Industrial Electrical Machines and Drives Servicing Level II

LEARNING GUIDE # 31

Unit of competence:-Industrial Electrical Machines and Drives Servicing Level II

Module Title:- Maintaining and repairing industrial electrical machines and drives

LG Code: E EEL EMD2 M08LO2 –LG31

TTLM Code: EEL EMD2 TTLM081019V1

LO2: Maintain electrical system or equipment

Instruction Sheet :1	Learning Guide 31

This learning guide is developed to provide you the necessary information regarding the following learning outcome and content coverage

- Follow safety policies and procedures
- Test/ Clean/Lubricate electrical system or equipment parts
- Identify and replace worn-out/malfunctioning electrical system or equipment parts
- Check and identify readings of electrical measuring instruments
- Check and tight Connectors, bolts, nuts and screws
- Conduct regular routine/visual/sensory inspection

This guide will also assist you to attain the learning outcome and contents stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Follow safety policies and procedures
- Test/ Clean/Lubricate electrical system or equipment parts
- Identify and replace worn-out/malfunctioning electrical system or equipment parts
- Check and identify readings of electrical measuring instruments
- Check and tight Connectors, bolts, nuts and screws
- Conduct regular routine/visual/sensory inspection

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 6.
3. Read the information written in the "Information Sheet 1, Sheet 2, Sheet 3, Sheet 4, Sheet 5 and Sheet 6" in page 3,6,10,43,51 and 56 respectively".
4. Accomplish the "Self-check 1, Self-check 2, Self-check 3, Self-check 4 , Self-check 5 and Self-check 6" in page 5,9,42,50,55 and 57 respectively".
5. If you earned a satisfactory evaluation from the "Self-check" proceed to "Operation Sheet 1 and Operation Sheet 2" in page 58 and 59 respectively.
6. Do the "LAP test" in page 60

Information Sheet :1	Follow safety policies and procedures

1.1. OHS policies and procedures

Your Company Name is committed to the goal of providing and maintaining a healthy and safe working environment, with a view to continuous improvement. This goal is only achievable by adherence to established objectives striving to exceed all obligations under applicable legislation, and by fostering an enthusiastic commitment to health, safety and the environment within Your Company Name personnel, contractors and visitors.

In particular:

- Management, working in cooperation with the Joint Health and Safety Committee, will strive to take all reasonable steps to reduce workplace hazards to as low as reasonably achievable.
- Supervisors and managers are held accountable for the health and safety of all employees under their supervision. This includes responsibility for applicable training and instruction, appropriate follow-up on reported health and safety concerns, and implementation of recommended corrective action. This accountability is integrated into the performance appraisal system.
- Supervisors, workers and visitors are expected to perform their duties and responsibilities in a safe and healthful manner, and are accountable for the Health and Safety of themselves and others.
- Your Company Name is committed to providing all necessary training and instruction to ensure that appropriate work practices are followed on the job, and to promote their use off the job.
- If necessary, Your Company Name will take disciplinary action where individuals fail to work in a healthy and safe manner, or do not comply with applicable legislation or corporate policies and procedures.

1.2. Electrical hazards prevention

Employees can prevent shocks and injuries/electrocution from electrical hazards by:

- Following safe work practices
- Understanding electric shock and electro caution
- Recognizing potential hazards around work involving electricity
- Following OHS requirements

- Maintaining clearances around panels
- Using proper protective devices
- Eliminating access to exposed energized parts Using proper PPE
- Using proper lockout/tag out procedures
- Maintaining proper clearance from overhead lines
- Following proper procedures for confined space/enclosed space/underground electrical work
- Following manufacturer's instructions

When you have to do maintenance work on a machine, take these four steps to protect yourself and your coworkers from injury:

- De-energize the machine. Positively disconnect it from the power source. If there is more than one source of power, disconnect them all.
- Lock out the disconnect switches. You must be given a lock and key for each disconnect before you begin working on the machine
- Tag the disconnect switches. Get tags or accident prevention signs from your supervisor.
- Test the machine to make sure it won't start
- Keep the key with you

Each worker who works on the machine must lock out and tag the power disconnect. Never assume that the machine you are working on has been disconnected and locked out unless you have done it yourself. Also remember that the current ratings off use and circuit breakers are at 15 to 30amperes for most residences. These safeguards cannot protect you against shocks. High voltage transmission and distribution lines carry a lot of electricity and if accidently touched it can be fatal. Since farm and construction workers use equipment that can reach high, these employees must be trained on the hazard supposed by high voltage overhead lines. Each year, workers who accidentally make contact with high voltage power lines are either killed or become permanently disabled. Electrically powered equipment is used daily by most workers. Power tools, metal and woodworking machines, restaurant equipment, computers and many other types of electrical equipment are found in the workplace. Failure to use the equipment correctly can create hazards to employees. Generally, there are instructions from the manufacturers on the use and maintenance of each piece of equipment. Workers need to follow the instructions while using and

- Replace broken 3-prong plugs and make sure the third prong is properly grounded.
- Never use extension cords as permanent wiring.

- Do not plug several power cords into one outlet.
- Do not disconnect power supplies by pulling or jerking the cords from the outlets.
- Always use the correct size fuse or breaker.
- Be aware that unusually warm or hot outlets may be a sign that unsafe wiring conditions exists.
- Use proper PPE for the electrical job.
- Always use ladders made of wood or other non-conductive materials when working with or near electricity or power lines.

Self-Check -1	Written Test

Directions: Choose the best answer

1. Which one of the following safety equipment?
   A. Measuring instrument
   B. Hand tool
   C. Glave
   D. All of the above
2. Which one of the following is not included in preventing shocks and injuries/electrocution from electrical hazards?
   A. Following safe work practices
   B. Understanding electric shock and electro caution
   C. Recognizing potential hazards around work involving electricity
   D. None of the above
3. Which one of the following is not included in PPE?
   A. Goggle
   B. Glave
   C. Safety shoes
   D. None of the above

***Note:* Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Information Sheet – 2	Test/ Clean/Lubricate electrical system or equipment parts

2.1. Introduction

The key to minimizing motor problems is scheduled routine inspection and maintenance. The frequency of routine maintenance varies widely between applications. Including the motors in the maintenance schedule for the driven machine or general plant equipment is usually sufficient. A motor may require additional or more frequent attention if a breakdown would cause health or safety problems, severe loss of production, damage to expensive equipment or other serious losses.

Written records indicating date, items inspected, service performed and motor condition are important to an effective routine maintenance program. From such records, specific problems in each application can be identified and solved routinely to avoid breakdowns and production losses. The routine inspection and servicing can generally be done without disconnecting or disassembling the motor.

All types of rotating machinery require regular inspections so to maintain their integrity and availability. The maintenance becomes simple and effective with the use of minor and major inspections categorized into levels representing the life of the product, be it running hours or years of installation. For each level, a defined number of inspection points are determined which can be undertaken within a specified time. The aim is not to lengthen the outages but to provide an effective solution that can be accommodated within planned maintenance periods and provide expert support when returning the equipment back on line.

2.2. Maintenance of Bearings

Keep the bearings dirt-free, moisture free, and lubricated. Water will rust the bearings and dirt will destroy the smoothness of the super finish on the bearing races, increasing friction. Clean the bearings when they become dirty or noisy with the most environmentally friendly cleaner that is suitable for dissolving oil, grease, and removing dirt from the steel, plastic and rubber surfaces. To obtain a long service life of bearings, they must be relubricated periodically. Used grease together with wear debris and any contamination should be removed from the contact zone and be replaced by fresh grease.

For most types, the sources of bearing failures are:

- Insufficient oil or grease.

- Too much grease causing churning and overheating.
- Worn bearings (i.e., broken balls or rough races, etc.)
- Hot motor or external environment.

Long service lives are possible when the following republication conditions are observed:

- the same grease is used as originally applied;
- the republication should be carried out at the operating temperature;
- the bearing should be re lubricated before a long interruption in operation occurs

Lubrication system	Inspection interval	
	Normal operating conditions	Severe operating conditions
Disk lubrication method	One year	6 months
Oil bath or splash lubrication	6 months	3 months
Circulating lubrication	9 months	1 to 3 months

Fig 2.1. Frequency of Lubricating Oil Analysis

2.3. Brush and Commutator Maintenance

The brushes and commutator are integral to the normal operation of a D.C. motor. The brushes ride or slide on the rotating commutator of the armature; there should be little brush noise, chatter or sparking when the motor is powered up. Excessive brush wear or chipping are signs that the motor is not commutating properly, which can be caused by a variety of factors. While de-energized, rotate the armature by hand to see if the brushes are free to ride on the commutator and there's adequate spring tension to keep them hugging the commutator. A good brush should have a polished surface which indicates that it has been seated properly. Check the brush connections to ensure they are tight and clean. Determine if the brushes are aligned properly. Misalignment from neutral can cause sparking (armature reaction). The brushes should have equidistant spacing around the commutator and parallel to the bars. Clean any debris around the brushes. Compare the brushes to a new set of brushes to gauge the amount of wear. If excessive or, if you don't think they will last until the next maintenance time, replace them.

The commutator should have a smooth, polished, brown appearance. There should be no grooves, scratches or scores. If there is any blackened, rough areas on the commutator, it's probably caused by brush sparking. If a commutator has a brassy appearance, there's excessive wear that could be caused by the wrong type of brush or the wrong spring tension. Check the manufacturer's technical documentation to verify the correct brushes are installed. Carbon dust and debris from the brushes can cause sparking and damage the commutator. If the commutator is rough and the bars are uneven, it will need to be turned on a lathe to restore its roundness. To clean the commutator, use a commutator cleaning brush (fiberglass) and some electric motor cleaner. Never use emery paper because it has metal particles in it that if rubbed off could cause electrical shorts. Remove the brush springs, slide the brush across the commutator hood and spray. When done, blow out the motor so it is dry and clean.

The usual defects in brushes and brush gear areas are as follows:

- ✓ Incorrect grade of brush and improper brush tension
- ✓ Improper bedding of brushes.
- ✓ Carbon brush chattering due to:

(a) Excessive clearance between carbon brush and its holder.

Fit up correct size brush. It should be good slide fit in its holder. Clearance should not be more than 2 mils.

(b) Excessive overhang of brush

Normally, the clearance between the bottom edge of brush holder and the commutator should only be 1.5mm (1/16 In.) or less. The brush holders should be properly reset and secured in position so that the clearance is correct.

- ✓ Carbon brush too tight in holder

This is generally due to accumulation of carbon dust. All carbon brushes should be removed entirely out of the holders once a month at least. Accumulated carbon dust should be blown off by compressed air and both the brush and the holder cleaned thoroughly with dry cloth. Carbon brushes must slide freely inside the holder.

- ✓ Brush tail connections

They should be secured properly. If the tail connection improperly secured strands are damaged, new brushes should be fitted.

- ✓ Excessive wear of brush

Normally, carbon brushes should last for several months. Excessive wear is definite sign of poor commutation, it requires detailed investigation. If the worn-out brush is not replaced quickly, the metallic pig tail connection imbedded inside the carbon brush may damage the commutator badly.

Self-Check -1	Written Test

Directions: Answer all the questions listed below. Say True / False.

1. Insufficient oil or grease is one of the sources of bearing failure.
2. Hot motor or external environment is not the sources of bearing failure.
3. Bearing should be re lubricated before a long interruption in operation occurs

***Note:* Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

3.1. Maintenance of A.C. Motors

A.C. Motors are run for extremely long periods without repairs. If the bearings are properly lubricated and air passages are kept clear, then most of the A.C. Motors do not have failure problems, as the motors have no commutators which cause motor failure. There are few motors which have commutators, such as universal motor, repulsion motors in single phase system.

- **Single Phase Motors:**

Centrifugal (CF) switch is one of the main cause of troubles in single phase motors. If the springs of centrifugal switch become weak, the C.F. switch will operate before reaching the full speed, which will cause motor to run at sub normal speed and stop. If the switch sticks closed, the starting winding will remain in the circuit, overheat and damage the starting winding. Commutator motors need almost same type of care and maintenance as in dc motors.

- **Squirrel Cage Induction Motor :**

Overheating and shock may damage the squirrel cage rotor, which may cause fractures in bars in the slots and end ring connections and joint in the rotor cage. Satisfactory operation of motor is difficult with fractured rotor cage and end rings. In large motors the bars are bolted or wedged in slots and can be tightened readily if these become loose. Loose coils can be detected with the help of growler. If it is not possible to disassemble the motor, connect an ammeter in in series with one phase and apply 25% of full voltage to one of the stator phase winding and turn the rotor slowly by hand. If the ammeter reading varies in excess of 3%, it can be assumed that there is loose bar in rotor.

- **Wound Rotor Motors:**

Working principle is same as 3 phase sq. cage rotor induction motor, having better torque and speed. Wound rotor may have low speed with starter resistance cut off from rotor circuit. If there are no openings in control and starter circuit, the rotor coils should be tested for continuity. Growler test may reveal open are short circuit in the coils. There is also possibility of brushes sticking in the holder or brushes may not have sufficient tension (sparking and overheating at contact area).

Growler is an electromagnet having 110 V /240 V supply voltage and suitably shaped for testing armature/ rotor, by placing the growler core (or rotary growler for testing stator winding)and slowly moving on/in it shorted or broken coils can be detected by noting the change in the humming noise of the growler.

- **General procedure for overhaul of motors:**
  - ✓ Disconnect the supply cables at the terminal box of the motor, uncouple the motor from the driven machine, unfasten the foundation bolts or nuts and remove the motor to the maintenance shop.
  - ✓ Remove the external fan covers, canopies, heat exchanger or other fitments.
  - ✓ Dismantle the motor without using the excessive force, and without the hammer blows. Care should be taken to see that the rotor does not touch the stator winding overhangs. If possible do not open cartridge bearing housings.
  - ✓ Clean dust, dirt, oil and grit from every part of the machine with the help of blower, compressed air hose, bellows or brushes and then wash with petrol to which a few drops of lubricating oil have been added. The windings may be cleaned by means of carbon tetra-chloride. Care being taken to avoid its application to slip rings and brushes.
  - ✓ Carry out visual inspection of all parts for wear or damage, replace worn out or damaged parts.
  - ✓ Measure insulation resistance. If low dry out the windings, until correct values are obtained. If necessary re-enamel or re-varnish all the winding and internal parts except the stator bore and rotor iron. Dry rotor and stator winding thoroughly.
  - ✓ Reassemble motor without using any excessive force. Make sure that machine leads are on the correct terminals and everything is well tightened.
  - ✓ Check the concentricity of the air gap through the air gap holes. Ensure that rotor can rotate freely. Any difficulty in rotating the rotor or unusual noise should be taken as sign of interference between stationary and moving parts. Investigate this and eliminate the cause of the trouble.
  - ✓ Check insulation resistance again.
  - ✓ Recommission the motor.

