PART – A

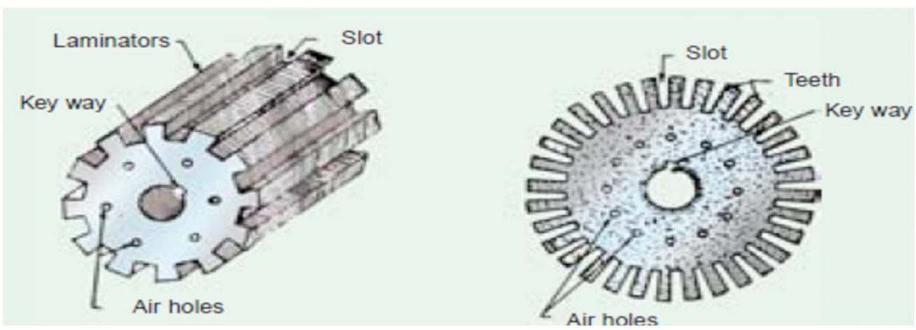
MODULE I : WINDING DIAGRAMS

Basic Terminologies :

Armature : Armature winding can be defined as an array of conductors or a number of coils placed in slots and connected in series where the desired magnitude of emf is generated and is a source of electrical energy.

Coil :

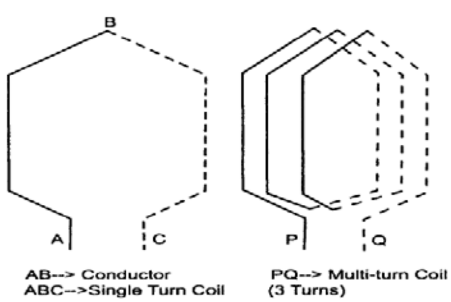
- A certain length of wire of conducting material wound for a desired shape and size to satisfy the electrical and mechanical requirements is called an armature coil.
- A length of wire lying in the magnetic field and in which an emf is induced is called a coil.



Conductor: Active length of winding wire or strip in a slot.

Turn: A turn consists of two conductors placed inside separate slots on the armature periphery approximately a pole pitch apart as shown in Fig.

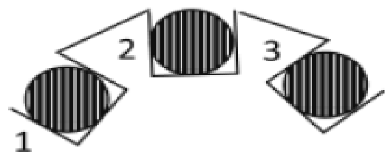
These conductors lie under opposite poles so that emf induced in the turn is additive.



Single Layer Winding :

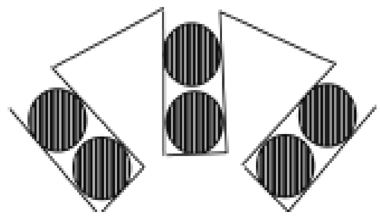
- There will be only one coil side in the slot having any number of conductors.

- The number of coils in the machine is equal to half the number of slots in the stator, or rotor and armature.



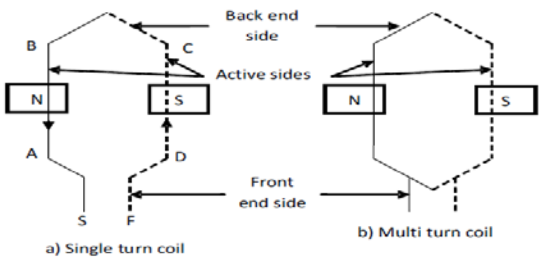
Double Layer Winding :

- In this type, as shown in Fig. each slot contains two coil sides, housed one over the other.
- The number of coils is equal to the number of slots in the stator and armature.



Active Portion Of The Coil :

- It is the part of a coil which lies in the slots under a magnetic pole and emf is induced in this part only.
- A Coil has 2 coil sides and are the active potion of the coil.
- Each length of wire of the active portion is called a conductor and is responsible in generating an emf in a generator and is producing a torque in a motor.



- For a double layer winding, one half portion of the coil drawn with solid line corresponds to the coil side lying on the top of a slot, and the dotted line corresponds to the coil side lying in the bottom layer of another slot.
- This type of representation is used for double layer winding.
- For a single layer winding, the complete coil is represented by a solid line.

Lap Winding :

- When the finishing end of the first coil is connected to the starting end of the next coil which starts from the same pole, as shown in Fig.
- Where the first coil started is called as lap winding

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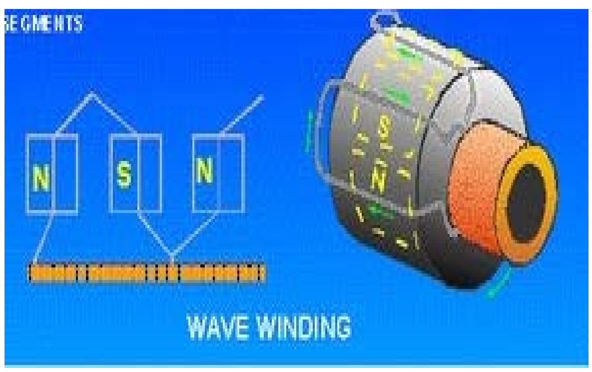
- Where the first coil started is called as lap winding.

