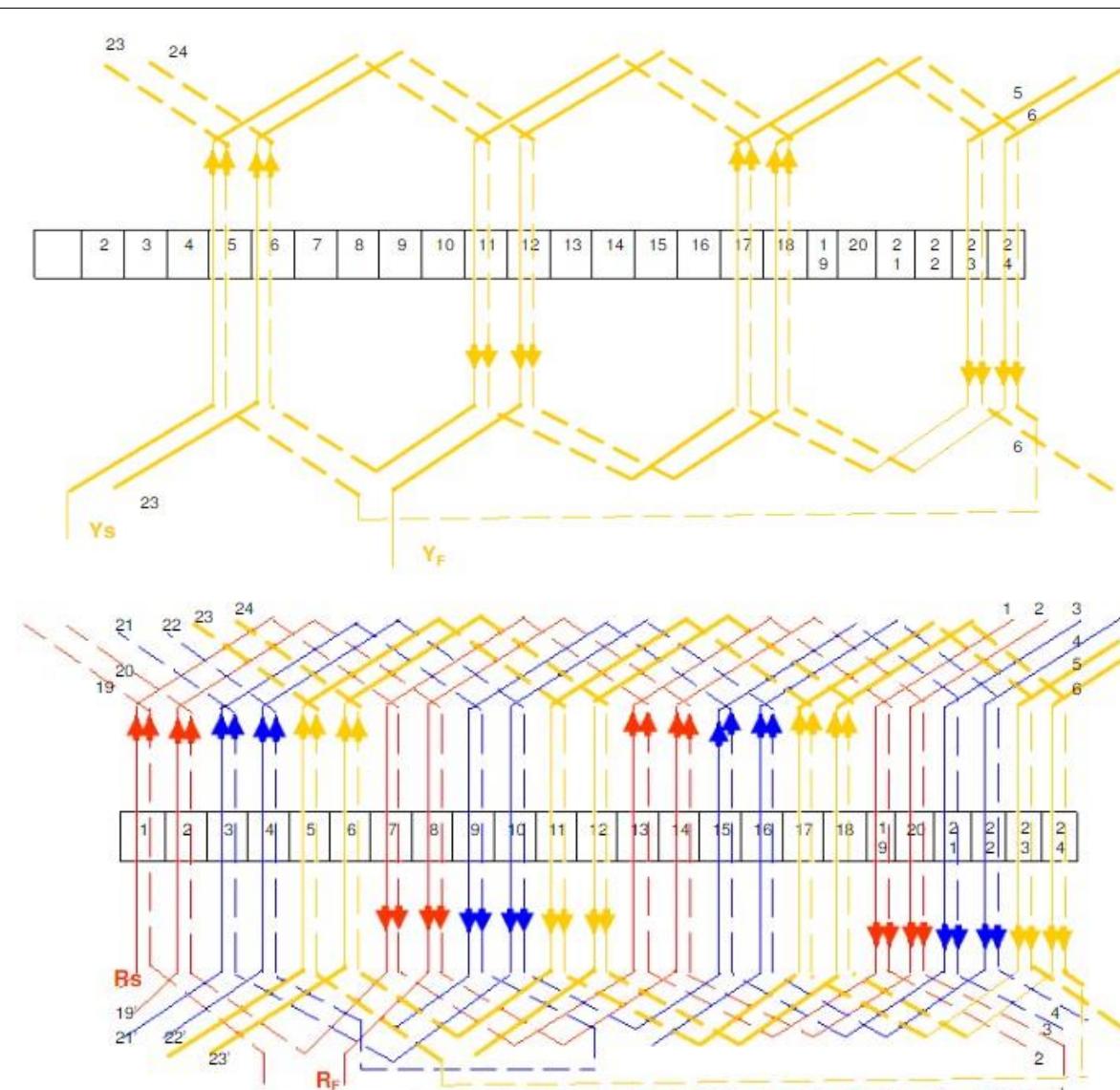
/ 30 = 6 slots
Connections: $R_s = 1, Y_s = 1 + 120/30 = 5; B_s = 1 + 240/30 = 9; Y_b = 13$ and 11
Winding

Table: Phase R $1 + 13 = 14$ $14 + 11 = 25$ $25 + 13 = 38$ $38 + 11 = 49$ (1)
Phase Y $2 + 13 = 15$ $15 + 11 = 26$ $26 + 13 = 39$ (2)
Phase B $3 + 13 = 16$ $16 + 11 = 27$ $27 + 13 = 40$ (3)

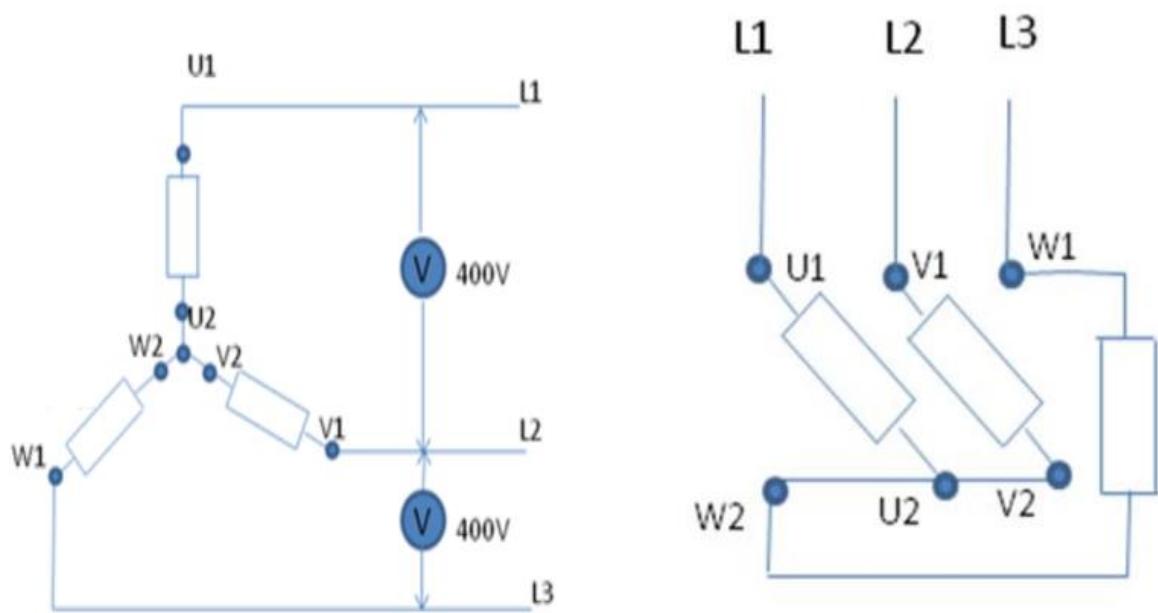
$$17 + 13 = 30 \quad 30 + 11 = 41 \quad 41 + 13 = 54 \quad (6) \quad 8 + 11 = 19 \quad 19 + 13 = 32 \quad 32 + 43$$

$$43 + 13 = 56 \quad (8) \quad 8 + 11 = 19 \quad Y \quad 9 + 13 = 22 \quad 22 + 11 = 33 \quad 33 + 13 = 46 \quad 46 + 57 \quad (9) \quad 11 + 13 = 24 \quad 24 + 11 = 35 \quad 35 + 13 = 48 \quad 48 + 11 = 59 \quad (11)$$