3.2. Details of AC Winding

The windings used in rotating electrical machines can be classified as

- **Concentrated Windings**

- ✓ All the winding turns are wound together in series to form one multi-turn coil.
- ✓ All the turns have the same magnetic axis

Examples of concentrated winding are

- ✓ field windings for salient-pole synchronous machines
- ✓ D.C. machines
- ✓ Primary and secondary windings of a transformer

- **Distributed Windings**

- ✓ All the winding turns are arranged in several full-pitch or fractional-pitch Coils.
- ✓ These coils are then housed in the slots spread around the air-gap periphery to form phase or commutator winding

Examples of distributed winding are

- ✓ Stator and rotor of induction machines
- ✓ The armatures of both synchronous and D.C. machines

3.3. Some of the terms common to motor windings are described below

1. **Conductor.** A length of wire which takes active part in the energy-conversion process is a called a conductor.
2. **Turn.** One turn consists of two conductors.
3. **Coil.** One coil may consist of any number of turns.
4. **Coil –side.** One coil with any number of turns has two coil-sides.
5. ***Active side of a coil***: It is that part of the coil which lies in the slots of the stator and EMF is induced in this part. It is also known as an **inductor**.

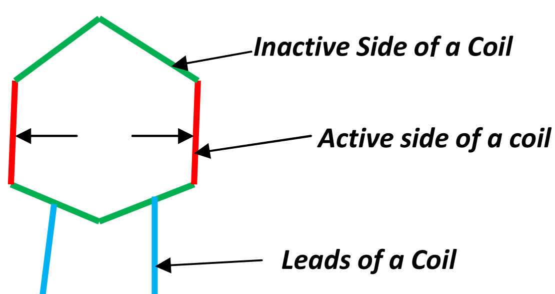
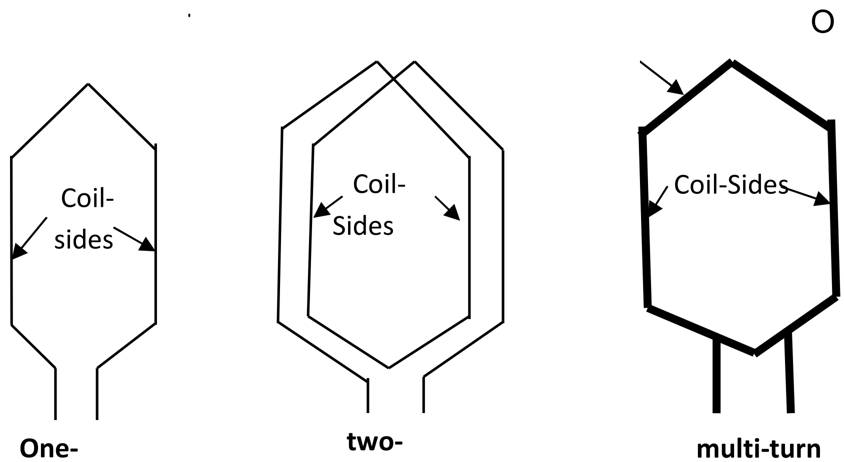


Fig 3.1: Active side of a coil

6. ***Inactive Side of a Coil or End Turn***: It is the portion of the conductor which joins the two inductors.

7. ***Leads of a Coil***: These are the starting and ending of a coil which are used for doing the connection.

The number of conductors ***(C)*** in any coil-side is **equal** to the number of turns ***(N)*** in that coil.



8. ***Coil Span or Winding Pitch***: The distance between the two active sides of a coil under the adjacent dissimilar poles. It is usually measured in terms of teeth, slots or electrical degrees.

If winding pitch is 6, then the coil throw is 1 to 7 and one side of the coil is put in slot no. 1 and the other side is inserted in slot no. 7. Then the winding pitch is 7-1 = 6.

Winding pitch may or may not be equal to pole pitch. While rewinding, it is always preferred not to change the winding pitch as it has been chosen by the designer after considering different factors leading to good performance of the machine. Any change in original winding pitch of a machine will affect the performance of that machine.

9. ***Coils per Pole***: The number of coils connected in series to produce a single pole when current pass through them.
10. **Coil Groups:** The total number of coil groups in a machine is called coil groups. It is the product of number of phases and number of poles in a machine, i.e.
    Coil groups = no. of phases **x** no. of poles

11. **Pole pitch:** The distance between the centers of two adjacent opposite poles. Pole pitch is measured in terms of slots. . Pole pitch is always equal to 180°

$$Pole\ pitch = \frac{No.of\ \ slots\ in\ a\ machine}{No.of\ \ Poles}$$

- if there are ***S*** slots and ***P*** poles, then pole pitch ***Q = S/P*** slots per pole.

12. **Pitch Factor**: Pitch factor is the ratio between the winding pitch and pole pitch.

$$Pitch\ factor = \frac{Winding\ pitch}{Pole\ Pitch}$$

13. **Full Pitch Winding**: In this winding, the winding pitch is equal to pole pitch. In other words, for a full pitch winding, the pitch factor is equal to unity and the winding is known as “Full Pitched Winding”.
14. **Chorded Winding:** In this winding, the winding pitch is not equal to pole pitch. Thus, the pitch factor is less than unity so the winding is named as ***short pitch or chorded winding***. If the pitch factor is more than unity, the winding is then termed as **long pitch winding**.
   - if coil-pitch ***Y = S/P*** , it results in ***full-pitch Winding.***
   - in case coil-pitch $Y < \frac{S}{P}$, it results in ***chorded***, ***short-pitched*** or ***fractional-pitch.***

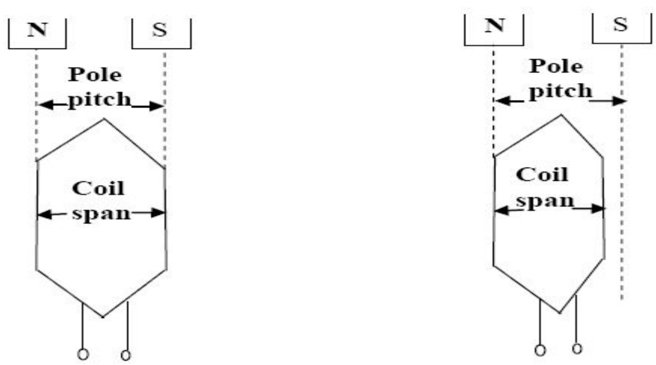


Fig 3.2: Full-pitch coil *Short-pitched or chorded coil*

15. ***Whole-Coil Winding***: A whole coil winding is one in which number of coils per phase is equal to the number of poles in the machine.
16. ***Half Coil Windings***: it is the winding in which number of coil per phase is equal to half of the number of poles in the machines. Half coil winding is generally done in the winding of ceiling fans, double speed motors etc

17. ***Balanced Winding***: When each pole of the same phase contains equal number of coils, then the winding is termed as balanced or even group winding.
18. ***Unbalanced winding***: If each pole of the same phase has unequal number of coils, then the winding is termed as unbalanced or odd group winding. It is important to note that there must be equal number of coils in each phase whether the winding is balanced or unbalanced.
19. **Number of slots per pole per phase (q)**: An important point in winding design is the selection of number of slots per pole per.

$$q = \frac{S}{Pm}$$

Where: S = no of slots

P = no of poles

m = no of phases

20. **Phase spread or phase apart**: - The requirement of a-c winding is that it must produce a symmetrical 3-phase of e.m.f.'s of identical magnitude, frequency and wave form of displaced in time by 120 electrical degrees for 3-phase system. This is secured by the following alternative methods.

i) Total electrical degrees = 360^0 X pole-pairs

ii) $\alpha slot^0 = \frac{Total\ Elect.degrees}{total\ No.of\ Slots}$, in degrees

iii) Phase spread (phase displacement) $= \frac{120^0}{\alpha slot^0}$, in slots

Or, $Phase\ spread = \frac{120^0 elect.}{180^0 elect.} x \frac{S}{p}$

$= \frac{2}{3} \times \frac{S}{P}$, in slots

21. **Phase sequence**; means the order in which the three voltages become successively positive.

22. Relations for drawing winding diagram

$$n_s = \frac{120xf}{p}$$

$$q = \frac{z}{Pxm}$$

$$Y_z \leq \frac{Z}{p}$$

$$\acute{\alpha}_{slot} = \frac{\frac{P}{2} x 360^0}{Z}$$

$$Z_{phase} = \frac{120^0}{\acute{\alpha}_{slot}}$$

3.4. Rewinding stator coils of single phase AC motor

3.4.1. AC Lap Winding

Example: 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 slots contains only one coil side. Therefore, number of coils, C = 12

$$\text{pole pitch} = \frac{Number\ of\ slots}{Number\ of\ Poles} = \frac{24}{4} = 6;\ \text{and slots per pole}$$

per phase, m = 24/4x1 = 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 1800ed. 1800ed 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, Yb = 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, Yf =Yb – 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

S.No.	$-Y_f$	$+Y_b$
1	1	7
2	2	8
3	3	9
4	4	10
5	5	11
6	6	12
7	13	19
8	14	20
9	15	21
10	16	22
11	17	23
12	18	24

Table 3.1. Single Phase AC Lap Winding Table

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 3.1.

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. 3.4.

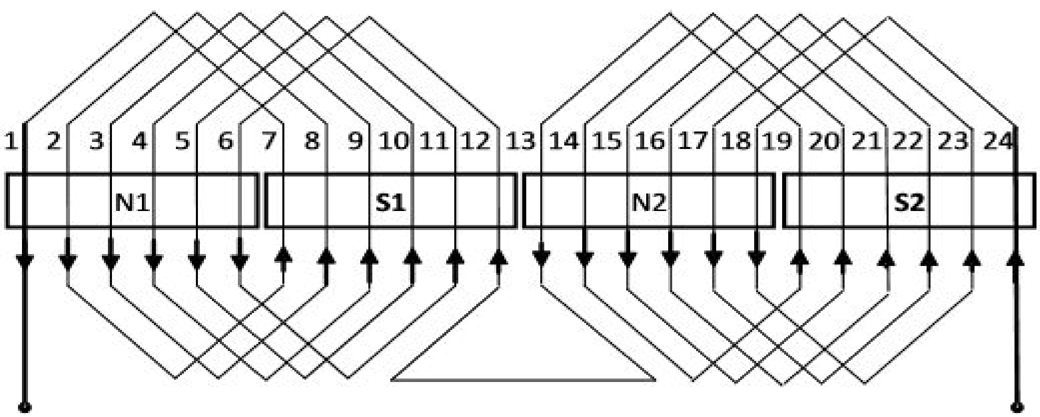


Fig.3.4: Single Phase AC Lap Main Winding Diagram

3.4.2. Wave Winding

Example: Develop a single phase, single layer wave winding for a 4 pole, 24 slot ac machine.

Solution: Number of coils, C = 12

Solution : Number of coils, C = 12

From equation 3.5, the pole pitch = $\frac{Number\ of\ slots}{Number\ of\ Poles} = \frac{24}{4}$ = 6; and slots per pole per phase, m = $\frac{6}{1}$ = 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 1800ed. 1800ed corresponds to 6 slots. For ac wave winding, back pitch, Yb = number of coils(or slots) per pole= 6 = front pitch, Yf. If one side of the coil is placed in slot no. 1, the other side of the coil should be placed in slot no. (1 + slots per pole = 1 + 6 =) 7. The finishing end of the coil side at slot no. 7 is connected to the starting end of the coil side at slot no. (7 + 6 =) 13. Now the other side of the coil side at slot no. 13 is placed at slot no. (13 + 6 =) 19. Adding 6 to slot no. 19 gives 25, which is slot no. 1, ie., 25 – 24 = 1. But a coil side is already placed at slot no. 1. So add 1 and place the coil side at slot no. 2. Similarly, add turn by turn back pitch and front pitch and at the end of each round add Yb + 1. Table 3.2 gives the complete winding table for a 4 pole 24 slot ac wave wound machine.

S.No.	Y_f	Y_b
1	1	7
2	13	19
3	2	8
4	14	20
5	3	9
6	15	21
7	4	10
8	16	22
9	5	11
10	17	23
11	6	12
12	18	24

Table 3.2. Single Phase AC Wave Winding Table

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 3.2.

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. 3.5.

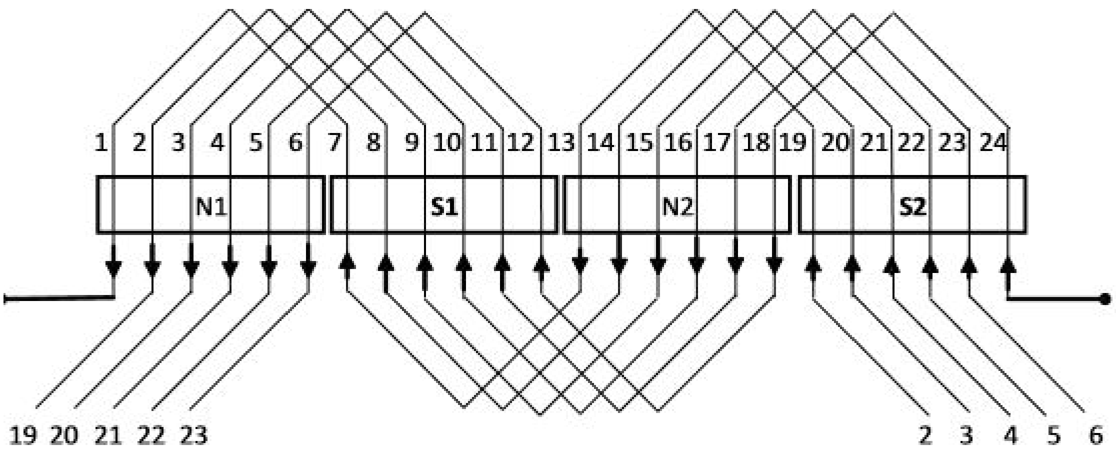


Fig. 3.5 Single phase AC Wave Main Winding Diagram

Spiral or Concentric Winding: Develop a single phase single layer concentric winding for a 4 pole AC Machine having 24 slots.

Solution : From equation 3.5, pole pitch = $\frac{slots}{Poles} = \frac{24}{4} = 6$

The pitch for larger coil = 6 – 1 = 5

The pitch for smallest coil = 1

Based on the rules, the winding is started from the starting end of the middle coil in the first North Pole, ie., coil side 4. The back end of the coil side 4 is connected to the back end of the coil side 9, ie., pitch for larger coil is added to coil side 4. The front end of the coil side 9 is connected to front side of coil side 5 to form concentric winding. Following the above procedure, Table 3.3 gives the complete winding table for 4 pole 24 slot AC Machine.