Wave Winding :

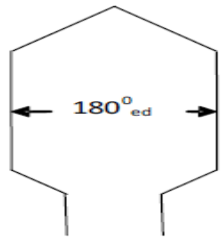
- The Fig. shows a wave winding on a drum-type armature.
- This type of winding is used in dc generators employed in high-voltage applications.
- This configuration allows the series addition of the voltages in all the windings between brushes.



- When the finishing end of the first coil is connected to the starting end of the next coil, as shown in Fig. which starts from the next adjacent pole where the first coil started is known as wave winding.

Full pitch coil :

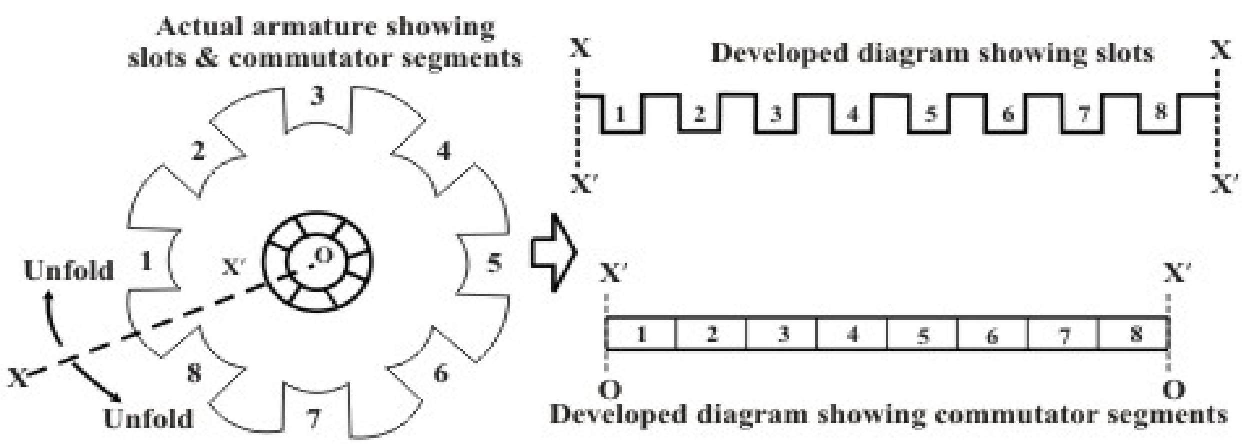
- **A coil having a coil span equal to 180 degrees electrical** is called a full pitch coil, as shown in Fig.



A coil having a coil span less than 180 deg by an angle â, is called a short pitch.

Developed Diagram :

- Instead of dealing with circular disposition of the slots and the commutator segments, it is always advantageous to work with the developed diagram of the armature slots and the commutator segments (sequence diagram)as elaborated in Fig.
- In the Fig. actual armature with 8 slots and 8 commutator segments are shown.



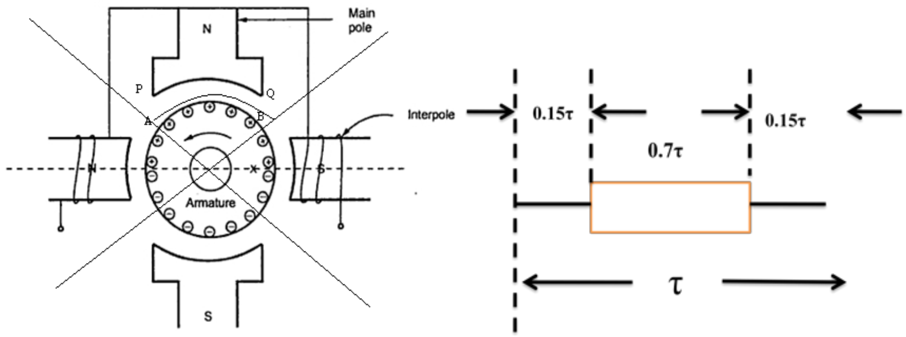
Pole Pitch, Pole Arc And Pole Fixing On A Developed Winding Diagram :

- The distance corresponding to a pole is called the **pole pitch (τ).**
- The actual distance covered by the pole or pole shoe is called the **pole arc**.

  - (generally the pole arc lies between 60 and 70 percent of the pole pitch)

  - Let the pole arc be **70 %** of the pole pitch.
  - The circumference of the armature is **πd**.

- Where d is the diameter of the armature or 360^0 Mech.
- However the distance between the first and last conductor + the distance between the 2 conductors considered to draw the developed winding diagram can be taken as the circumference of the armature.