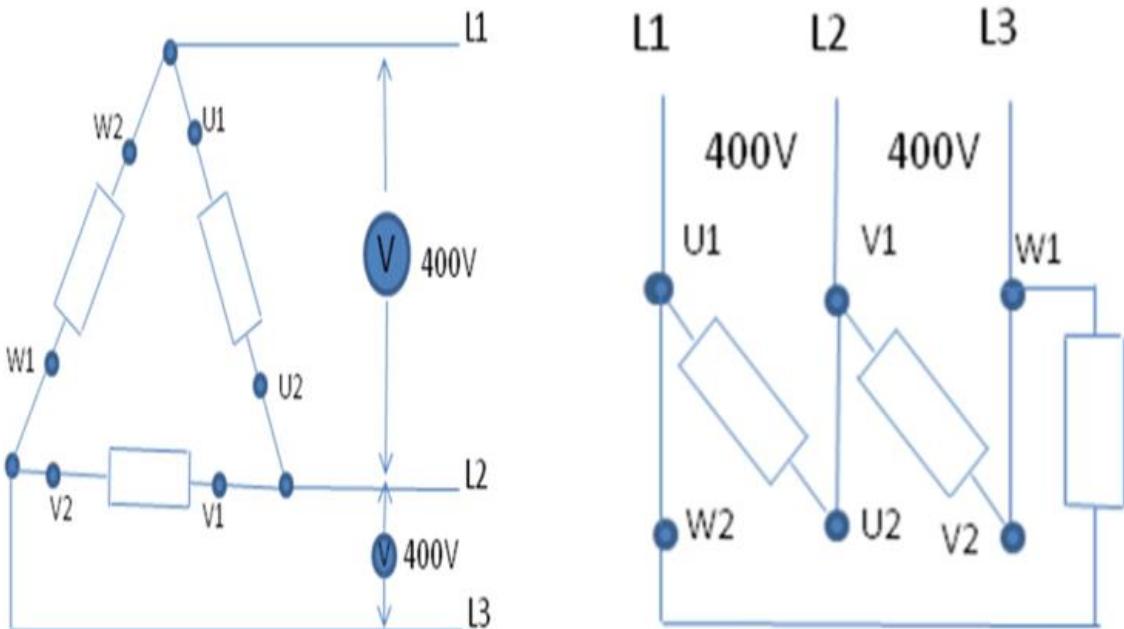




STAR CONNECTION



DELTA CONNECTION

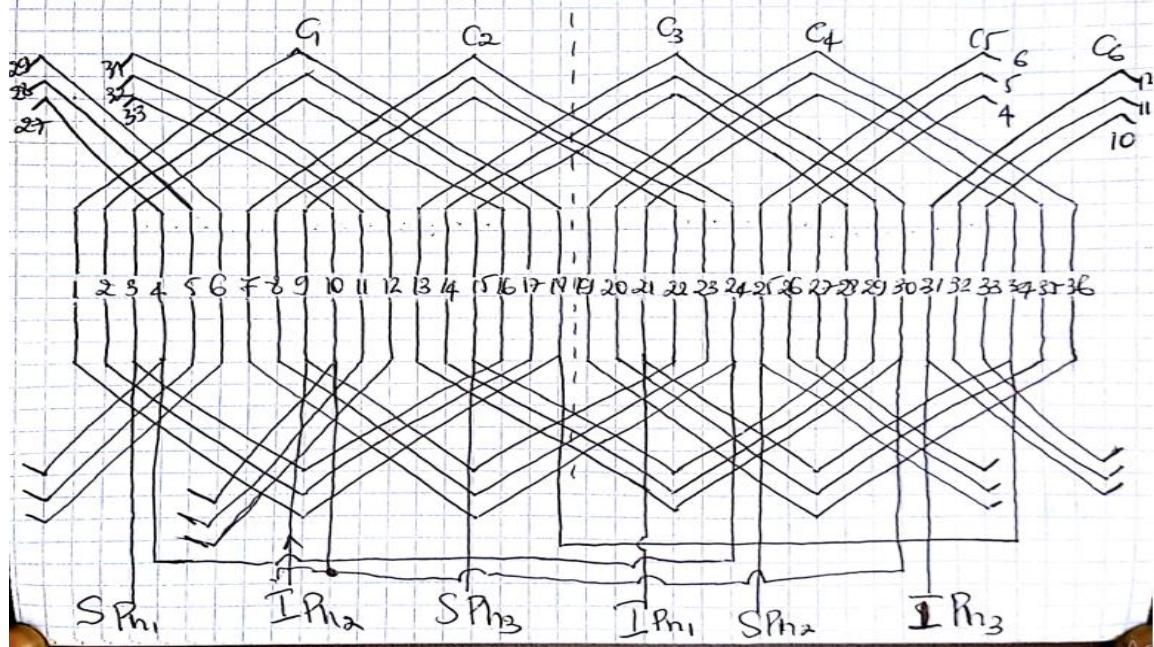


Types of winding

- Single layer winding
- Double layer winding
- Apart of this it can be concentric or lap wings

Single layer winding(concentric)

Example 2800rpm 24slots single layer winding(concentric)



Interpretation

- Number of slots=24
- Number of poles= $120*50/2800= 2$
- This means that the number of slots is divided into two part.
- Number of slots per pole= $24/2=12$ slots

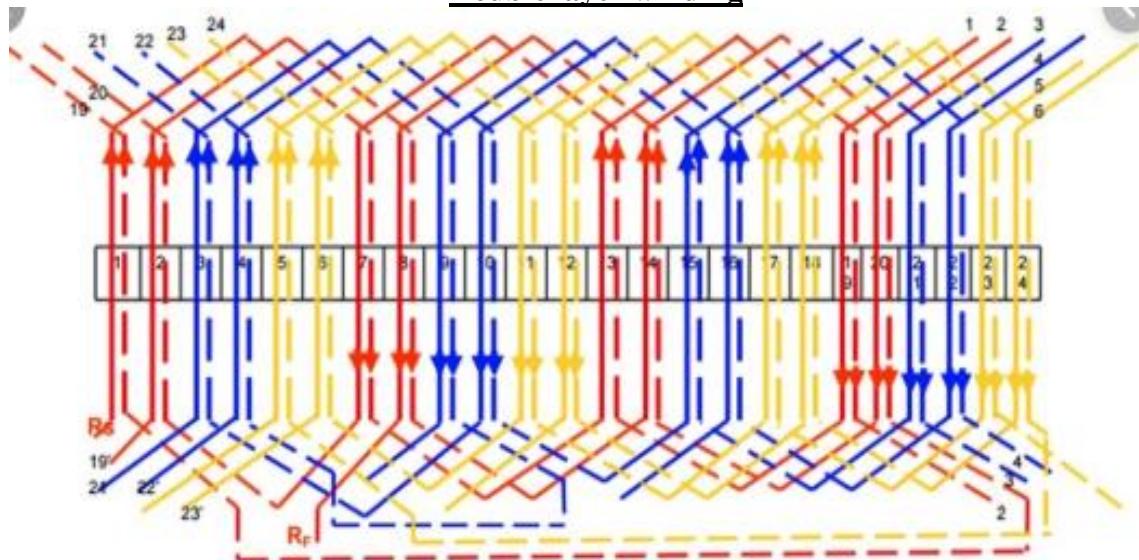
Number of slots per pole per phase= $12/3=4$ slots

In single layer winding the single coil occupies 2 slots which means that each phase will be having two coils per pole i.e a single group will have to coils

Keep in mind that:

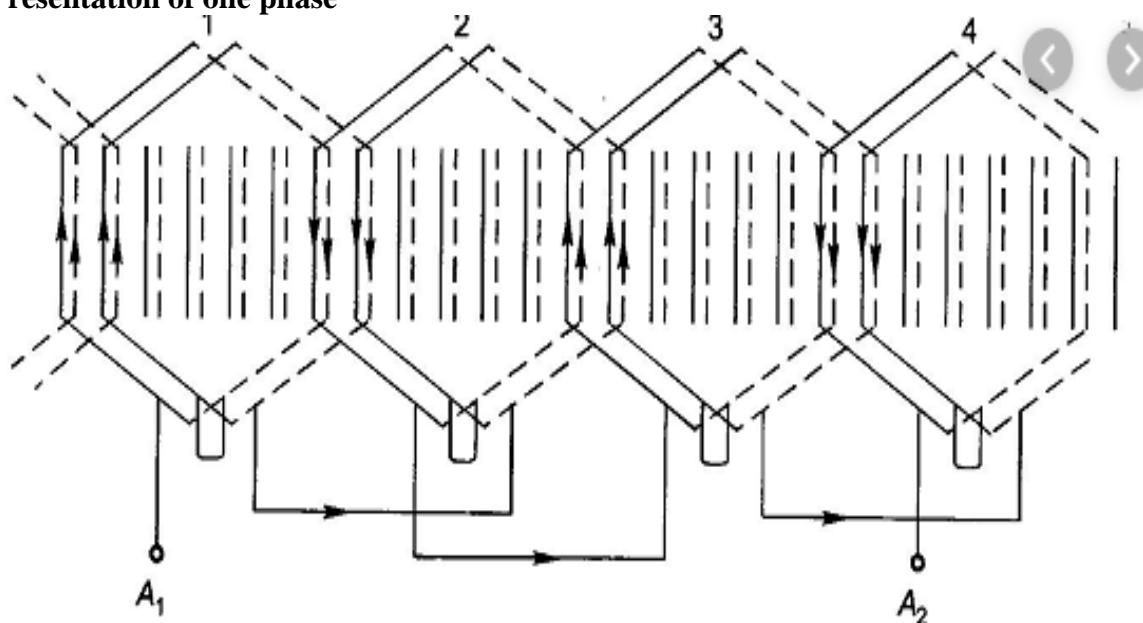
- Always group 1 is connected to group 4
- Group 2 to group 5
- Group 3 to group 6
- The outer part of a winding is connected to the last side of the next winding for avoiding all sides to be in the same poles
- One phase must be reverse while other two phases are forward.

Double layer winding



Drawing the development diagram of A.C 3 – Phase, 4 Pole 24 slots double layer winding

Presentation of one phase



Advantages of double layer winding

- ✓ Significant advantage of the aforementioned winding is a smaller mass of inserted copper because of shortest winding-ends
- ✓ Smaller contents of higher harmonics in the motor's magnetic field.



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about connections of three phase induction motor



Practical learning Activity

- ✓ Trainee in pair draw star and delta connections of three phase induction motor



Points to Remember (Take home message)

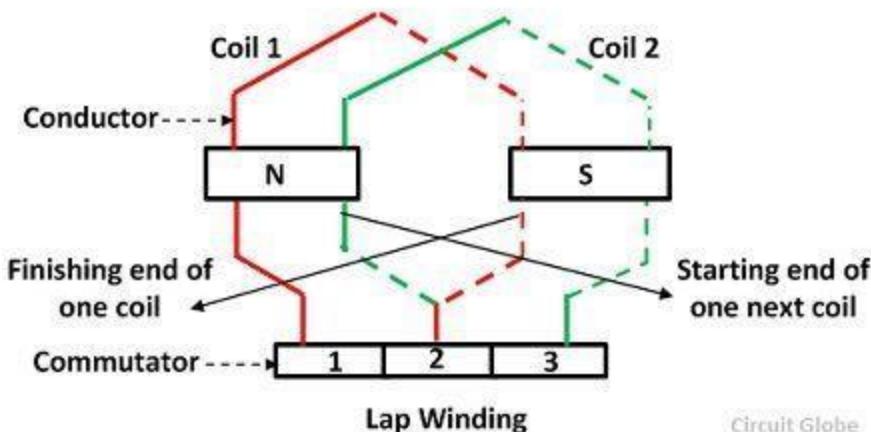
Connect motor in star for low speed and in delta for high speed



1.4.2. Armature winding for DC machine

➤ Lap Winding

In lap winding, the conductors are joined in such a way that their parallel paths and poles are equal in number. The end of each armature coil is connected to the adjacent segment on the commutator. The number of brushes in the lap winding is equal to the number of parallel paths, and these brushes are equally divided into negative and positive polarity.