Draw 24 solid lines of equal length at equal distance. This represents the number of slots. This also represents the number of coils, as this is a single layer winding. Then assign numbers to the top side of the coils, as shown in Fig. 3.5. With reference to Table 3.2.3, complete the winding diagram

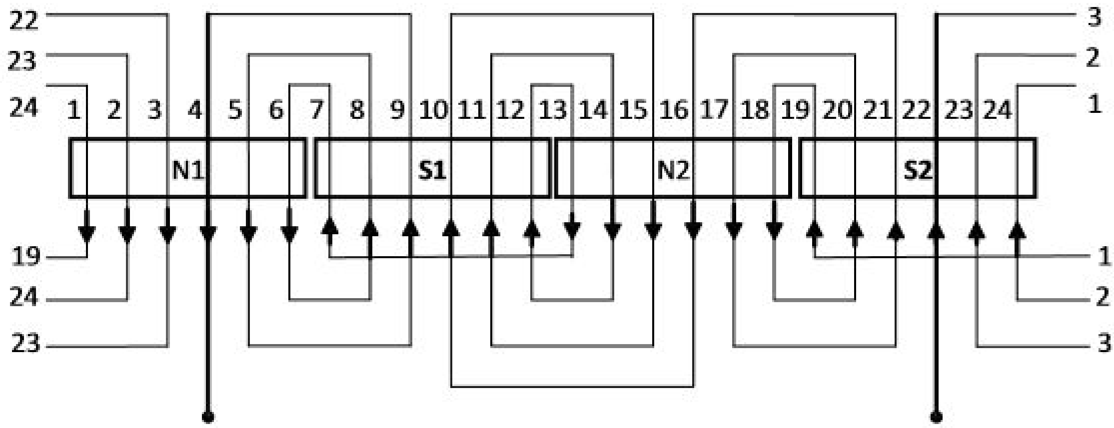


Fig.3.5 - Single Phase AC Concentric Main Winding Diagram

3.5. Types of Three-phase Windings

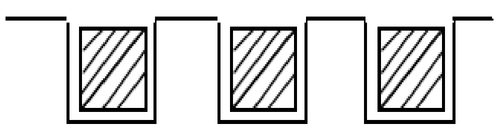
According to the number of layers per slot, three-phase a-c windings are divided in to two main groups:

- **Single –layer windings**

In single – layer windings, there is only one coil- side per slot. Therefore, number of coils in single- layer windings is half of the number of slots i.e

$$C = \frac{1}{2}S$$

Where : C = number of total coils , S = number of stator slots



one coil-side per slot

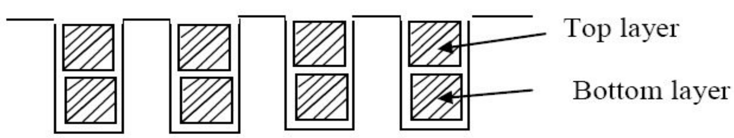
- One coil-side occupies the total slot area
- Used only in small ac machines

Examples of single- layer winding,

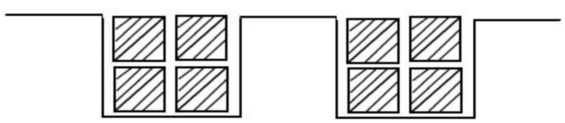
- ✓ Concentric windings
- ✓ Chain windings
- ✓ Mush(basket) windings (with mush over -hang)
- ✓ Chain winding with diamond over-hang(end connection)

- **Double- layer windings**

In double-layer windings, Slot contains even number (may be 2,4,6 etc.) of coil-sides in two layers.



Two coil –sides per slot



4-coil-sides per slot

Fig 3.6: coil side per slot

- Double-layer winding is more common above about 5kW machines

- In double layer windings, total number of coils is equal to the number of slots, i.e.

C = S

Examples of double- layer windings,

a) Integral slot winding
b) Fractional slot winding

The advantages of double-layer winding over single layer winding are as follows:

- ✓ Easier to manufacture and lower cost of the coils
- ✓ Fractional-slot winding can be used

- ✓ Chorded-winding is possible
- ✓ Lower-leakage reactance and therefore , better performance of the machine
- ✓ Better emf waveform in case of generators

In ***AC armature windings***, the separate coils may be connected in several different manners, but the two most common methods are ***lap*** and ***wave***

In polyphase windings it is essential that

- ✓ The generated ***emfs*** of all the phases are of ***equal magnitude***
- ✓ The ***waveforms*** of the ***phase emfs*** are ***identical***
- ✓ The ***frequency*** of the ***phase emfs*** are ***equal***

The ***phase emfs*** have mutual time-phase displacement of $\beta = \frac{2\pi}{m}$ electrical radians. Here ***m*** is the number of phases of the a.c. machine.

3.5.1. Types of *Single-layer windings*

- One coil side occupies one slot completely, in view of this, number of coils ***C*** is equal to half the number of slots ***S***, $C = \frac{1}{2}S$
- The 3-phase single –layer windings are of two types
  - ✓ Concentric windings
  - ✓ Mush windings

3.5.1.1. Concentric windings

- The coils under one pole pair are wound in such a manner as if these have one center
- the concentric winding can further be sub-divided into
  - ✓ half coil winding or unbifurcated winding
  - ✓ Whole coil winding or bifurcated winding

In concentric windings the coil pitch of the individual coil is different, the coil pitch of the outer coil is more than the pole pitch, while the coil-pitch of the inner coil is less than the pole-pitch.

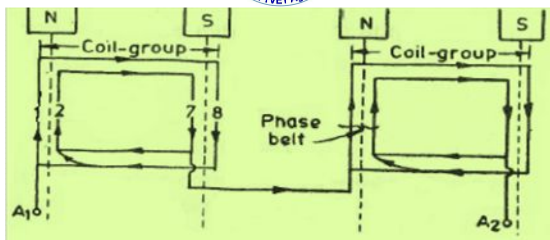


*Fig 3.7: Half coil winding, for phase **A** only*

- The half coil winding arrangement with 2-slots per pole per phase and for $\sigma=60^0$
- coil group may be defined as the group of coils having the same center
- The number of coils in each coil group = the number of coil sides in each phase belt (phase group)
- The carry current in the same direction in all the coil groups

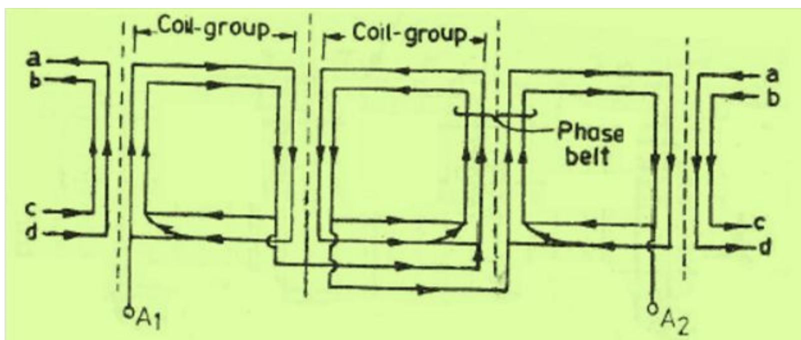


Fig 3.8: whole coil winding, For phase A only

- The whole coil winding arrangement with 2-slots per pole per phase
- The number of coil sides in each phase belt (here 4) are double the number of coils (here 2) in each coil group
- There are ***P*** coil groups and the adjacent coil groups carry currents in opposite directions

Example 1

Develop the single layer concentric winding diagram of a 3-phase, 24-slots, 4-poles stator of an induction motor.

Given:- S = 24 , P = 4 , m = 3

Type of winding: single-layer concentric

Phase connection: star connected,

Solution

1) $C = \frac{1}{2}S = \frac{1}{2} \times 24 = 12$

2) Total coil groups $= m \times \frac{P}{2} = 3 \times 2 = 6$

3) $Y_p = \frac{S}{P} = \frac{24}{4} = 6$

4) $q = \frac{S}{mp} = \frac{24}{3 \times 4} = 2$

5) Phase spread $= \frac{2}{3} \times \frac{S}{P} = \frac{2}{3} \times \frac{24}{4} = 4$

6) $Y_L = Y_p|a| + q = 6 + 2 = 8$

Therefore, coil throws will be:

Phase A =	Phase B=	Phase C =
1 – 8	5 – 12	9 - 16
2 – 7	6 = 11	10 – 15
13 – 20	17 – 24	21 - 4
14 - 19	18 – 23	22 - 3

7) Phase sequence A C' B A' C B' A C' B A' C B'

2 2 2 2 2 2 2 2 2 2 2 2 = 24

No.of slots 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

phase seq. A A C' C' B B A' A' C C B' B' A A C' C' B B A' A' C C B' B'

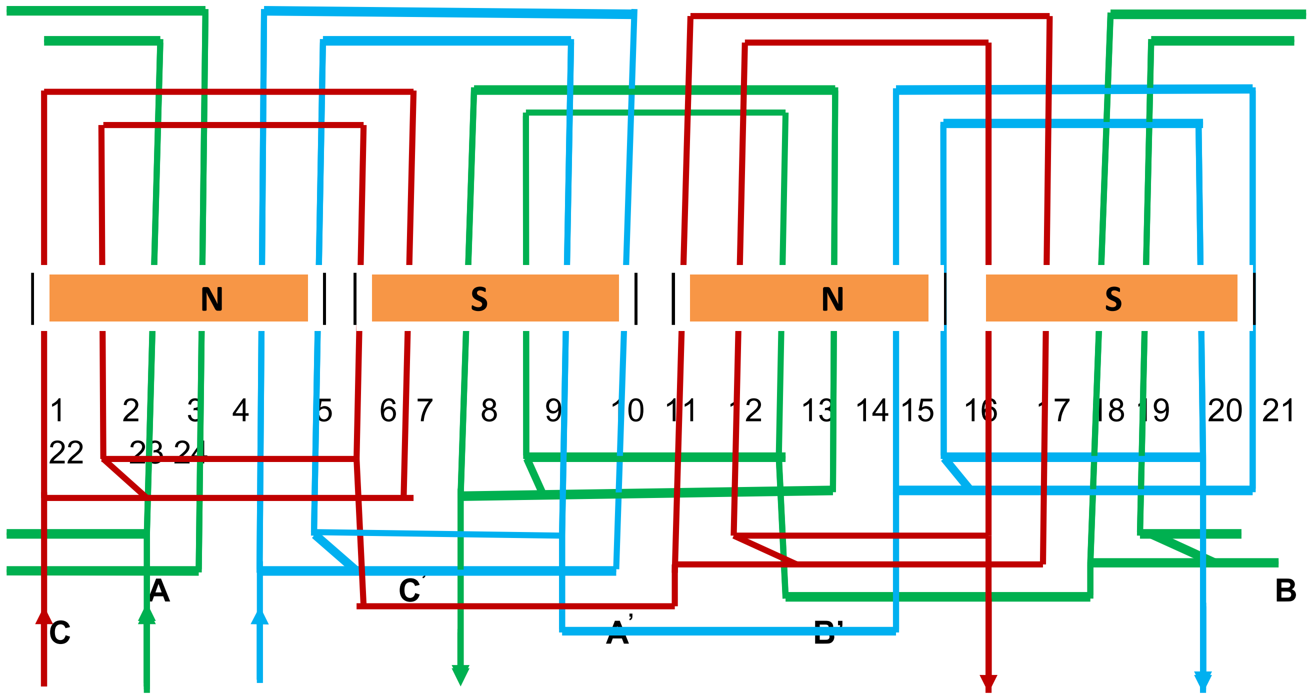


Figure 3.9: Concentric winding coils

Examlpe2*. If No. of Slots* = 36, No. of Poles = 4, No. of phase, m=3 and type of winding is concentric, then

$$Y_p = \frac{36}{4} = 9$$

$$q = \frac{36}{3\times4} = 3$$

Phase apart (phase spread) = 2/3x36/9 = **6**

$$Y_L = Y_p|a| + q$$, where: a=parallel path, a =1

$$Y_L = 9 + 3 = 12$$

Then coil throw for phase A, **1 – 12 19 - 30**

2 – 11 20 - 29

3 – 10 21 – 28

coil throw for phase B, **7 – 18 25 – 36 ,**

8 – 17 **26 - 35**

9-16 **27 - 34**

then coil throw for phase C, 13 – 24 **31 - 6**

14 – 23 **32 - 5**

15 – 22 **33 – 4**

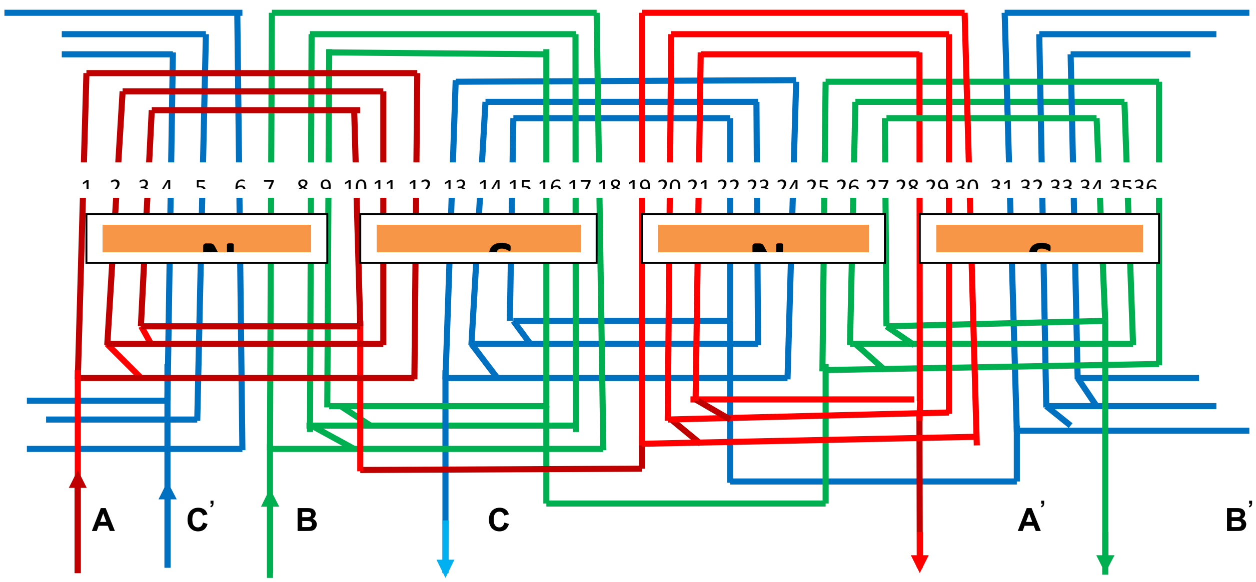


Figure 3.10: Concentric winding coils

Example 3. Design and draw ***(a)*** half coil and ***(b)*** whole coil single layer concentric windings for a 3-phase machine with 24-slots, 4-poles and 60^o phase spread