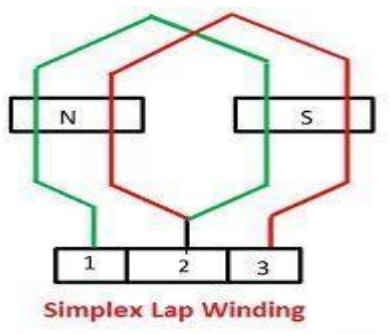


Circuit Globe The lap winding

is mainly used in low voltage, high current machine applications. They are three types

1. Simplex Lap Winding
2. Duplex Lap Winding
3. Triplex Lap Winding

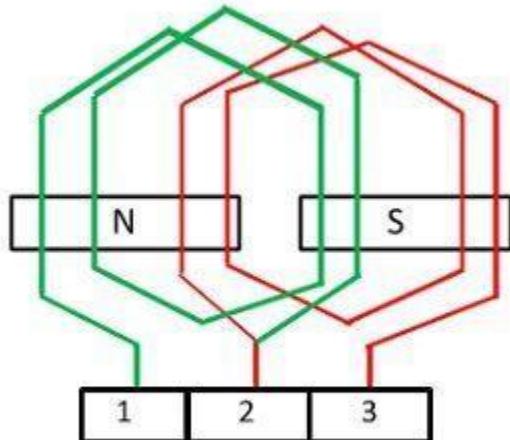
1. Simplex Lap Winding: In simplex lap winding, the terminating end of one coil is joined to the commutator segment and the starting end of the next coil is placed under the same pole. Also, the number of parallel paths is similar to the number of poles of the windings.



Circuit Globe

2. Duplex Winding:

In duplex winding the number of parallel paths between the pole is twice the number of poles. The duplex lap winding is mainly used for heavy current applications. Such type of winding is obtained by placing the two similar winding on the same armature and connecting the even number commutator bars to one winding and the odd number to the second winding.



Duplex Lap Winding

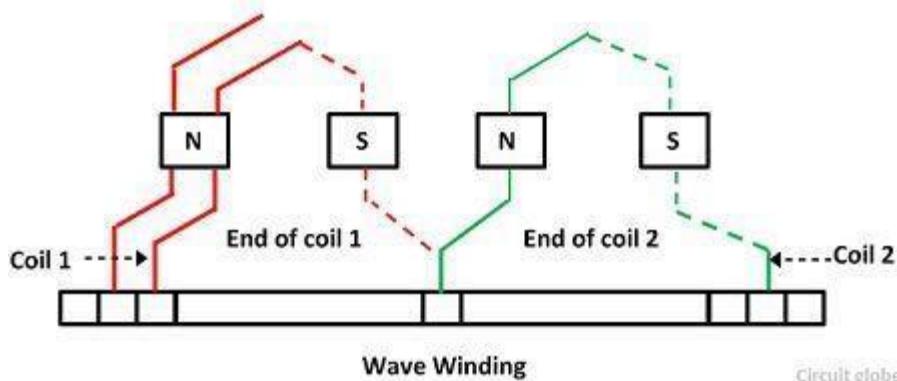
Circuit Globe

3. Triplex Lap Winding: In triplex lap winding the windings are connected to the one-third of the commutator bars.

The lap winding has many paths and hence it is used for the larger current applications. The only disadvantage of the lap winding is that it requires many conductors which increase the cost of the winding.

✓ **Wave Winding**

In wave winding, only two parallel paths are provided between the positive and negative brushes. The finishing end of the one armature coil is connected to the starting end of the other armature coil commutator segment at some distance apart.

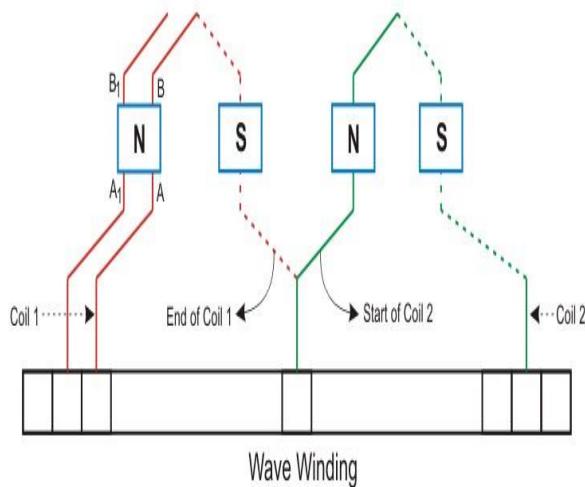


Wave Winding

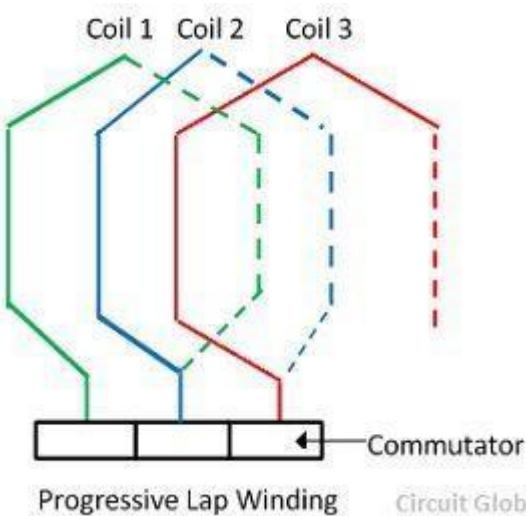
Circuit globe

In this winding, the conductors are connected to two parallel paths irrespective of the number of poles of the machine. The number of brushes is equal to the number of parallel paths. The wave winding is mainly used in high voltage, low current machines.

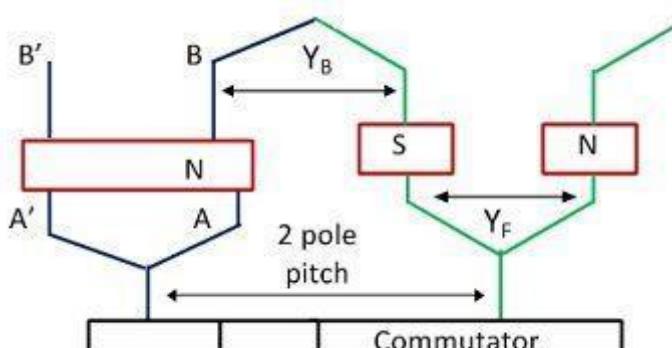
If after passing one round, the armature winding falls into a slot to the left of its initial point, then the winding is said to be retrogressive.



And if the armature windings fall on one slot to the right then it is called progressive winding.



Assume the two layers winding and suppose that the conductor AB must be at the upper layer half of the slot on the left or right. Consider that the Y_B is the back pitch and Y_F is the front pitch. The sum of the back pitch and the front pitch is nearly equal to the pole pitch of the winding.



The equation gives

average pitch of the winding

$$Y_A = \frac{Y_B + Y_F}{2}$$

If Z_A is the total number of conductor or coil side, then the average pitch is expressed by the

$$Y_A = \frac{Z \pm 2}{P}$$

equation, Where, P – number of poles

Since P is always even, then $Z = PY_A \pm 2$, will always be considered as an even integer.

For progressive winding plus sign will use and for retrogressive winding negative winding will be used.



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about connections of three phase induction motor



Practical learning Activity

- ✓ Trainee in pair draw star and delta connections of three phase induction motor



Points to Remember (Take home message)

Connect motor in star for low speed and in delta for high speed

ASSESSMENT

1. Differentiate wave winding from lap winding of armature of DC machine.

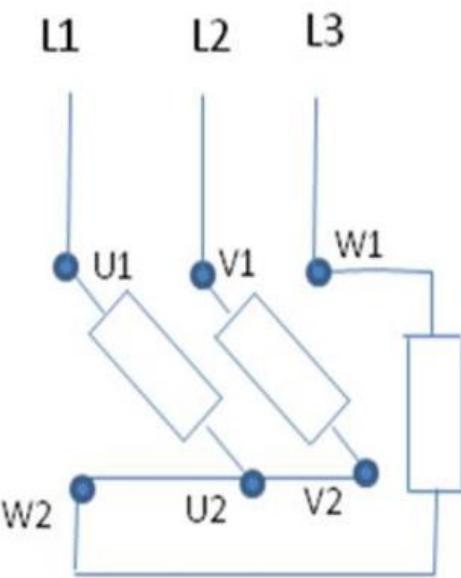
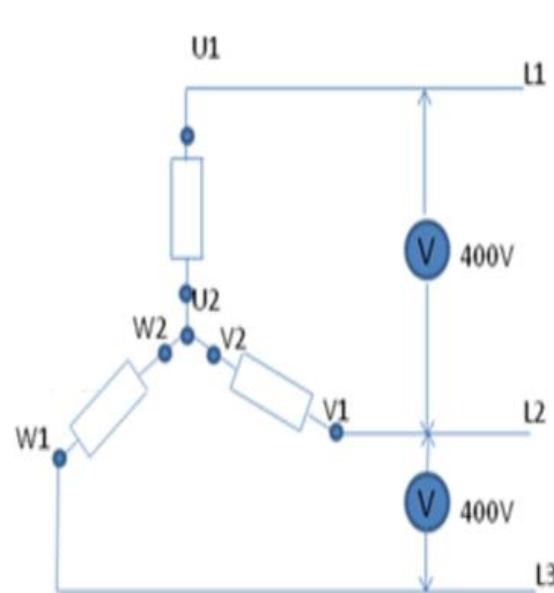
Answer:

- **Lap Winding:** In lap winding, the conductors are joined in such a way that their parallel paths and poles are equal in number. The end of each armature coil is connected to the adjacent segment on the commutator. The number of brushes in the lap winding is equal to the number of parallel paths, and these brushes are equally divided into negative and positive polarity.
- **Wave Winding:** In wave winding, only two parallel paths are provided between the positive and negative brushes. The finishing end of the one armature coil is connected to the starting end of the other armature coil commutator segment at some distance apart.