Solution: *(a) half coil concentric winding*

Slots angular pitch $\gamma = \frac{4\times180^0}{24} = 30^0$

Full pitch or Pole pitch$=\frac{24}{4} = 6\ slots\ pitches$

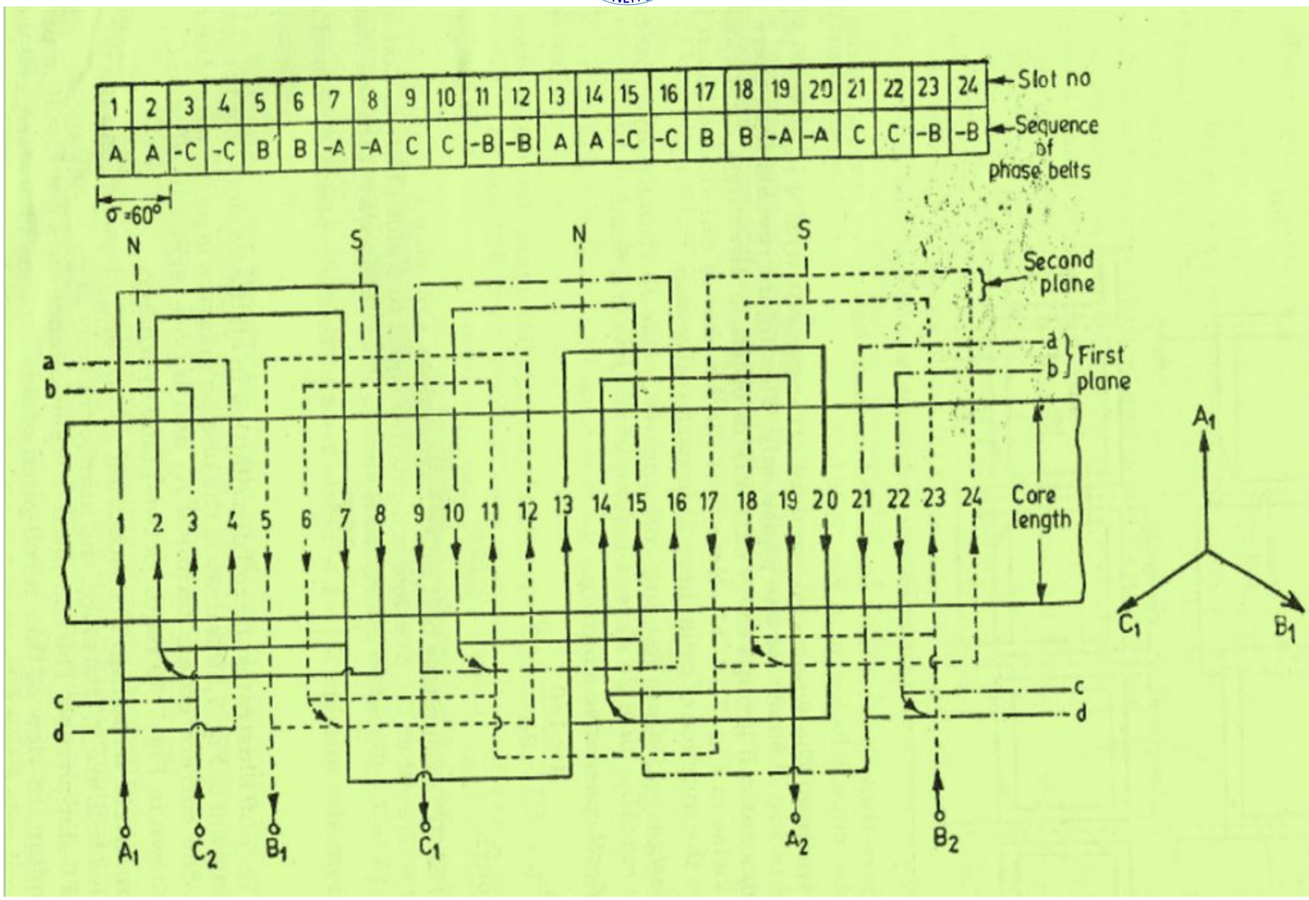


Figure 3.11: 4 poles, 60° phase spread single layer concentric winding (two – plane overhang)

(b) Whole-coil concentric winding

For slot pitch γ = 30o & phase spread σ = 60^0

- ✓ The number of coils per phase belt = 2 ,
- ✓ The number of coils in each coil group = 1
- ✓ The pole pitch=6
- ✓ The coil pitch of 6 slot pitches does not result in proper arrangement of the winding
- ✓ In view of this, a coil pitch of 5 is chosen

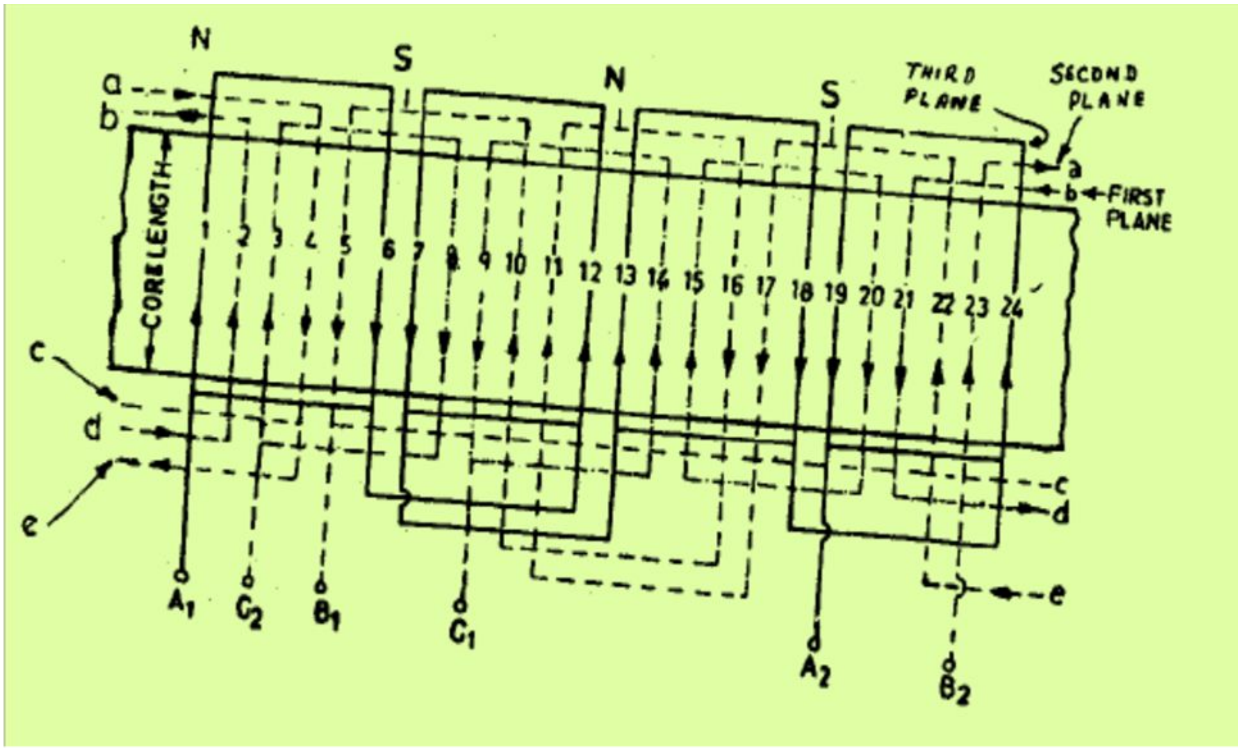


Figure 3.12: Whole-coil winding arrangement of 24 slots, 4 poles, 60° phase spread, single layer concentric winding (three-plane overhang)

Example:4: Draw the developed winding diagram of a 3 phase induction motor with 18 slots, 2 poles, single layer, full pitched winding with delta connection.

Soln: No. of slots per pole per phase = 18/(2 x 3) = 3 Pole pitch = no. of conductor / pole = 18/2 = 9 Slot angle = 180/ pole pitch = 180/9 = 200 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 3 + 9 = 12	11+ 9 = 20 (2) 13 + 9 = 22(4)
B	5 + 9 = 14	15 + 9 = 24 (6)
Y	7 + 9 = 16 9 + 9 = 18	17 + 9 = 26 (8)

Connections: Rs = 1, Ys = 1 + 120/slot angle = 1+120/20 = 7; Bs = 1 + 240/slot angle = 1+ 240/20 = 13

Winding Diagram

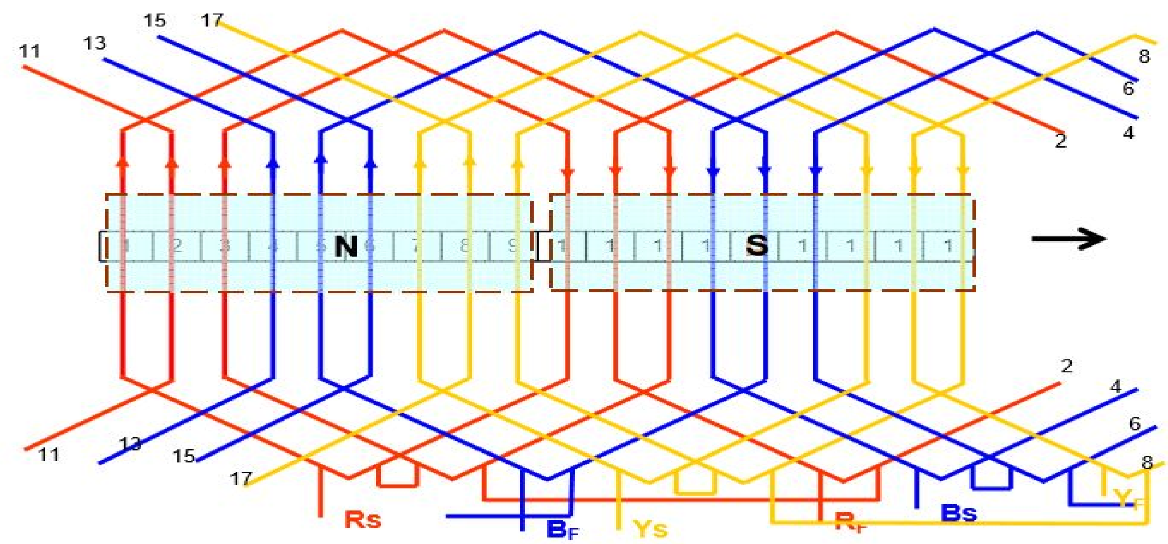


Fig. 23 Winding diagram

Example:5. Design and draw the developed winding diagram of an alternator with following details: No of poles = 2 no. of phases = 3, No. of slots = 24, single layer lap winding, short pitched by one slot.

Soln: No. of poles = 2; No. of conductors = 24; Pole pitch = 24/2 = 12; no of slots/pole /phase =24/ (2x3) = 4 No. of coils = 24/2 = 12 No of coils/pole/phase = 12/(2x3) = 2 Slot angle = 180/pole pitch = 180/12 = 150 Winding pitch = 180 – (slot angle x no of slots shorted) = 180 – 1 x15 = 165 Hence coil span = 1650 = 11 slots Connections: Rs = 1, Ys = 1 + 120/15 = 9; Bs = 1 + 240/15 = 17

Winding Table:

Phase	1st pole	2nd pole
R	1 + 11= 12	13 + 11 = 24
	3 + 11 = 14	15 + 11 = 26 (2)
B	5 + 11 = 16	17 + 11 = 4
	7 + 11 = 18	19 + 11 = 6
Y	9 + 11 = 20	21 + 11 = 8
	11 + 11 = 22	23 + 11 = 10

Winding Diagram:

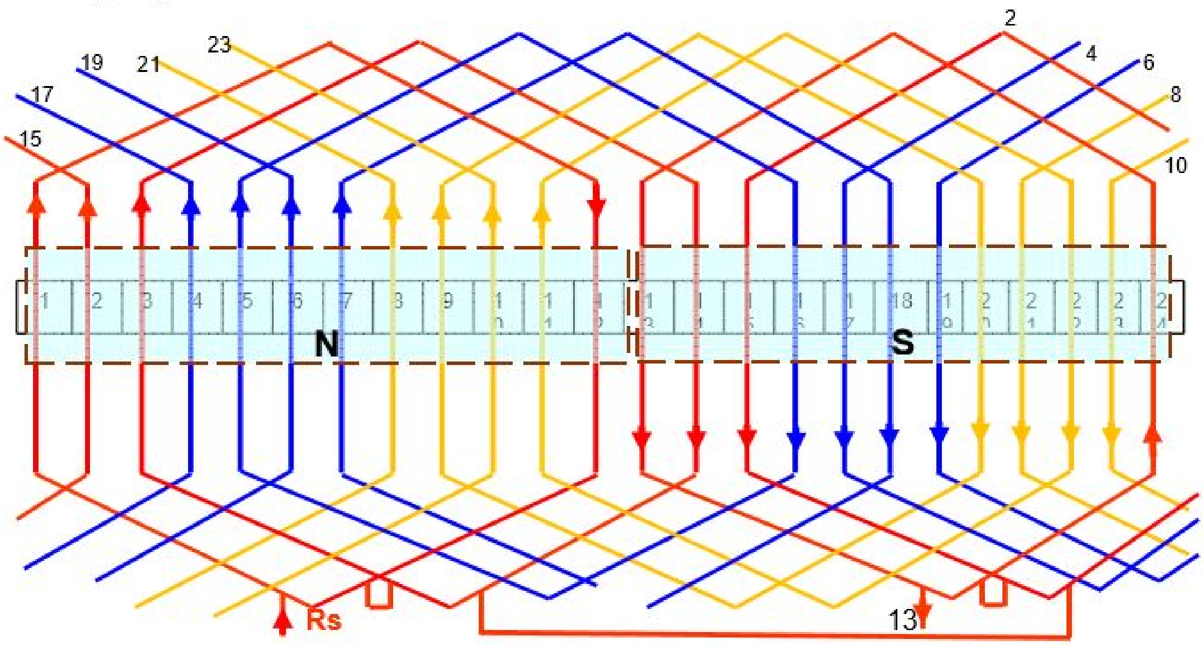


Fig. 25 Winding diagram

Example. 6. Design and draw the developed winding diagram of an alternator with following details: No of 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/ (4x3) = 2 No. of coils = 24/2 = 12 Slot angle = 180/pole pitch = 180/6 = 300 Winding pitch = 180 – (slot angle) = 180 – 30= 150 Hence coil span = 1800 / 30 = 6 slots Yb = 6 and Yf = 6

Connections: Rs = 1, Ys = 1 + 120/30 = 5; Bs = 1 + 240/30 = 9

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 + 6 = 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	

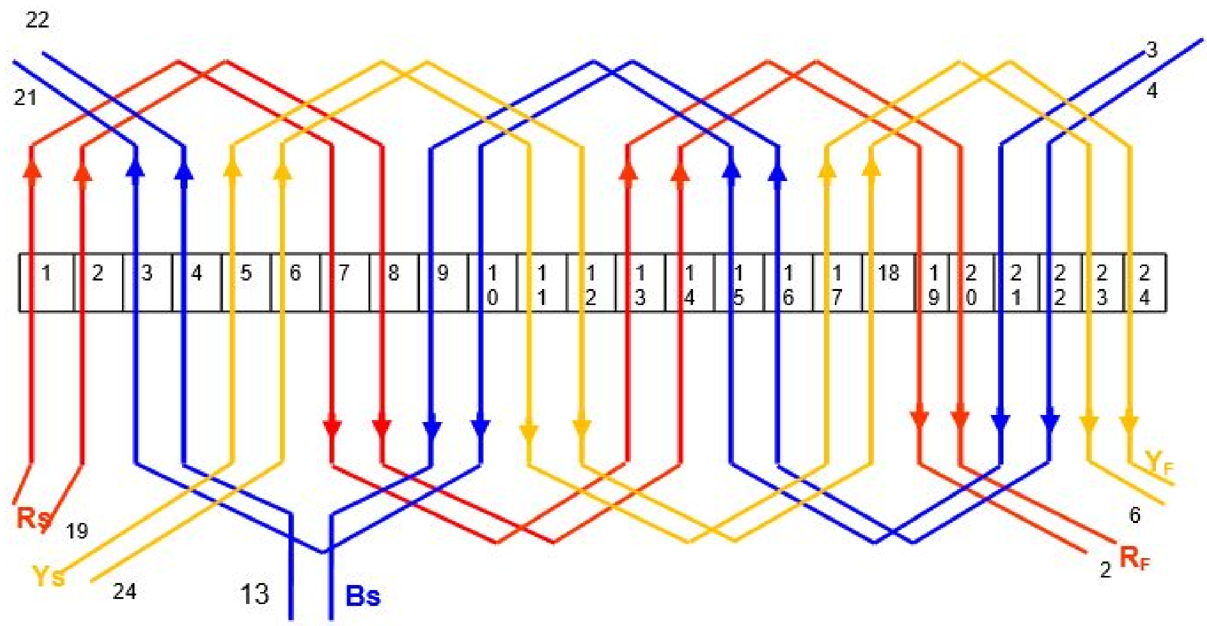


Fig . 24 Winding diagram

3.5.1.2. Mush Winding

- ✓ The coil pitch is the same for all the coils
- ✓ Each coil is first wound on a trapezoidal shaped former. Then the short coil sides are first fitted in alternate slots and the long coil sides are inserted in the remaining slots

✓ The number of slots per pole per phase must be a whole number
✓ The coil pitch is always odd

For example.1: for 24 slots, 4 poles, single-layer mush winding, the pole pitch is 6 slots pitches. Since the coil pitch must be odd, it can be taken as 5 or 7. Choosing here a coil

Pitch of 5 slot pitches.

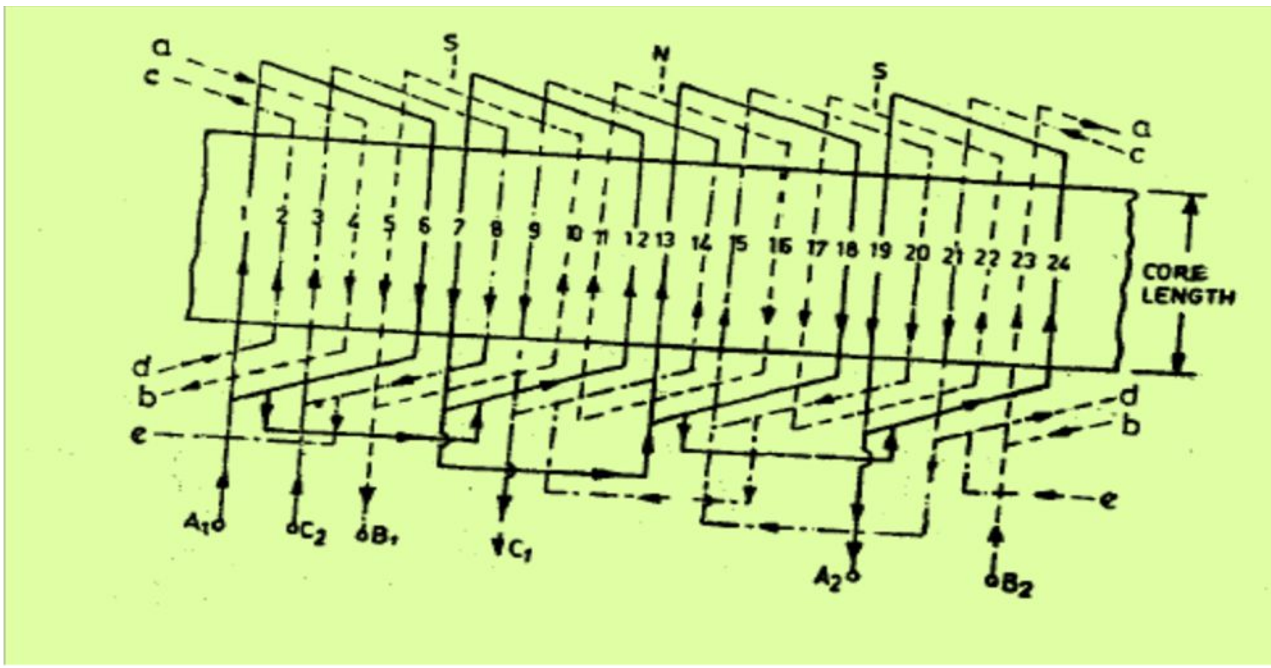


Figure *3.13:* Single – layer mush winding diagram for 24 slots, 4 poles and 60^{o} phase spread

3.5.2. Types of Double Layer Winding

3.5.2.1. Integral slot full pitch winding:- If the number of slots per pole per phase i.e. $q = \frac{S}{mP}$ is an integer, then the winding is called an integral-slot winding.

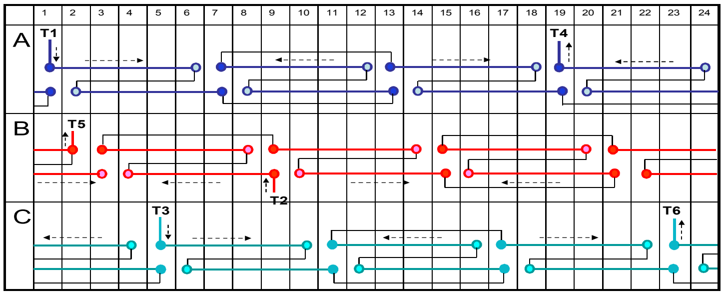


Figure 3.14: Motor Rewinding Diagram

Example 2 : Develop a full-pitch double-layer winding diagram for the following data.

S= 12, P = 2, m = 3, a = 1

Solution

$Y_p = \frac{12}{2} = 6$, $Y_c = \frac{P}{2} = 6$ (full pitch) , a= 1

$q = \frac{12}{3 \times 2} = 2$

Phase sequence : A C' B A' C B'

2 2 2 2 2 2 = 12 Slot

No. of slots	1	2	3	4	5	6	7	8	9	10	11	12
Phase sequence of the upper layer	A	A	C'	C'	B	B	A	A	C'	C'	B	B
Phase sequence of bottom layer	A'	A'	C	C	B'	B'	A'	A'	C	C	B'	B'

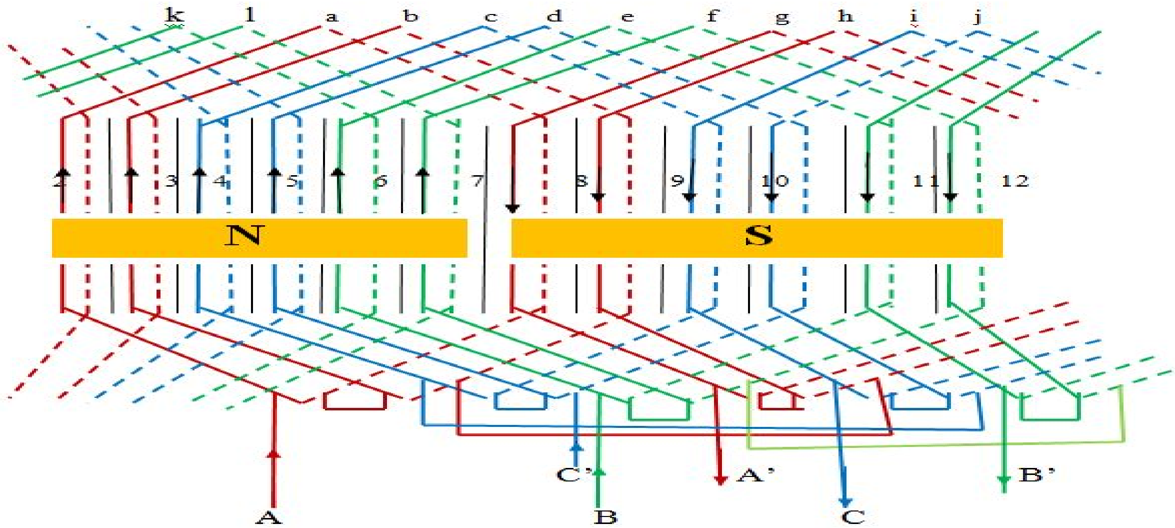


Figure *3.15 Double Layer winding with 12 slots*

Example 3: make a winding table for the armature of a 3-phase machine with the following specifications:

Total number of slots = 24   Double – layer winding

Number of poles = 4   Phase spread=60^0

Coil-span = full-pitch

(a) Draw the detailed winding diagram for one phase only

(b) Show the star of coil-emfs. Draw phasor diagram for narrow-spread(σ=60 ^{0}) connections of the 3-phase winding showing coil-emfs for phases A and B only.

Solution: slot angular pitch, $\gamma = \frac{4\times180^0}{24} = 30^0$

Phase spread, $\sigma = 60^0$

Number of slots per pole per phase, $q = \frac{24}{3\times4} = 2$

Coil span = full pitch $= \frac{24}{4} = 6$

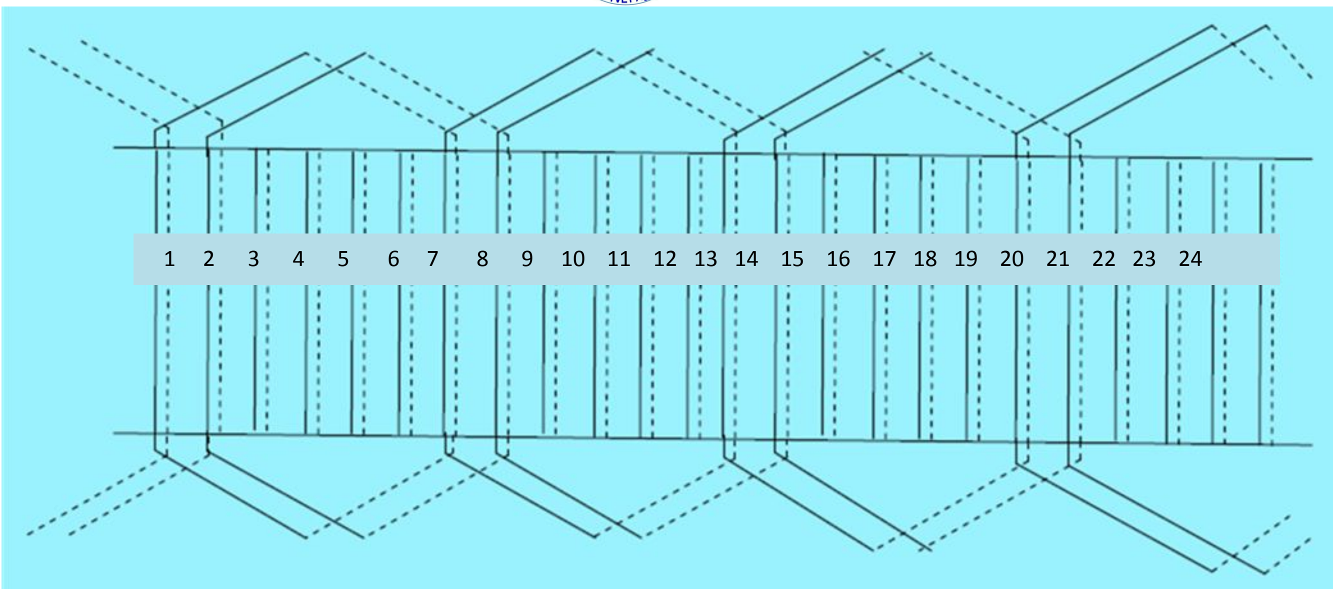
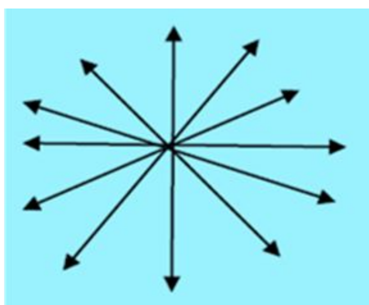
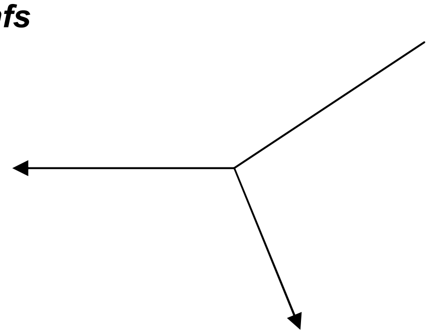


Figure 3.16: Detailed double layer winding diagram for phase A for 3-phase armature having 24 slots, 4 poles, phase spread 60^o



b) The ***star*** of ***coil emfs*** can be drawn similar to the star of ***slot emfs*** or star of ***conductor emfs***



Phasor diagram showing the phasor sum of coil-emfs to obtain phase voltages A and B

3.5.2.2. Integral slot chorded winding

- Coil span (coil pitch) **<** pole pitch (***y* < *τ***)
- The advantages of using chorded coils are:
  - ✓ To reduce the **amount of copper** required for the end-connections (or over hang)
  - ✓ To reduce the **magnitude of certain harmonics** in the waveform of phase emfs and mmfs
- The coil span generally varies from **2/3 pole pitch** to **full pole pitch**

  Example. Let us consider a double-layer three-phase winding with q = 3, p = 4, (S = pqm = 36 slots), chorded coils y/τ = 7/9