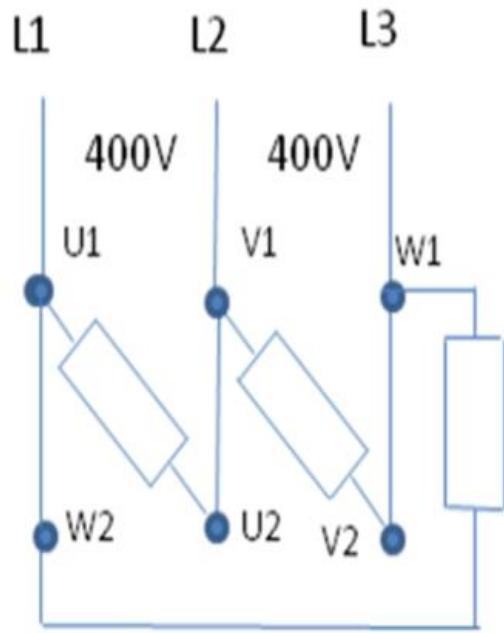
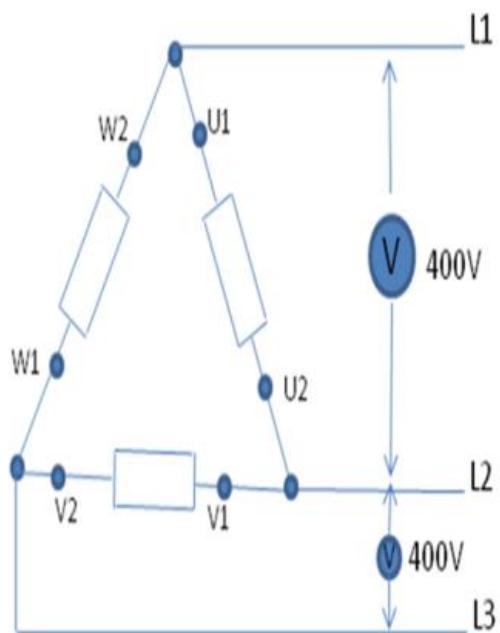
2. Draw the winding diagram of three phase induction motor when connected in star and when connected in delta.

Answer:

For Star Connection



For Delta Connection



(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING UNIT 2: SELECT TOOLS, EQUIPMENT AND MATERIALS.



STRUCTURE OF LEARNING UNIT TWO

Learning outcomes:

- 2.1. Identify tools, equipment and materials
- 2.2. Arrange tools, equipment and materials at working area
- 2.3. Identify Personal Protective Equipment (PPE)

LEARNING OUTCOME 2.1. IDENTIFY TOOLS, EQUIPMENT AND MATERIALS



Duration: 1hr



Learning outcome 2.1 objectives:

By the end of the learning outcome, the trainees will be able to:

- 1. Identify properly tools, equipment and materials of motor winding/rewinding activity

 Resources		
Equipment	Tools	Materials
Three phase motor	Set of Screw drivers	Internet
Coil winding machine	Set of Pliers	manuals
 Advance preparation: Tool box		



2.1.1. Types of tools and equipment

- ✓ **Tools and equipment required during rewinding motor**
- screw drivers (flat and star)
- pliers (combination)
- Side cutter pliers
- Long noise pliers
- Rubber mallet
- Water pipe pliers
- Adjustable spanner
- Ring spanner
- Allen key
- Cold chisel
- Center punch
- Scissors
- Wheel pulley
- Crisp pliers
- Open and spanner
- Ball pain hummer
- Former chisel
- Wire brush

2.1.2. Types of materials

S/N	Description	Quantity
1	Super enamelled copper wire size and quantity	As required
2	Triplex or melinex paper size and quantity	As required
3	Empire sleeve 1mm,3mm and 5mm	2m each
4	20mm cotton tape 15 metre long	1roll
5	Twine thread	As needed
6	Bamboo or fibre wedge	As required
7	Thinner-1 bottle of 300ml	300ml
8	Soldering flux	10grms
9	Brush 25mm	1no.
10	Insulating varnish (air dry)	1litre
11	Resin cored soldering wire 60/40	25 grms
12	PVC insulated cable 650V grade>size and quantity	As required
13	Leatheroid paper size and quantity	As required



Theoretical learning Activity

- ✓ Ask trainees to select tools, equipment and materials used in wind/rewind electrical rotating machine



Practical learning Activity



Points to Remember (Take home message)

Everyone must know the difference between tool, material and equipment

ASSESSMENT

1. Tools required during rewinding motor are the following except:

- a) Adjustable spanner
- b) Ring spanner
- c) Allen key
- d) Digital multi-meter
- e) Cold chisel

ANSWER : d) Digital multi-meter

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 2.2. ARRANGE OF TOOLS, EQUIPMENT AND MATERIALS



Duration: 2hrs



Learning outcome 2.2 objectives:

By the end of the learning outcome, the trainees will be able to:

- 1. arrange properly tools, equipment and materials at working area**



Resources

Equipment	Tools	Materials
Three phase motor	Set of Screw drivers	Internet
Coil winding machine	Set of Pliers	manuals



Advance preparation:

Tool box



2.2.1 Selection of tools, equipment and materials needed for rotating machine winding/rewinding

Disposition of tools, equipment and materials according to their nature with flow of different steps.

In order to keep tools in good working condition during storage, there are some basics preparatory steps that should be taken. It is important to follow the cleaning and storage instruction

- ✓ Clean tools after each use
- ✓ Dispose of Any Broken or defective tools
- ✓ Use metal protectant spray on all metal parts
- ✓ Never store tools near the ground
- ✓ Get creative with storage options
- ✓ Make a list of all items that are stored



Theoretical learning Activity

- ✓ Ask trainees to state the method used to arrange tools, equipment and materials into working area



Practical learning Activity

- ✓ Trainees in pair perform arrangement of tools, equipment and materials.



Points to Remember (Take home message)

Tools, equipment and materials are kept in different places

ASSESSMENT

1. Complete the following sentence:

“Tools, equipment and materials are disposed according to their..... with flow of different steps”

- a) Type
- b) Nature
- c) Application

Answer: b) Nature

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)



LEARNING OUTCOMES 2.3. IDENTIFY PERSONAL PROTECTIVE EQUIPMENT

2.3.1. Safety equipment used for rotating machines winding/rewinding

Safety equipment used for rotating machines winding/rewinding

- ✓ Overcoat and overall
- ✓ Gloves
- ✓ Safety shoes
- ✓ Helmet
- ✓ Goggles
- ✓ Nose protection mask



Theoretical learning Activity

- ✓ Ask trainees to brainstorm about personal protective equipment



Practical learning Activity

- ✓ The trainees must wear PPE



Points to Remember (Take home message)

The trainees must wear PPE

ASSESSMENT

1. Match the following PPE with their functions

MATCH	TYPE OF PPE	FUNCTION
.....	1. Overcoat and overall	A. For protecting head
.....	2. Gloves	B. For feet protection
.....	3. Safety shoes	C. For body protection
.....	4. Helmet	D. For hand protection

Answer:

MATCH	TYPE OF PPE	FUNCTION
C	1. Overcoat and overall	A. For protecting head
D	2. Gloves	B. For feet protection
B	3. Safety shoes	C. For body protection
A	4. Helmet	D. For hand protection

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING UNIT 3: WIND / REWIND ELECTRICAL ROTATING MACHINES



STRUCTURE OF LEARNING UNIT

Learning outcomes:

- 3.1. Dismantle the machine**
- 3.2. Prepare winding/rewinding diagram**
- 3.3. Wind/Rewind the rotating machine**

LEARNING OUTCOME 3.1 DISMANTLE THE MACHINE



Duration: 10hours



Learning outcome 3.1. objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify clearly the tools used during dismantling
2. Identify clearly the burnt winding
3. Identify clearly the windings connection



Resources

Equipment	Tools	Materials
<ul style="list-style-type: none">- Motors- Generators- Multi-meter	N/A	<ol style="list-style-type: none">1. Handouts2. User`s manual3. Electrical drawings4. Voltage tester5. Screw driver6. Combination plier



Advance preparation:

- Workplace preparation



3.1.1: Major machine's parts

- ✓ Electrical part
- ✓ Mechanical part

- **Motor parts and their functions**

- Stator: for supporting the windings
- Rotor: for driving a machine
- Shaft: hold the rotor
- Bearings: for easy rotor rotation
- End cover: for supporting the rotor
- Fan: for cooling the windings
- End shield: to isolate the fan /
- Terminal box: where the wire for the supply and windings are connected

AC MOTOR REWINDING

- Bolt and nuts or screws: for holding the end cover to the stator
- Name plate: colure cell the motor (information is available)
- Pulley: for driving a machine - Base for fixing the motor
- Hook: for lifting the motor (to move up)



Theoretical learning Activity

- ✓ Discuss about the motor parts and their functions



Practical learning Activity

- ✓ By your own skills inspect these given damaged motors to present the findings, by either testing or assuming



Points to Remember (Take home message)

1. Motor's electrical and mechanical faults identification requires more skills about the normal working principle of the motor
2. Motor's faults identification requires more skills about control and power circuit operation of the motor installation



3.1.2. Assembling and disassembling of the machine

✓ **Tools required during rewinding motor**

- Screw drivers (flat and star)
- Pliers (combination)
- Side cutter pliers
- Long noise pliers
- Lubber mallet
- Water pipe pliers
- Adjustable spanner
- Ring spanner
- Allen key
- Cold chisel
- Center punch
- Scissors
- Wheel pulley
- Crisp pliers
- Open and spanner
- Ball pain hummer
- Former chisel
- Wire brush

✓ **Motor rewinding procedures**

1. To check all mechanical and electrical faults

2. Note down all information on name plate
3. Dismantle the motor
4. Record all information on the stator
5. Cut one side of winding foreign matters from slots
6. Pull out the windings
7. Check and record Weight of the coil
8. Remove the remaining foreigner matters from slots
9. Check the slot dimension
10. Cut the insulation paper (inners)
11. Insert the inner insulations in all slots
12. Select the suitable size of former
13. Wind the designed number of turns
14. Tie the coil width wire on other side of coil
15. Remove from former and check its correctness be inserting in the slots
16. Make the required number of coils
17. Insert the coils in the slots
18. Insert wedges in the slots
19. Insert half-moon chapped phase insulation paper between each group
20. Strip and connect the group
21. Tie the coils width binding rope AC MOTOR REWINDING
22. Test the windings
23. Varnish the windings
24. Assebly the motor and test run the motor with load



Theoretical learning Activity

- ✓ Discuss about motor winding procedures



Practical learning Activity

- ✓ By your own skills inspect these slots insulation to present the findings, by Check the slot dimension.



Points to Remember (Take home message)

Discuss about the motor winding connection either star or delta

ASSESSMENT

1. Answer True or False

‘Electrical part and mechanical part are the major parts of electrical rotating machine ?’

Answer: True

2. Identify at least three tools used while winding/rewinding electrical rotating machine.

Answer: Screw drivers (flat and star), Pliers (combination), Side cutter pliers, Long noise pliers, Rubber mallet, Water pipe pliers, Adjustable spanner, Ring spanner, Allen key, etc.

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 3.2: PREPARE WINDING/REWINDING DIAGRAM



Duration: 15hours



Learning outcome 3.2. objectives:

By the end of the learning outcome, the trainees will be able to:

1. Insert the coils in the slots in proper sequence
2. Attach the former securely to the winding stand.
3. Confirm and select the size of winding wire



Resources

Equipment	Tools	Materials
-Electrical motors		- small wires
- Multi-meter		- insulation paper



Advance preparation:

- . Workshop preparation.



3.2.1. Procedure for development of winding diagram of rotating machines

MOTOR REWINDING WINDING DIAGRAMS

Synchronous speed versus number of poles

Poles	RPM for 50 Hz	RPM for 60 Hz	RPM for 400 Hz
2	3,000	3,600	24,000
4	1,500	1,800	12,000
6	1,000	1,200	8,000
8	750	900	6,000
10	600	720	4,800
12	500	600	4,000
14	428.6	514.3	3,429
16	375	450	3,000
18	333.3	400	2,667
20	300	360	2,400

40	150	180	1,200
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BASIC CALCULATIONS BEFORE MAKING WINDING DIAGRAM

Consider a three phase induction motor with 4-pole and 24-slots

$$\text{Number of slots per phase} = \frac{\text{Number of slots}}{\text{Number of phase}}$$

$$\text{Number of slots per phase per pole} = \frac{\text{Number of slots}}{(\text{Number of poles} \times \text{Number of Phase})}$$

$$\text{Coil span or pole pitch} = \frac{\text{Number of slots}}{\text{Number of poles}}$$

$$\text{Number of coils for single layer winding} = \frac{\text{Number of slots}}{2}$$

$$\text{Number of coils for double layer winding} = \text{Number of slots}$$

$$\text{Angular displacement between the slot} = \frac{180^\circ}{\text{Number of slots per pole}}$$

$$\text{Number of coils group} = \frac{\text{Number of poles}}{2}$$

WINDING SEQUENCE

U_1 enters by 1st

V_1 enters by 1+ Coil span

W_1 enters by 1+ Coil span + Coil span

Examples

Design of a 3 phase motor having 12 slots, 2pole, "group type

Calculations: 3phase/2pole: \longrightarrow 12 slots

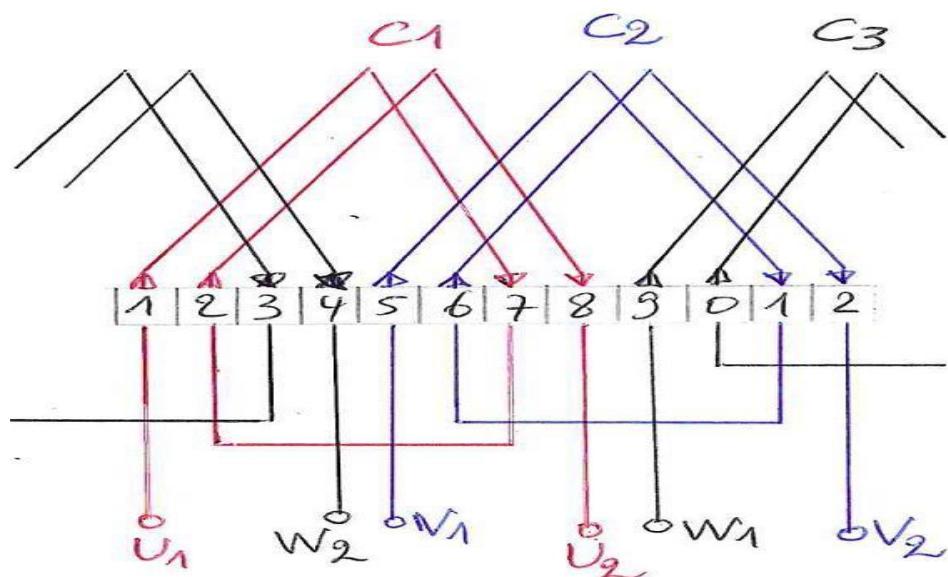
1phase/2pole \longrightarrow 4 slots

1phase/1pole \longrightarrow 2 slots

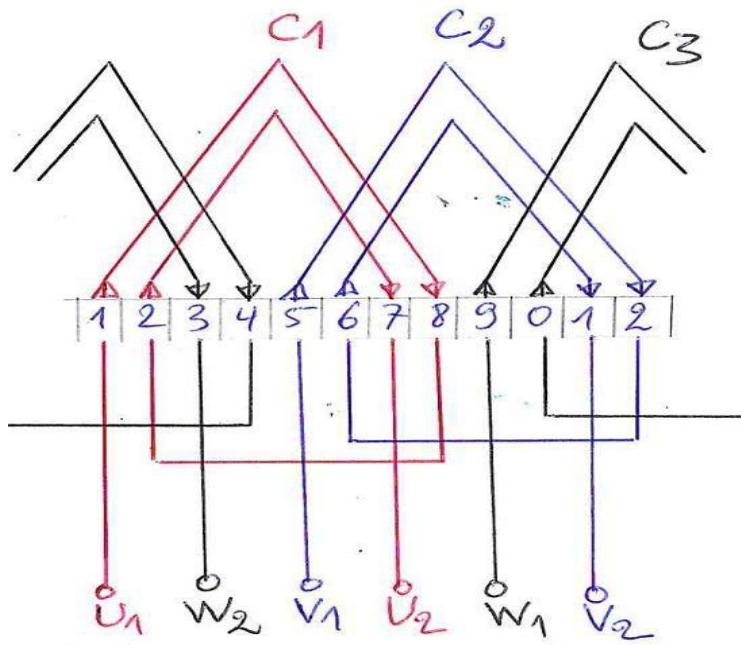
1group \longrightarrow 2 coils

1coil \longrightarrow 2 slots

$$\text{Sequence} = \frac{120 \times 12}{360 \times 1} = 4 \text{ slots}$$



Design of three phase induction motor having 12-slots 2-poles WAVE winding



Design of a 3 phase motor having 18 slots, 2pole, “Group type”