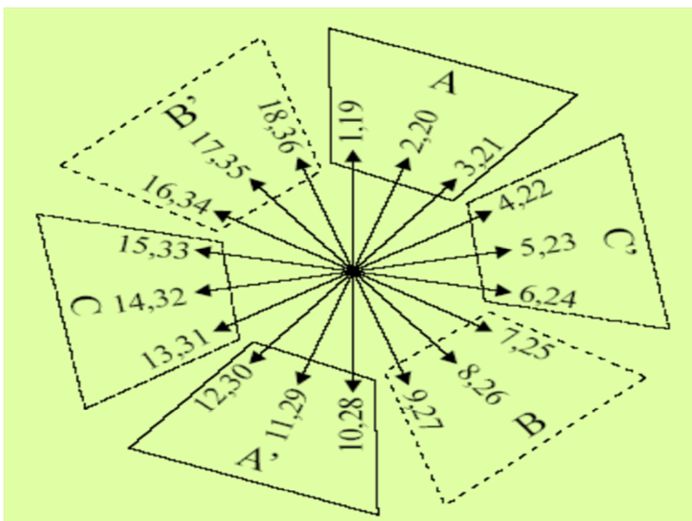


Figure 3.17 The star of slot emf phasors for a double-layer winding p = 4 poles,

q = 3 slots/pole/phase, m = 3, S = 36

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
layer1	A	A	A	C'	C'	C'	B	B	B	A'	A'	A'	C	C	C	B'	B'	B'
layer2	A	C'	C'	C'	B	B	B	A'	A'	A'	C	C	C	B'	B'	B'	A	A

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
layer1	A	A	A	C'	C'	C'	B	B	B	A'	A'	A'	C	C	C	B'	B'	B'
layer2	A	C'	C'	C'	B	B	B	A'	A'	A'	C	C	C	B'	B'	B'	A	A

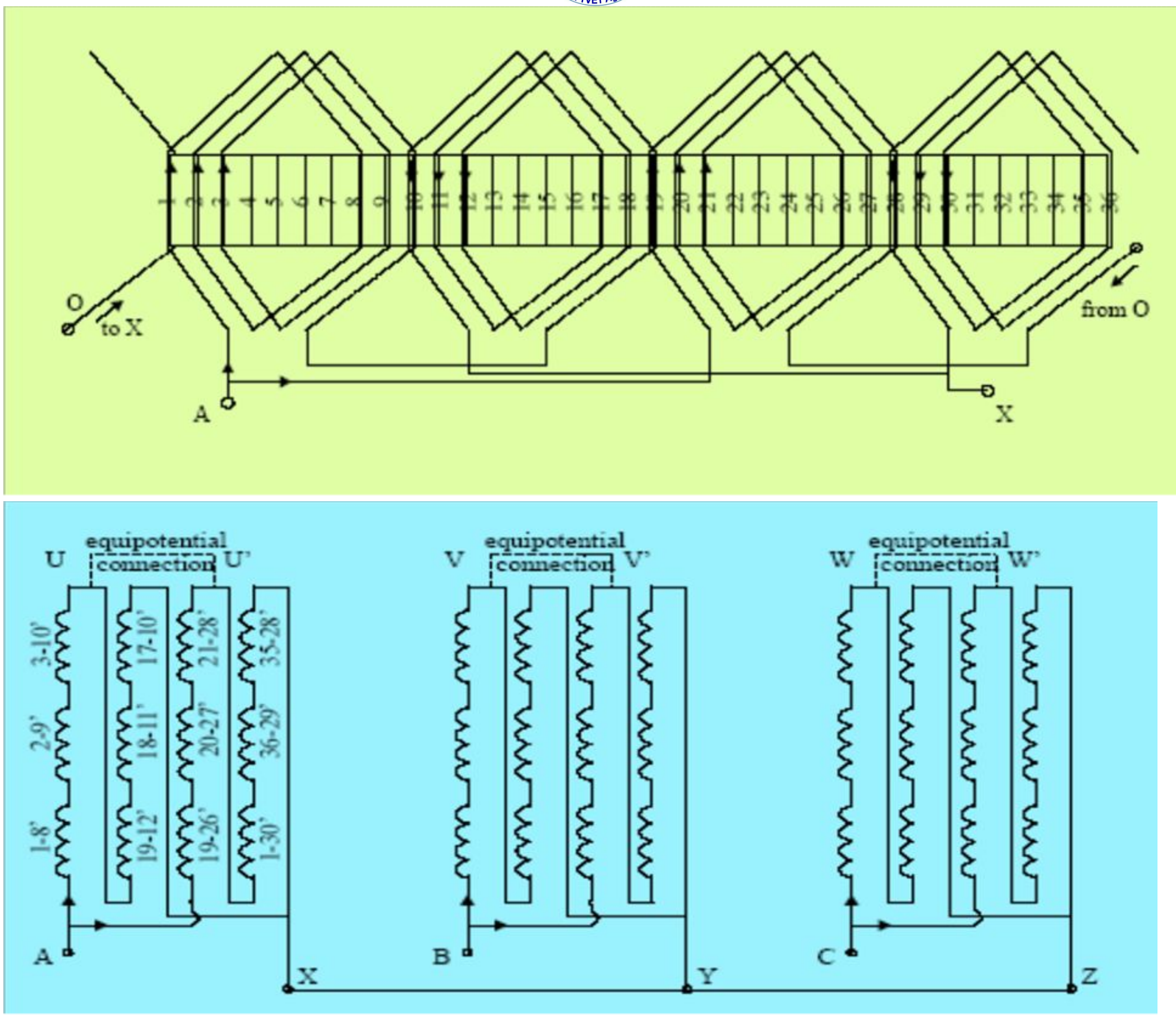


Figure 3.18: Double-layer winding: p = 4 poles, q = 3, y/τ = 7/9, S = 36 slots.

3.6. Fractional Slot Windings

If the number of slots ***q*** of a winding is a fraction, the winding is called a ***fractional slot winding.***

Example: If S = 30 , P = 30 , P = 8, m = 3 ,then $q = \frac{S}{mP} = \frac{30}{3\times 8} = \frac{5}{4} = 1\frac{1}{4}$

Advantages of fractional slot windings when compared with integral slot windings are:

- a great freedom of choice with respect to the number of slot a possibility to reach a suitable magnetic flux density

- this winding allows more freedom in the choice of coil span
- if the number of slots is predetermined, the fractional slot winding can be applied to a wider range of numbers of poles than the integral slot winding the segment structures of large machines are better controlled by using fractional slot windings
- this winding reduces the high-frequency harmonics in the emf and mmf waveforms

Let us consider a small induction motor with ***p*** = 8 and *q* = 3/2, ***m*** = 3. The total number of slots ***S*** = pqm = 8*3*3/2= 36 slots. The coil span ***y*** is ***y*** = (S/p) = (36/8) = 4slot pitches

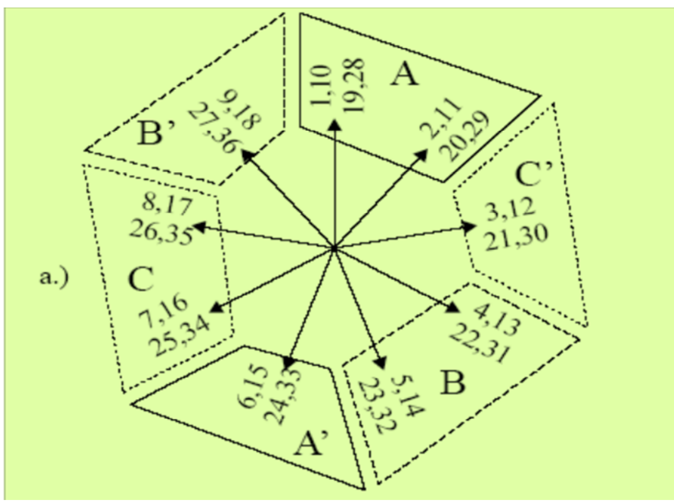


Figure 3.19: Fractionary q (q = 3/2, p = 8, m = 3,S = 36) winding- emf star,

- ✓ The actual value of q for each phase under neighboring poles is 2 and respectively, to give an average of 3/2

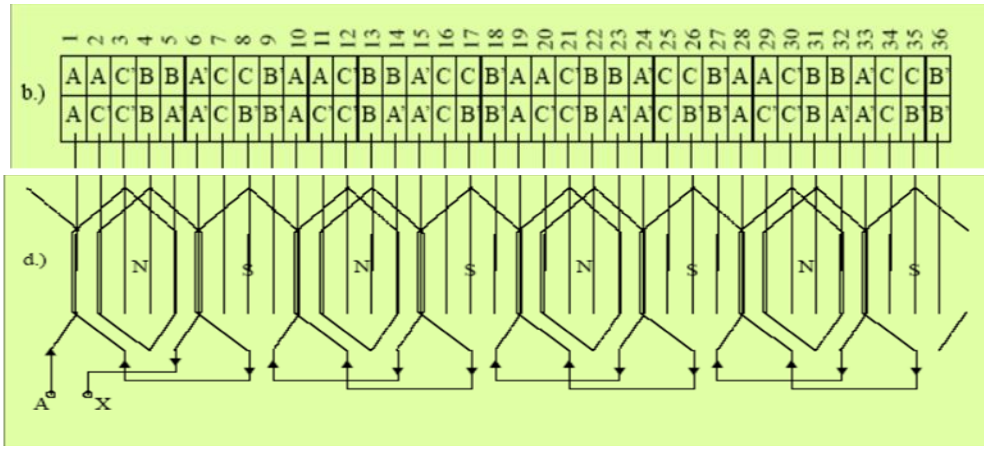


Figure 3.20: Fractionary q (q = 3/2, p = 8, m = 3, S = 36) winding slot/phase allocation & Coils of phases

- **Steps and procedures of designing and laying out fractional slot windings.**

Step 1: First of all find out the number of slots per pole per phase (q) as under;

$$q = \frac{Q}{P}$$

Where:

q= a fraction reduced to its lowest terms

Q = No. of slots per repeat group

Example

With 60 slots, 16 poles, 3 -phase

$$q = \frac{60}{16 \times 3} = \frac{5}{4}$$

Comparing this with the standard form, Q = 5 and P = 4 Thus a unit is of 4 poles (P) and in 4 poles there are 5 slots /phase and hence 15 slots in all.

Step 2 : Find **d,** the number difference between two slots as

$$d = \frac{1 + xQm}{P}$$

Where, m = numbers of phases

x = the smallest number which makes **d** an integer

Example

For the example under consideration,

$$d = \frac{1 + x \times 5 \times 3}{4} = \frac{1 + 1 \times 5 \times 3}{4} = 4$$

Step 3: write down the sequence of slots as:

1, **1 + d**, **1 + 2d**, **1 +3d**, ... **mQ** terms

Where, mQ = Slots in a repeatable group.

Example

For the example under consideration, **mQ = 3 X 5 = 15**.

Hence the slot numbers are;

1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53 and 57 .

Note that these all 15 terms.

Step 4: Since the repeatable group consists of mQ slots, subtract mQ from the above numbers which exceed mQ.

Example

For the example under consideration, mQ =15 and so the slot numbers will appear as:

1, 5, 9, 13, 17-15, 25-15, 29-15, 33-30, 37 -30, 41-30, 45 30, 49-45, 53-45 and 57-45.

i.e

1, ***5***, ***9, 13***, ***2,*** **6, 10, 14, 3, 7, 11**, **15, 4, 8, 12*,***

Step 5 : Allot the first one third of the above slot numbers to phase A, next, one third to phase C and then remaining one third to phase B. (with phases sequence AC'B)

Example

For the example under consideration, the distribution is as follows.

Phase A : ***1, 2, 5, 9, 13***

Phase C: **3, 6, 7, 10, 14**

Phase B: **4, 8, 11, 12, 15**

Step 6 ; Assume a suitable pitch and lay out the winding.

Example;

For the example consideration,

$$Pole\ pitch = \frac{15}{4} = 3\frac{3}{4}\ slots$$

We could either select 3 or 4 slots as the coil pitch. Always the smaller value is selected which effects saving in copper due to a smaller over hang.

- **Laying out the winding diagram**

Draw 15 full lines and 15 dotted lines to represent the coil-sides in 15 slot of repeatable group of 4 poles.

- ✓ Draw the north south poles as show in fig. (a) and make the direction of emf's in the upper coil-sides pertaining to phase A.
- ✓ Selecting a coil pitch of 3 slots the coils are completed as shown in fig. ' b'
- ✓ connect these coils, pertaining to phase A, Over a repeatable group of 4 poles .

Note that an arrow is shown at the end of phases A. This signifies that the winding will now continue , in a similar fashion, in the second set of a repeatable pole group.

N.B; Phase apart $= \frac{2}{3} \times \frac{S}{P} = \frac{2}{3} \times \frac{60}{16} = \frac{5}{2} = 2.5 \approx 3 slots$

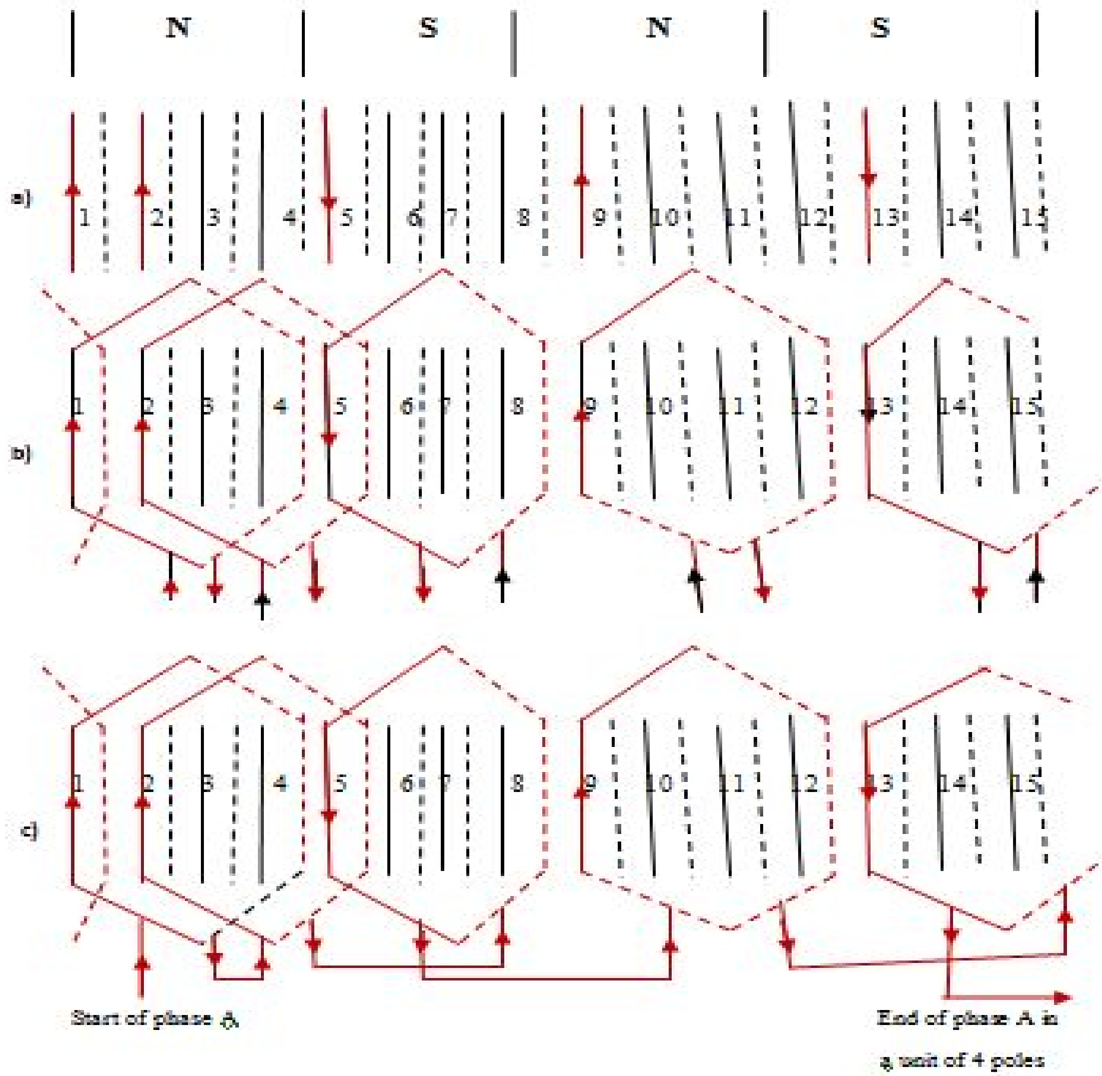


Figure 3.21: Fractional Slot winding with 60 slots 16 poles

Example 2 ; Design a fractional slot winding with the following data

108 slots - 16 Pole - 3 phase

<u>Solution</u>

Step1.