Calculations: 3phase/2pole: \rightarrow 18 slots

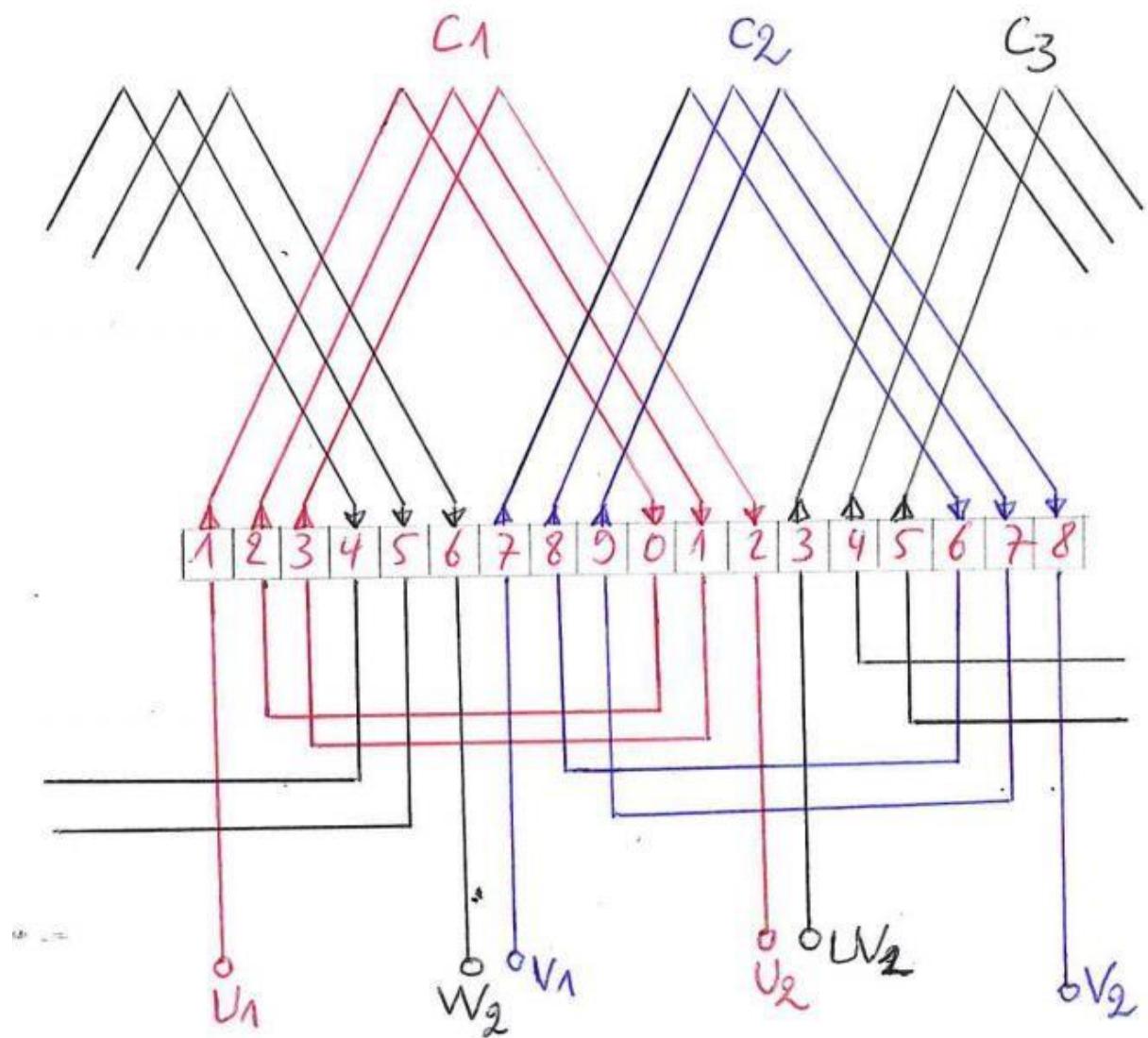
1phase/2pole \rightarrow 6 slots

1phase/1pole \rightarrow 3 slot

1group \rightarrow 3 coils

1coil \rightarrow 2 slots

$$\text{Phase Sequence} = \frac{120 \times 18}{360 \times 1} = 6 \text{ slots}$$



Design of a 3 phase motor having 18 slots, 2pole, "Spread type"