With $q = \frac{108}{18 \times 3} = \frac{9}{4}$

we get Q = 9 and P = 4

Step 2

$$d = \frac{1 + xQm}{P} = \frac{1 + (x * 9 * 3)}{4} = \frac{1 + (1 * 9 * 3)}{4} = 7$$

Step 3 The sequence of slots is,

1, 1 + d, 1 +2d, . . . mQ terms

Since mQ = 27, the sequence of the above 27 slots is,

1, 1 + 7, 1 + 14, 1 + 21, 1 + 28 , 1 + 35 , 1 + 42, 1 + 49, 1 + 56, 1 + 63, 1 + 70 , 1 + 77, 1 + 84, 1 + 91, 1 + 98, 1 + 105, 1 + 112, 1 + 119, 1 + 126, 1 + 133, 1 + 140, 1 + 147, 1 + 154, 1 + 161, 1+168, 1 + 175, 1 + 182,

Step 4 Taking account of the 27 slots in a repeatable group of 4 poles, the above slot numbers will become;

1, 8, 15, 22, 2, 9, 16, 23, 3,

10, 17, 24, 4, 11, 18, 24, 5, 12,

19, 26, 6, 13, 20, 27, 7, 14, 21,

Step 5 Re-arranging and allotting to each phase in order

Phase A → 1, 2, 3, 8, 9, 15, 16, 22, 23

Phase C → 4, 5, 10, 11, 12, 17, 18, 24, 25,

Phase B → 6, 7, 13, 14, 19, 20, 21, 26, 27,

Phase apart = 2/3 x27/4=5

Yp =108/16 =27/4=6¾

$\therefore Y_c = 6$

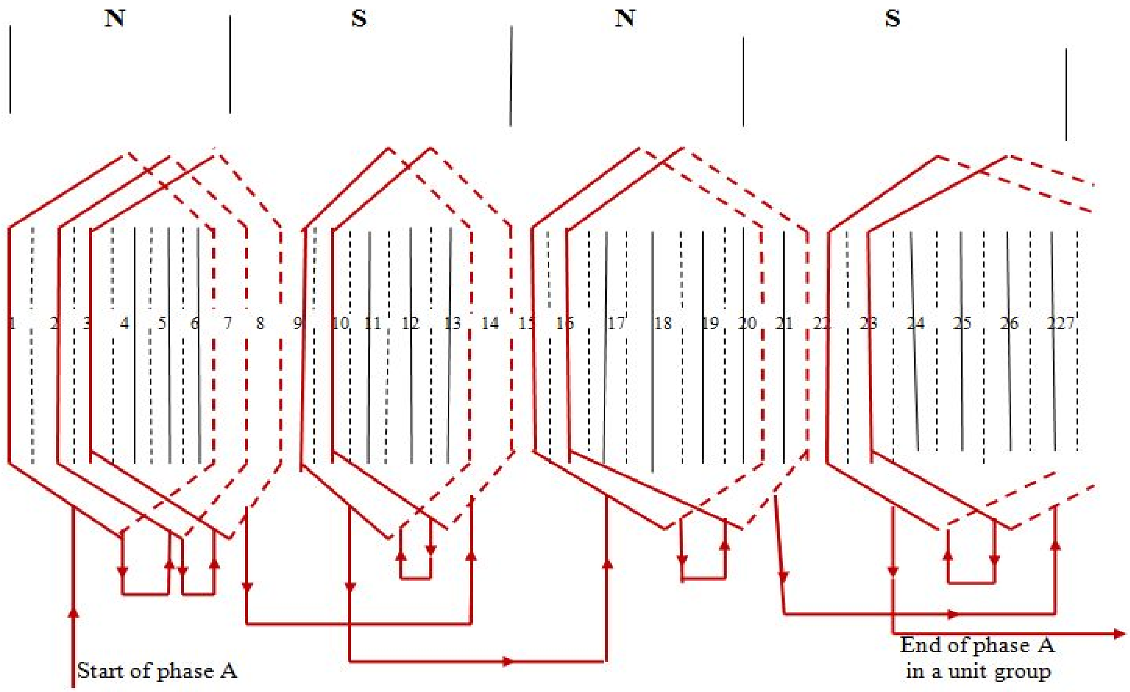


Figure 3.22: Fractional slot winding for 108 slots and 16 poles

Self-Check -3	Written Test

Directions: Choose the best answer

1. -------- It is the distance between the two active sides of the same coil under adjacent opposite poles. It is expressed in terms of number of slots per pole or electrical degrees.

A. Single layer　　B. Coil Span or coil pitch

C. Full pitch coil　　D. a and c

2.-------- A coil having a coil span equal to 1800ed is called a full pitch coil,

A double layer　　B .Full pitch coil

C. Coil Span or coil pitch　　D. None of the above

3.--------- : A coil having a coil span less than 1800ed by an angle â, is called a short pitch coil,

A. Short pitch coil　　B. Full pitch coil

C. Coil Span or coil pitch　　D. all of the above

4.-----------is the Distance between the poles in terms of slots is called pole pitch

A double layer　　B Full pitch coil

C. Coil Span or coil pitch　　D Pole Pitch

5._____Whenoneormoreturnsareconnectedinseriesandplacedinalmostsimilarmagneticpositions

A. coil　　B. double layer

C. Full pitch coil　　D. Coil Span or coil pitch

***Note:* Satisfactory rating - 2 points**　　**Unsatisfactory - below 2 points**

Score = ____________

Rating: _____________

Name: ______________________________　　Date: _______________

Information Sheet – 4	Check and identify readings of electrical measuring instruments and refer defective instruments or calibration/replacement

4.1. Introduction

The measurement of an amount is based on some international standards which are completely accurate compared with others. Generally, measurement of any quantity is done by comparing it with derived standards with which they are not completely accurate. Thus, the errors in measurement are not only due to error in methods, but are also due to derivation being not done perfectly well. So, 100% measurement error is not possible with any methods.

It is very important for the operator to take proper care of the experiment while performing on industrial instruments so that the error in measurement can be reduced. Some of the errors are constant in nature due to the unknown reasons, some will be random in nature, and the other will be due to gross blunder on the part of the experimenter.

4.2. Errors in Measurement System

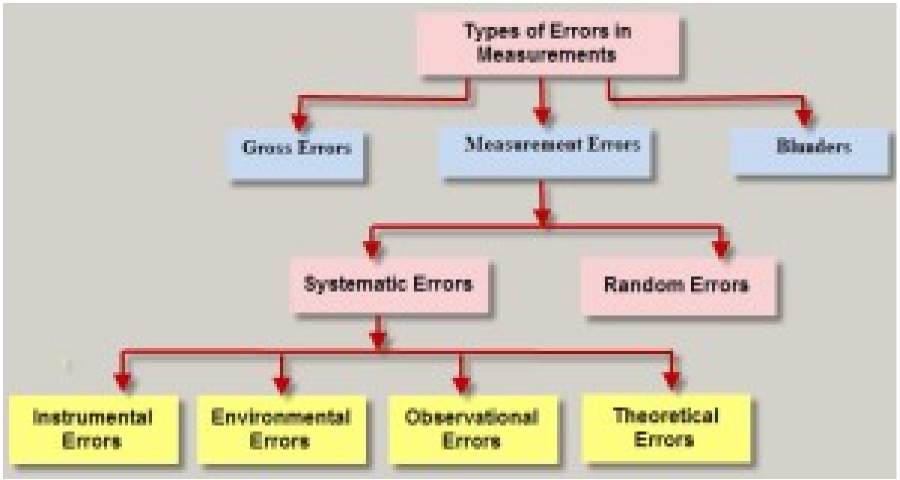
An error may be defined as the difference between the measured value and the actual value. For example, if the two operators use the same device or instrument for finding the errors in measurement, it is not necessary that they may get similar results. There may be a difference between both measurements. The difference that occurs between both the measurements is referred to as an ERROR.

Sequentially, to understand the concept of errors in measurement, you should know the two terms that define the error. They are true value and the measured value. The true value is impossible to find out the truth of quantity by experimental means. It may be defined as the average value of an infinite number of measured values. Measured value can be defined as the estimated value of true value that can be found by taking several measured values during an experiment.

4.3. Types of Errors in Measurement System

Generally errors are classified into three types:

1. Gross Errors
2. Systematic Errors
3. Random Errors



1. Gross Errors in Electrical Measuring Instruments:

This class of errors mainly covers human mistakes in reading measuring instruments and recording and calculating measurement results. The responsibility of the mistake normally lies with the experimenter. The experimenter may grossly misread the scale. For example, he may, due to an oversight, read the temperature as 31.5°C while the actual reading may be 21.5°C. He may transpose the reading while recording.

For example, he may read 25.8°C and record 28.5`C instead. But as long as human beings are involved, some gross errors will definitely be committed. Although complete elimination of gross errors is probably impossible, one should try to anticipate and correct them. Some **gross errors** are easily detected while others may be very difficult to detect.

- Gross errors may be of any amount and therefore their mathematical analysis is impossible. However, they can be avoided by adopting two means. They are :
  - ✓ Great care should be taken in reading and recording the data.
  - ✓ Two, three or even more readings should be taken for the quantity under measurement.

These readings should be taken preferably by different experimenters and the readings should be taken at a different reading point to avoid re-reading with the same error. It should be understood that no reliance be placed on a single reading. It is always advisable to take a large number of readings as a close agreement between readings assures that no gross error has been committed.

2. Systematic Errors in electrical measuring instruments:

These types of errors are divided into three categories

- ✓ Instrumental Errors
- ✓ Environmental Errors
- ✓ Observational Errors
- ✓ Instrumental Errors

These errors arise due to three main reasons:

(a) Due to inherent shortcomings in the instrument

(b) Due to misuse of the instruments

(c) Due to loading effects of instruments

(a) Inherent shortcomings of instruments:

These errors are inherent in instruments because of their mechanical structure. They may be due to construction, calibration or operation of the instruments or electrical measuring devices. These errors may cause the instrument to read too low or too high. For example, if the spring (used for producing controlling torque) of a **permanent magnet instrument** has become weak, the instrument will always read high. Errors may be caused because of friction, hysteresis or even gear backlash.

While making precision measurements, we must recognize the possibility of such errors as it is often possible to eliminate them, or at least reduce them to a great extent by using the following methods :

(i) The procedure of measurement must be carefully planned. Substitution methods or calibration against standards may be used for the purpose.

(ii) Correction factors should be applied after determining the instrumental errors.

(iii) The instrument may be re-calibrated carefully.

(b) Misuse of instruments:

There is an old saying that instruments are better than the people who use them. Too often, the **types of errors** caused in measurements are due to the fault of the operator than that of the instrument.

A good electrical measuring instrument used in an unintelligent way may give erroneous results. Examples which may be cited for this misuse of the instrument may be a failure to adjust the zero of instruments, poor initial adjustments, using leads of too high a resistance etc.

No doubt the above improper practices may not cause a permanent damage to the instrument but all the same, they cause errors. However, there are certain ill practices like using the instrument contrary to manufacturer's instructions and specifications which in addition to producing errors cause permanent damage to the instruments as a result of overloading and overheating that may ultimately result in failure of the electrical measuring instrument and sometimes the system itself.

(C) Loading effects:

One of the most common errors committed by beginners is the improper use of an instrument for measurement work. For example, a well calibrated voltmeter may give a misleading voltage reading when connected across a high resistance circuit. The same voltmeter, when connected in a low resistance circuit, may give a more dependable reading. These examples illustrate that the voltmeter has a loading effect on the circuit, altering the actual circuit conditions by the measurement process.

Therefore errors caused by loading effects of the meters can be avoided by using them intelligently. For example, when measuring a low resistance by ammeter-voltmeter method a voltmeter having a very high value of resistance should be used. In planning any measurement, the loading effect of instruments should be considered and corrections for these effects should be made, if needed, or more suitable **electrical measuring instruments** should be used. Preferably those methods should be used which result in negligible or no loading effects. Static and Dynamic Characteristics of Electrical Measuring Instruments

(ii) Environmental Errors:

These **errors in electrical measuring instruments** are due to conditions external to the measuring device including conditions in the area surrounding the instrument. These may be effects of temperature pressure, humidity, dust, vibrations or of external magnetic or electrostatic fields. The corrective measures employed to eliminate or to reduce these undesirable effects are:

- Arrangements should be made to keep the conditions as nearly as constant as possible. For example, the temperature can be kept constant by keeping the equipment in a temperature controlled enclosure.
- Using equipment which is immune to these effects. For example, variations in resistance with temperature can be minimized by using resistance materials which have a very low resistance temperature coefficient.
- Employing techniques which eliminate the effects of these disturbances. For example, the effect of humidity dust etc. can be entirely eliminated by hermetically sealing the equipment.
- In case it is suspected that external magnetic or electrostatic fields can affect the readings of the electrical measuring instruments, magnetic or electrostatic shields may be provided.
- Applying computed corrections: Efforts are normally made to avoid the use of application of computed corrections, but where these corrections are needed and are necessary, they are incorporated for the computations of the results.

(iii) Observational errors:

There are many sources of observational errors. As an example, the pointer of a voltmeter rests slightly above the surface of the scale. Thus an error on account of PARALLAX will be incurred unless the line of vision of the observer is exactly above the pointer. To minimise parallax errors, highly accurate meters are provided with mirrored scales, as shown in the figure 'errors due to parallax'.

When the pointer's image appears hidden by the pointer, observer's eye is directly in line with the pointer. Although a mirrored scale minimizes parallax error, an error is necessarily present though it may be very small. Since the parallax errors arise on account of the pointer and the scale not being in the same plane, we can eliminate this error by having the pointer and the scale in the same plane as shown in figure arrangements showing scale and pointer in the same plane'.

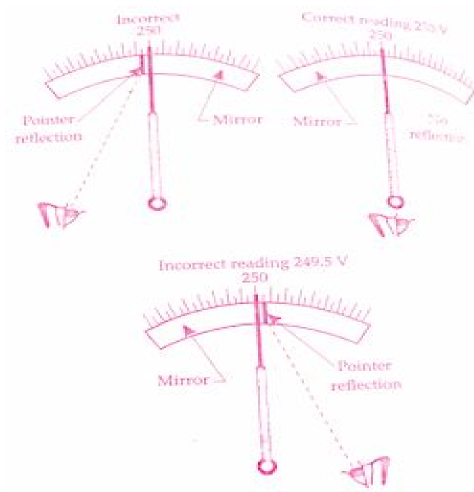


Fig 4.1. Errors due to parallax

There are human factors involved in measurement. The sensing capabilities of individual observers affect the accuracy of measurement. No two persons observe the same situation in exactly the same way where small details are concerned. For example, there are observational errors in measurements involving timing of an event. One observer may tend to anticipate the signal and read too soon.

Different experimenters may produce different results, especially when sound and light measurements are involved since no two observers possess the same physical responses. Modern electrical instruments have a digital display of output which completely eliminates the errors on account of human observational or sensing powers as the output is in the form of digits.

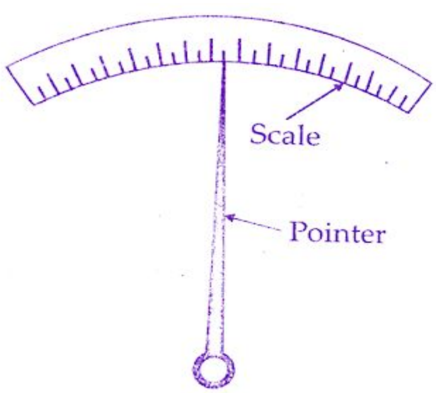


Fig.3.2. Arrangements showing scale and pointer in the same plane

3. Random (Residual) Errors in electrical measuring instruments: :

It has been consistently found that experimental results show variation from one reading to another; even after all systematic errors have been accounted for. These **types of errors in electrical measuring instruments** are due to a multitude of small factors which change or fluctuate from one measurement to another and are due surely to chance. The quantity being measured is affected by many happenings throughout the universe.

We are aware of and account for some of the factors influencing the measurement, but about the rest we are unaware. The happenings or disturbances about which we are unaware are lumped together and called "Random" or "Residual". Hence the errors caused by these happenings are called ***Random (or Residual) Errors***. Since these type of errors remain even after the systematic errors have been taken care of, we call these errors as ***Residual (Random) Errors***.

Self-Check -4	Written Test

Directions: Choose the best answer

1. An error may be defined as the difference between the measured value and the actual
2. Different experimenters may produce the same results
3. Great care should be taken in reading and recording the data

Note: **Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: ___________________________ Date: ______________

Information Sheet –5	Check and tight Connectors, bolts, nuts and screws

5.1. Introduction

A pressurized bolted flange joint assembly begins to leak, creating a safety hazard. A rotor with its blades separates from the nacelle and spins off a wind turbine, crashing to the ground. Under constant vibration from the engine of an ocean freighter, loose bolts on a large piece of mining equipment work their way off the bolted joints and roll around the hull, inflicting further damage to the equipment.

Bolted joints are critical to the safe operation of many types of equipment in a wide range of applications, including power generation, manufacturing, mining, and transportation.

In a bolted joint, tightening the nut actually stretches the bolt a small amount, like pulling on a stiff spring. This stretching, or tension, results in an opposing clamp force that holds the two sections of the joint together. If the bolt comes loose, this clamp force weakens.

Loose bolts are not just an irritating nuisance. If the joint is not quickly retightened, the application may begin to leak fluid or gas, the bolt may break, equipment may become damaged, or catastrophic accidents may occur.

5.2. Causes of Loose Bolts

There are at least five causes of loose bolts, which can occur separately or in combination:

- **Under - tightening.**

By definition, an under-tightened bolt is already loose and the joint does not have enough clamp force to hold the individual sections together. This can lead to sideways slippage between sections, placing unwanted shear stress on the bolt that could eventually cause it to break.

- **Vibration**

Experiments on bolted joints under vibration show that many small “transverse” movements cause the two sections of the joint to move in parallel with each other and with the bolt head or nut. These repeated movements work against the friction between the bolt and joint threads that is holding the joint together. Eventually, vibration will cause the bolt to “unwind” from the mating threads and the joint to lose its clamp force.

- **Embedding**

The design engineers who specify the tension on a bolt allow for a break-in period, during which bolt tightness relaxes to a certain degree. This relaxation is caused by micro-embedding of the bolt head and/or nut into the joint surface, and can occur with both soft materials, such as composites, as well as hard, polished metals. If the joint has not been designed properly, or if the specified tension was not achieved on the bolt at the start, this embedment of the joint can lead to a loss of clamp force.

- **Gasket creep**

Many bolted joints include a thin, flexible gasket between the bolt head and the surface of the joint to seal the joint completely against gas or liquid leaks. The gasket itself acts as a spring, pushing back against the pressure of the bolt and the joint face. Over time, and especially near high heat or corrosive chemicals, the gasket may “creep,” which means it loses its springiness, leading to loss of clamp force. This can also happen if the gasket area directly next the bolt is crushed or if the bolts are not tightened evenly across the entire face of the joint.

- **Differential Thermal Expansion**

If the material of the bolt and the joint are different, large differences in temperature due to rapid environmental changes or cycling industrial processes can cause bolt material to expand or contract rapidly, possibly loosening the bolt.

- **Shock**

Dynamic or alternating loads from machinery, generators, wind turbines, etc., can cause mechanical shock – a sudden force applied to the bolt or the joint – causing the bolt threads to slip relative to the threads of the joint. Just as with vibration, this slippage can ultimately lead to loosening of the bolts.

5.3. Steps to Prevent Loose Bolts

Because loose bolts are so common, an astonishing array of devices has been invented to prevent them from occurring. Here are five basic types of prevention methods:

- **Washers**

Washers are typically wider than the bolt head, with the additional surface area adding extra friction to the joint to maintain the clamp force. However, simple split washers, sometimes called helical spring washers, have been found to actually loosen the bolt under vibration even faster than a joint with no washer. Conical, or Belleville washers, are cup-shaped washers that perform little better than spring washers in vibration tests.
Several types of locking washers have been developed, with flutings, ribs or teeth that dig into the surface of the joint during the tightening process, in order to prevent loosening. This may cause permanent damage to the joint finish or surface, which may be unacceptable, such as in critical aerospace applications where surface indentations may cause fatigue stresses. It may also prevent re-tightening of the joint to the proper tension.

Wedge-locking washers work in sets of two, with each washer having opposite facing wedges that interact with each other and with the joint and nut surfaces to prevent self-turning of the bolt. The wedges are designed to add tension (stretch) to the bolted joint if the bolt begins turning due to vibration or shock, preventing a loss of clamp force.

- **Mechanical devices**

Numerous clever gimmicks have been developed to lock a tightened nut into place on a bolted joint. Castellated nuts have a slotted end and are used with a cotter pin or wire that fits through a hole drilled in the bolt. Locking fastener systems have a shaped flat retainer, similar to a washer, and a clip that fits into a groove on the bolt head. Tab washers have two tabs on opposite sides, which fold up to secure the bolt head or nut after installation, and may have teeth that can penetrate the surface of the joint to hold it in place. While these devices do prevent the nut from falling off the bolt, they generally do not help the joint maintain the specified clamp force.

- **Prevailing torque nuts**

Nylon or metal inserts inside a nut (sometimes called a “lock nut”) can add extra friction to prevent loosening. A related idea is to fit a spring inside the nut, which firmly grasps the bolt threads and is designed to move in the opposite direction of the nut if vibration or other forces cause it to unwind. Nylon inserts cannot be used in harsh chemical or high-heat applications, and typically can’t be reused because the bolt threads cut grooves into the nylon, diminishing its ability to hold after re-tightening. Because the insert on most lock nut styles only covers part of the internal threads, a strong transverse motion or shock can still cause the bolt to self-loosen.

- **Double nuts**

According to an article in Fastener + Fixing, the idea of using two nuts, a thick one and a thinner one (called a jammer nut), has been used for over 150 years to prevent loosening of bolted joints. A modern application is a system using two nuts each having different sized threads which advance at different rates on a dual-threaded bolt. In this way, transverse motions that may cause one nut to advance will not affect the second nut.

- **Adhesives**

Liquid adhesives, as well as heated thermoplastic coatings or solid adhesive patches, have successfully been used to ensure bolts in certain applications do not come loose. The problem is that they make it harder to disassemble the joint later.

Self-Check -5	Written Test

Directions: Choose the best answer

1. Nylon or metal inserts inside a nut (sometimes called a "lock nut") can add extra friction to prevent loosening.
2. Washers are typically wider than the bolt head, with the additional surface area adding extra friction to the joint to maintain the clamp force.
3. Loose bolts are just an irritating nuisance.

Note: **Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: ______________

Information Sheet :6	Conduct regular routine/visual/sensory inspection

6.1. Visual Inspection

A regular visual inspection should be carried out in all electrical installations. A visual inspection of this type does not necessarily need to be carried out by an electrician, but it should reveal any areas which are obviously in need of attention.

A visual inspection should look for:

- Breakages
- Wear & deterioration
- Signs of over heating
- Missing parts (covers, screws) and
- Loose fixings and confirm
- Switchgear accessibility (no obstructions) and
- Doors of enclosures are secure It should also check the operation of
- Equipment – switch on & off where equipment is not in regular use or where it is left off or on standby for long periods and
- Residual current devices using test button.(It is recommended that, independent of any other inspection and test regime, residual current devices undergo a push-button test at least twice per year to ensure that they operate correctly when needed).

These routine checks need not to be carried out by an electrically skilled person but should be done by someone who is able to safely use the installation and recognize any obvious defects.

Self-Check -6	Written Test

Directions: Choose the best answer

1. A regular visual inspection should be carried out in all electrical installations
2. Residual current devices using test button.(It is recommended that, independent of any other inspection and test regime

Note: **Satisfactory rating - 1 points** **Unsatisfactory - below 1 points**

Score = ___________

Rating: ____________

Name: ___________________________ Date: ______________

Operation Sheet-1	Rewinding stator coils of single phase AC motor

Procedure:

1 Note down the name plate data before dismantling the motor.

2 Dismantle the motor after making the end-plates with punch marks.

3 Note down the coil data before stripping off the damaged winding.

4 Strip off the damaged coils

5 Prepare a winding diagram.

6 Clean the stator's slot and remove the burnt insulation.

7 Record the data of the coils, both running and starting winding.

8 Record the data of the turns in each coils group.

9 Line the slots with the required type and size of insulating materials.

10 Make the former as per the dimensions of the removed coil.

11 Wind one test coil on the former, insert it in the slot and check its dimension.

12 Change the former, if necessary, and wind the coils.

13 Recheck for untapped joint, sleeves etc. before closing the end plates and reassemble the motor.

14 Test the motor for insulation resistance.

15 Have a trial run on load and note the parameters e.g. intake current, speed, temperature rise, etc.

16 If the trial is successful, dismantle the motor and impregnate with proper insulating varnish.

17 Heat the motor in oven with a controlled temperature 80- 100·C for 10 to 12 hours.

18 Clean the stator by removing the excessive deposits of varnish on the cores.

19 Reassemble the motor and have a trial run on load and no-load.

Operation Sheet-2	Rewinding stator coils of three phase AC motor

1 Note down the name plate data before dismantling the motor.

2 Dismantle the motor after making the end-plates with punch marks.

3 Note down the coil data before stripping off the damaged winding.

4 Strip off the damaged coils

5 Prepare a winding diagram.

6 Clean the stator's slot and remove the burnt insulation.

7 Record the data of the coils

8 Record the data of the turns in each coils group.

9 Line the slots with the required type and size of insulating materials.

10 Make the former as per the dimensions of the removed coil.

11 Wind one test coil on the former, insert it in the slot and check its dimension.

12 Change the former, if necessary, and wind the coils.

13 Recheck for untapped joint, sleeves etc. before closing the end plates and reassemble the motor.

14 Test the motor for insulation resistance.

15 Have a trial run on load and note the parameters e.g. intake current, speed, temperature rise, etc.

16 If the trial is successful, dismantle the motor and impregnate with proper insulating varnish.

17 Heat the motor in oven with a controlled temperature 80- 100·C for 10 to 12 hours.

18 Clean the stator by removing the excessive deposits of varnish on the cores.

19 Reassemble the motor and have a trial run on load and no-load.

LAP Test	Practical Demonstration

Task 1. Develop a single phase, single layer AC lap winding for a 4 pole AC machine having 24 slots.

Task 2. Develop a single phase, single layer AC lap winding for a 4 pole AC machine having 48 slots.

Task 3. Develop and draw ***(a)*** half coil and ***(b)*** whole coil single layer concentric windings for a 3-phase machine with 24-slots, 4-poles and 60^{o} phase spread.

List of Reference Materials

1. A. Bellini, F. Filippetti, C. Tassoni, G. A. Capolino, "Advances in diagnostic techniques for induction motors", *IEEE Trans. Energy Convers.*, vol. 55, no. 12, pp. 4109-4126, Dec. 2008.

2. M. J. Devaney, L. Eren, "Detecting motor bearing faults", *IEEE Instrum. Meas. Mag.*, vol. 7, no. 4, pp. 30-50, Dec. 2004.

3. J. Faiz, B. M. Ebrahimi, "Mixed fault diagnosis in three-phase squirrel-cage induction motor using analysis of airgap magnetic field", *in Proc. Prog. Electro-Magn. Res. Symp.*, pp. 239-355, 2006.

4. M. E. H. Benbouzid, "A review of induction motors signature analysis as a medium of faults detection", *IEEE Trans. Ind. Electron.*, vol. 47, no. 5, pp. 984-993, Oct. 2000.

5. Eectric Machinery, 6e, Fitzgerald.

6. Principles of electrical machines(mehta)

7. Theraja

The trainers (who developed the Learning Guide)

No	Trainer Name	Education back graund	Region
1	SERKABEBA ABERA	MSC	DEBUB
2	MULU DAMANE	MSC	ADDIAABEBA
3	ABERA GEBRE	BSC	DIRADAWA
4	ESUBALEW AMSALU	MSC	HARER
5	MERON HUSEN	BSC	HARER
6	SHIMELS CHEKOLE	BSC	AMHARA
7	FISIHA BIREHANU	MSC	AMHARA
8	YIMER SEID	MSC	AFAR
9	HINDA IBRAHIM	BSC	SOMALI
10	TADDELE GASHAW	MSC	SOMALI