Calculations: 3phase/2pole: \longrightarrow 18 slots

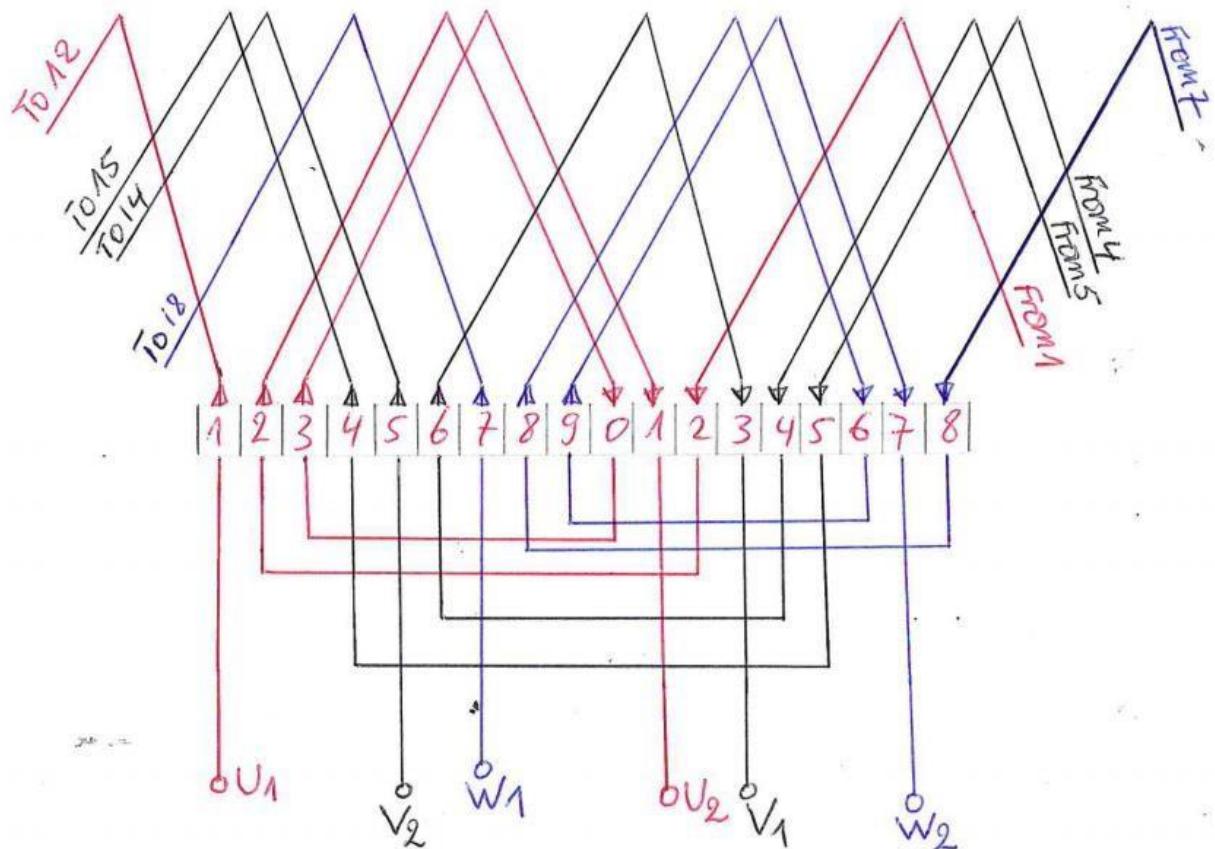
1phase/2pole \longrightarrow 6 slots

1phase/1pole \longrightarrow 3 slots

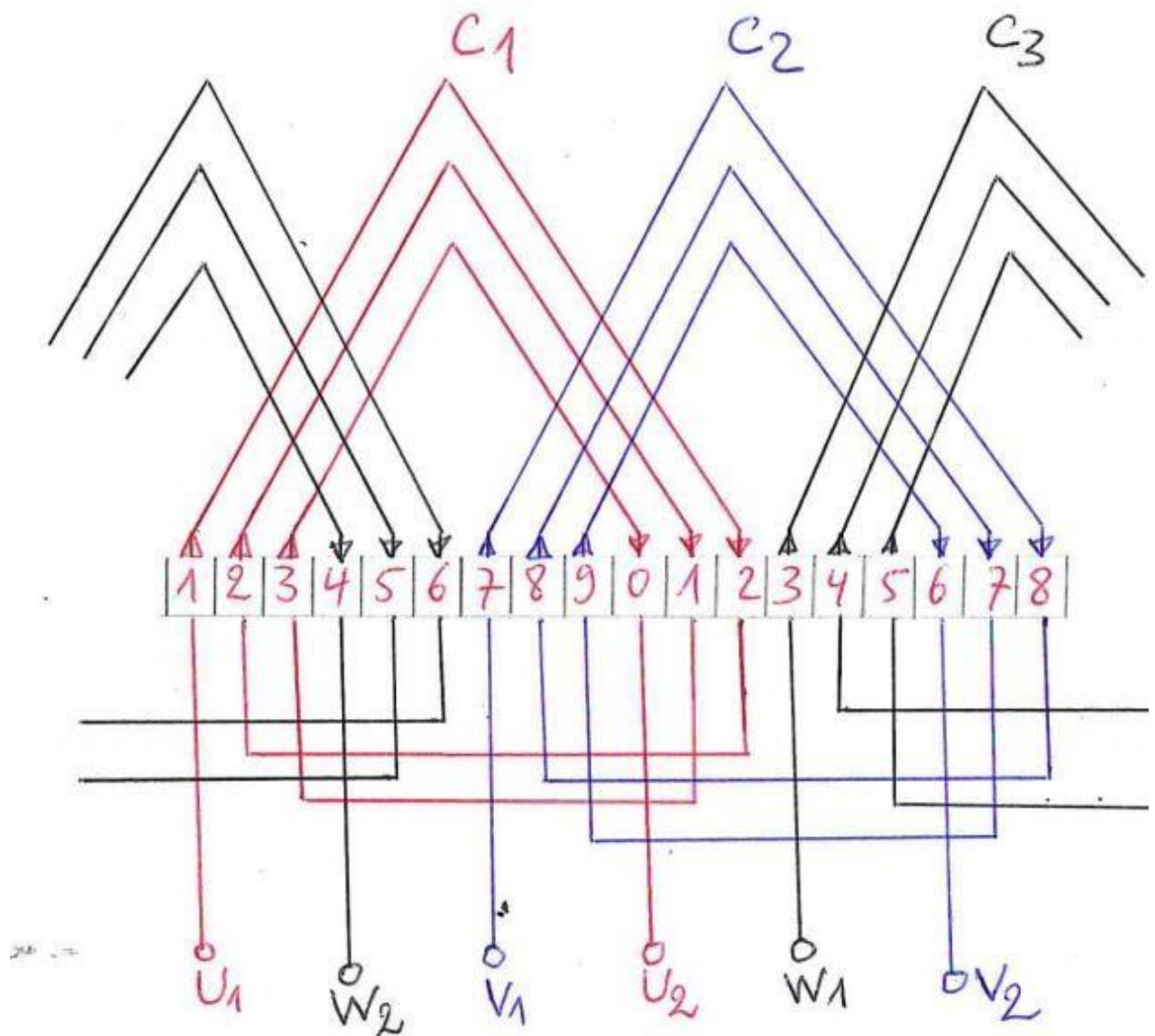
1group \longrightarrow 3 coils

1coil \longrightarrow 2 slots

$$\text{Phase Sequence} = \frac{120 \times 18}{360 \times 1} = 6 \text{ slots}$$



Design of three phase induction motor having 18 slots 2 poles wave winding



Design of a 3 phase motor having 24 slots, 2pole, “group type”

Calculations: 3phase/2pole: \longrightarrow 24 slots

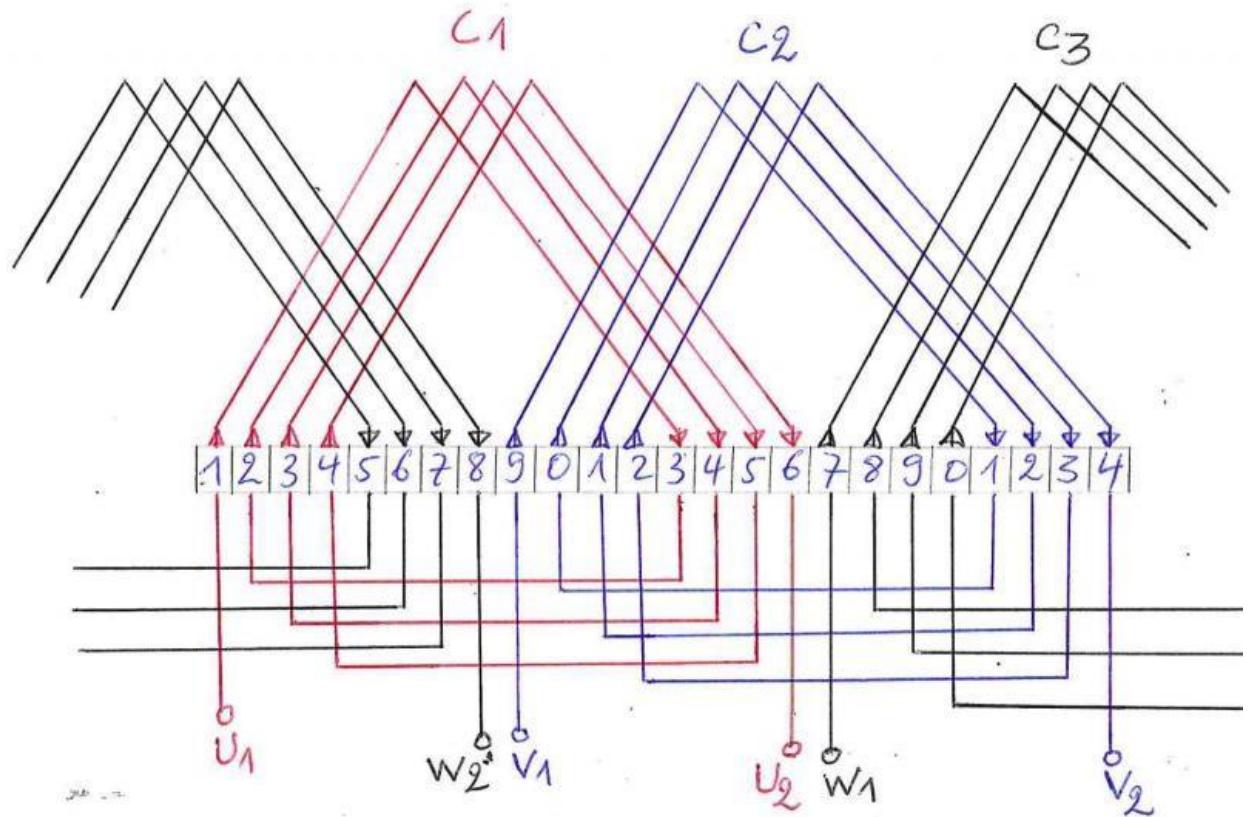
1phase/2pole \longrightarrow 8 slots

1phase/1pole \longrightarrow 4 slots

1group \longrightarrow 4 coils

1coil \longrightarrow 2 slots

$$\text{Phase Sequence} = \frac{120 \times 24}{360 \times 1} = 8 \text{ slots}$$



Theoretical learning Activity

Question: Discuss the procedure to be followed during development of winding diagram of rotating machine



Practical learning Activity

Question: How to rewind the three phase induction motor of different number of slots and poles



Points to Remember (Take home message)

Discuss about how to develop the winding diagram of motor having different number of slots and poles and also how to calculate the phase sequences

FORMATIVE ASSESSMENT

1. Draw the winding diagram of three phase induction motor with 2800rpm, 24slots single layer winding (concentric), 50Hz.

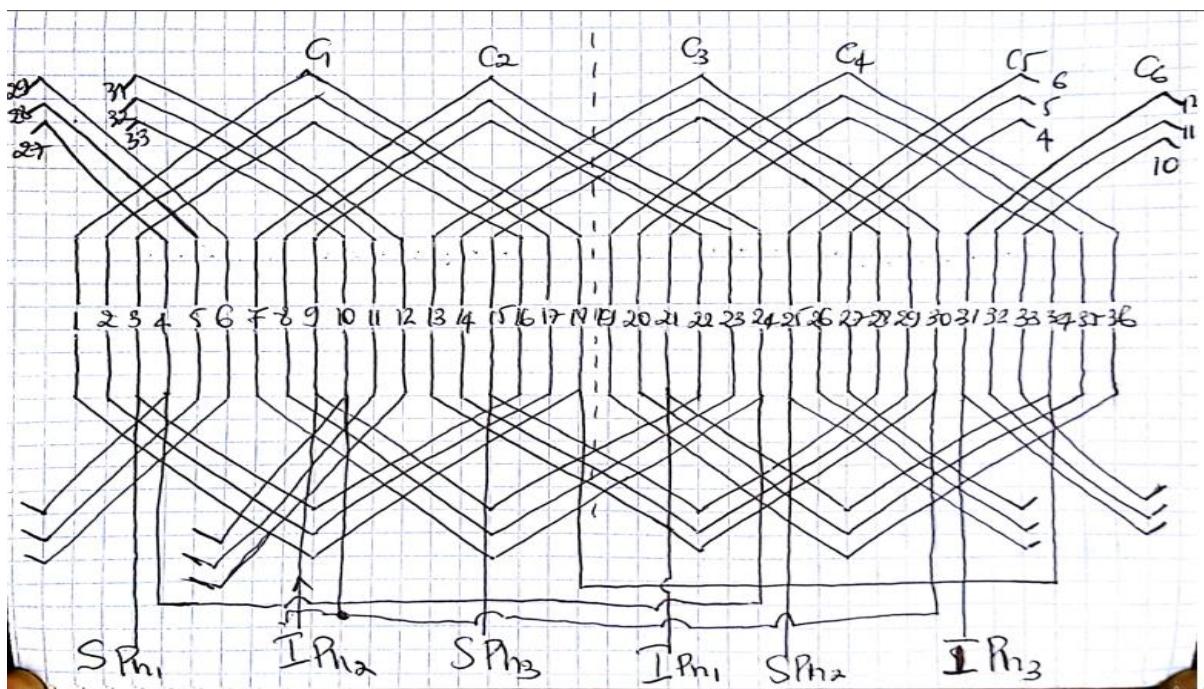
Answer:

- Number of slots=24
- Number of poles= $120*50/2800= 2$
- This means that the number of slots is divided into two part.
- Number of slots per pole= $24/2=12$ slots

Number of slots per pole per phase= $12/3=4$ slots

In single layer winding the single coil occupies 2 slots which means that each phase will be having two coils per pole i.e a single group will have to coils

- Always group 1 is connected to group 4
- Group2 to group 5
- Group 3 to group 6
- The outer part of a winding is connected to the last side of the next winding for avoiding all sides to be in the same poles
- One phase must be reverse while other two phases are forward.



(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 3.3.: WIND/REWIND THE ROTATING MACHINE



Duration: 5hours



Learning outcome 3.3. objectives:

By the end of the learning outcome, the trainees will be able to:

1. Differentiate correctly the winding methods according to the application.
2. Differentiate clearly the steps for winding/rewinding of rotating machine.



Resources

Equipment	Tools	Materials
N/A	N/A	<ul style="list-style-type: none"> - Books - Internet - Service manuals - Repair report templates - Handout notes



Advance preparation:

- . Hand out notes



3.3. 1: Winding methods

✓ Hand coil winding

The most common method of coil winding is manual winding for many types of smaller to mid-size coils. In this process, the wire is wrapped around and formed by hand. However, there are also automated methods for coil winding that can be used for larger coils that use larger materials such as tube or rods.

✓ Formed coil winding

Another most common type of coil winding is called helical or spiral winding. In this technique, the wire is wound in a spiral like form. The wire may be wrapped tightly together, or it may be spaced apart slightly. This type of winding creates a coil with good electromagnetic properties

✓ **Flat coil winding**

This type of coil winding is also called parallel winding. In this technique, the wire is laid flat on the form and wound in parallel layers. This type of winding creates a coil with good mechanical properties

✓ **Orthocyclic winding**

Orthocyclic winding is a type of coil winding where the wire path starts and ends at the same point. This type of winding is often used in application for inductors. Orthocyclic winding results in lower losses and higher efficiencies than other types of coil winding, making it a popular choice for this type of applications

The characteristics of a coil are largely determined by the raw materials used, the size of the wire/tube/rod, spacing between turns and shape of the form. In general, thinner wires produce coils with less resistance, while thicker wires produce coils with more resistance. Coils with more layers typically have a higher inductance than those with fewer layers.

Engineers often select the winding method based on these factors:

- The amount of space available for winding coils
- The exact position of this available space on the device
- The location where the final part of the coil is expected to end up



3.3.2. Steps for winding/rewinding of rotating machines

- ✓ Line the slots with the required type of insulating material
- ✓ Winding the coil according to the winding diagram
- ✓ Insert the coils to the slots
- ✓ Insulate the winding
- ✓ Reassemble the machine

ASSESSMENT

1. The following are the methods of coil winding except

- i. Hand coil winding
- ii. Formed coil winding
- iii. Flat coil winding
- iv. Lap winding

v. Orthocyclic winding

Answer: iv) Lap winding

2. Identify the steps followed while winding/rewinding of rotating machines.

Answer:

- **Line the slots with the required type of insulating material**
- **Winding the coil according to the winding diagram**
- **Insert the coils to the slots**
- **Insulate the winding**
- **Reassemble the machine**

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING UNIT 4: TEST THE WOUND / REWOUND MACHINE



STRUCTURE OF LEARNING UNIT FOUR

Learning outcomes:

- 4.1. Test the machine**
- 4.2. Report the work done**

LEARNING OUTCOME 4.1. TEST THE MACHINE



Duration: 3hours



Learning Outcome 4.1. Objectives:

By the end of the learning outcome, the trainees will be able to:

1. Interpret correctly the purposes of testing motor after being rewound
2. Apply correctly testing methods as applied in motor rewinding



Resources

Equipment	Tools	Materials
<ul style="list-style-type: none"> - motor - Multimeter 		<ul style="list-style-type: none"> - Books - Hand notes - Internet



Advance preparation:

- . Damaged motor
- . Multi-meter
- . Operating motor



4.1.1: General faults in rotating machine

✓ Electrical Faults

- No power
- Open circuit
- Short circuit
- SC between phase-phase
- Earth leakage
- Single phasing
- Loose connection

✓ Mechanical faults

- Overload unusual sound
- Bent rotor shaft
- Jam
- Wrong alignment
- Loose rotor bar
- Brocken fan



4.1.2: Testing the machine's electrical parts

- ✓ Winding states (short-circuit, open-circuit)

No-load test

This test gives the no-load power loss of the motor and R_0 , X_0 parameters of the equivalent circuit. In this test the motor is run without load its shaft at rated voltage and frequency. The applied voltage, stator current and power consumed by the motor are measured by meters

The motor at no-load condition rotates at a speed very close to the synchronous speed. Therefore, the value of slip 's' is very small at no-load. Hence, the emf induced in the rotor circuit ($s.E_2$) is very small and very small amount of current will flow through the rotor circuit as well as the stator circuit. Therefore, the copper loss at no-load condition is negligible. Hence, the power consumed by the motor at no-load is approximately equal to the sum of iron loss and friction loss.

Power consumed by the motor at no-load = $W_0 = W_1 + W_2$

= No-load loss = Iron loss + friction loss

Here, it shall be noted that one of the wattmeter may give negative reading due to low power factor at no-load. In such a case, the power consumed by the motor will be algebraic sum of W_1 and W_2 .

Blocked rotor test

This test gives the copper loss at full load and R_{01} , X_{01} parameters of the equivalent circuit. The circuit diagram for block rotor test is same as that in case of no-load test. But, the test procedure is different. The circuit diagram for block rotor test of a three phase induction motor

In this test, the rotor is kept locked mechanically and very low voltage is applied to the stator winding and the applied voltage is gradually increased until the ammeter indicates the full load current. It shall be noted here that normal rated voltage shall not be applied to the stator in this test, otherwise the stator will draw very high current like a short circuit and stator winding will get burnt out.

Let $W_{sc} = W_1 + W_2$ (Sum of the readings of two watt-meters)

I_{sc} = Ammeter reading

$$V_{sc} = \text{Voltmeter reading}$$

Since the rotor is blocked, the speed is zero and slip is one. Therefore, the voltage V_{sc} required to circulate the full load current will be very small. Hence, the magnetic flux in the machine will be very small with compare to that in case of normal operation with full rated voltage supply. Therefore, the iron loss during the block rotor test is negligible accordingly the shunt branch currents I_w and I_μ will be very small. Hence, the sum of the wattmeter readings will be equal to the copper loss at full and the shunt branch of the equivalent circuit can be neglected

✓ **Brush wearing, springs tension, excitation)**

It is the purpose of this standard to provide a procedure for determining certain operating characteristics of carbon, carbon-graphite, electrographite, graphite, and metal-graphite brushes under prescribed test conditions for all types of rotating AC and DC motors and similar apparatus. The operating characteristics covered in this standard are: voltage drop, coefficient of friction, wear ratio as affected by low humidity, and commutating ability



4.1.3: Testing the machine's mechanical parts

- ✓ Bearings wear
- ✓ Load coupling on Shaft
- ✓ Belt and conveyors alignment



Theoretical learning Activity

- ✓ Discuss about the purpose of testing the machine



Practical learning Activity

- ✓ By applying skills acquired from this above topic of testing the motor after being rewound



Points to Remember (Take home message)

- Use different measuring instruments
- testing of windings continuity



4.1.4. Test machine characteristics on load and no load

No-loads and Loads Test Function characteristics:

- 1 Measure no load loss, load loss, average value of voltage effective value, current effective value, impedance voltage, zero sequence impedance, power factor, harmonic and frequency etc parameters.
- 2 With three voltage testing channels and three independent current testing channels, which are in accordance with three phase power testing.
- 3 Meet with power measurement of the non-metallic alloy and large power transformer etc testing product with low power factor.
- 4 Automatically trap and accurately lock testing data.
- 5 Compare to similar foreign instrument, measurement scope can be switched automatically within whole current testing scope; it is not necessary to replace the current measurement module.
- 6 Input transformer parameter, synchronously display conversion data.
- 7 Suitable to power measurement of the motor and air fan etc at same time.
- 8 Meet with voltage and current measurement of 150Hz and 200Hz induction voltage withstand test.
- 9 Harmonic analysis function.

ASSESSMENT

1. Test of electrical rotating machine must be done through measurement instrument list at least two those instrument.

Answer:

Those instrument are:

- Multi-meter
- Ohmmeter

2. Distinguish mechanical fault to electrical fault of electrical rotating machine.

Answer:

Mechanical fault	Electrical fault
-------------------------	-------------------------

Mechanical fault it is abnormal of electrical rotating machine that occur on mechanical part like bearings ,rotor etc	Electrical fault it is abnormal of electrical rotating machine that occur on Electrical part like winding coils ,connection etc
--	--

3. Identify Two faults for the following categories:

- a) Electrical faults
- b) Mechanical faults

Answer

- a) Electrical faults
 - Short circuit
 - Open circuit
- b) Mechanical faults
 - Jam
 - Rotor bent

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

LEARNING OUTCOME 4.2 REPORT THE WORK DONE



Duration: 2hours



Learning outcome 4.2. objectives:

By the end of the learning outcome, the trainees will be able to:

1. Prepare correctly the repair report as workshop
2. Keep correctly records of repair as done in maintenance activities
3. Analyse correctly the billing report



Resources

Equipment

Tools

Materials

N/A	N/A	<ul style="list-style-type: none"> - Books - Internet - Service manuals - Repair report templates - Handout notes
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Advance preparation:

- . Repair report template
- . Workplace preparation



4.2.1: Elaborate the work report

report format

The element of repair report format includes:

- Company/institution name,
- Technician name,
- Date of repair,
- Equipment specifications,
- Fault description

Billing of repair work

Bills of Quantities comprise a list of items of work which are briefly described. The Bills also provide a measure of the extent of work and this allows the work to be priced.

Describe the content of the work done report



Practical learning Activity

In a group of two trainees, analyse and provide the repair report of the activity according to your own observation



Points to Remember (Take home message)



4.2.2. Keeping records of current machine state

Each time maintenance schedules occur, users should document the tests performed, and the results gathered for the purpose of establishing trends. Record all repairs or replacements made on every motor component.

ASSESSMENT

1. Elaborate The main element of report after rewinding and testing of three phase induction motor.

Answer

The main elements of report are:

- **Company/institution name,**
- **Technician name,**
- **Date of repair,**
- **Equipment specifications,**
- **Fault description**

(Bird, 1997)

(Patrick, 2009)

(THERAJA, 2003)

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