Brush Width :

- Minimum brush width = one segment width for simplex lap or wave winding
  = two segment width for duplex lap or wave winding
  = three segment width for triplex lap or wave winding

Following points regarding simplex lap winding should be carefully noted :

a) The back and front pitches are odd and of opposite sign. But they cannot be equal. They differ by 2 or.

b) Resultant pitch YR is even, YR =YB – YF=2.

c) The number of slots for a 2-layer winding is equal to the number of coils.

The number of commutator segments is also the same.

d) The number of parallel paths in the armature (A)=P

where P the number of poles.

e) If YB > YF i.e. YB = YF + 2, then we get a progressive or right-handed winding

i.e. a winding which progresses in the clockwise direction as seen from the commutator end. In this case, YC = + 1.

f) If YB < YF i.e. YB = YF - 2, then we get a retrogressive or left-handed winding i.e. one which advances in the anti-clockwise direction when seen from the commutator side. In this case, YC = -1.

Z/P must be even to make the winding possible.

h) The total number of brushes is equal to the number of poles.

i) The number of armature conductors (connected in series) in any parallel path is Z/P.

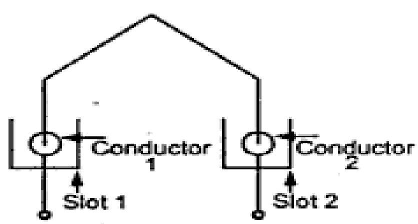
Introduction To Ac Windings :

- Armature winding of alternators is different form that of d.c machines. Basically three phase alternators carry three sets of windings arranged in the slots in such as way that there exists a phase difference of 120 deg between the induced emf's in them.
- In a d.c machine, winding is closed while in alternators winding is open i.e., two ends of each set of winding is brought out.
- In three phase alternators, the six terminals are brought out which are finally connected in star or delta and then the three terminals are brought out.
- Each set of windings represent winding per phase and induced e.m.f, each set is called induced e.m.f per phase denoted as Eph.
- All the coils used for one phase must be connected in such a way that their e.m.f.s help each other.

Winding Terminology :

1. **Conductor:** The part of the wire, which is under the influence of the magnetic field and responsible for the induced e.m.f is called active length of the conductor. The conductor are placed in the armature slots.

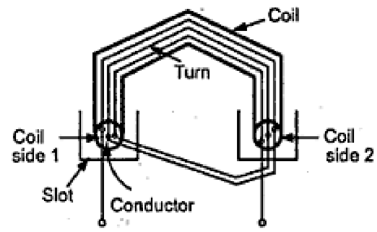
2. **Turn:** A conductor in one slot, when connected to a conductor in another slot forms a turn. So two conductors constitute a turn. This is shown in Fig. below



3. **Coil:** As there are number of turns, for simplicity the number of turns are grouped together to form a coil.

Such a coil is called multi-turn coil. A coil may consist of single turn called single turn coil. The Fig. 2 shows a multi-turn coil.

4.**Coil Side:** Coil consists of many turns. Part of the coil in each slot is called coil side as shown in the Fig. below



5. **Pole Pitch**: It is centre to centre distance between the two adjacent poles. We have seen that for one rotation of the conductors, 2 poles are responsible for 360^0 electrical of e.m.f., 4 poles are responsible for 720^0 electrical of e.m.f and so on. So 1 pole is responsible for 180^0 electrical of induced e.m.f

Key point: so 180^0 electrical is also called one pole pitch.

Practically how many slots are under one pole which are responsible for 180^0 electrical, are measured to specify the pole pitch.

e.g. Consider 2 pole, 18 slots armature of an alternator. Then under 1 pole there are 18/2 i.e. 9 slots. So pole pitch is 9 slots or 180^0 electrical.

This means 9 slots are responsible to produce a phase difference of 180^0 between the e.m.f.s induced in different conductors.

This number of slots/pole is denoted a ‘n’.

Pole pitch = 180^0 electrical

= slots per pole (no. of slots/P) = n

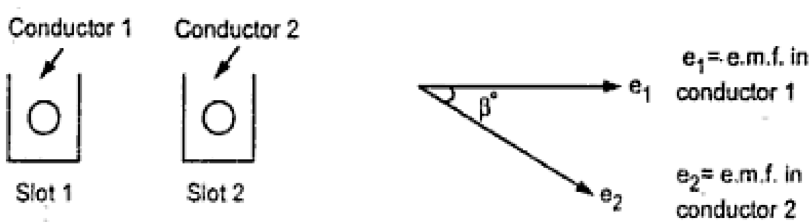
6.Slot angle (β): The phase difference contributed by one slot in degrees electrical is called slot angle β.

As slots per pole contributes 180^0 electrical which is denoted as 'n', we can write,

1 slot angle = $\frac{180\ deg}{n}$

In the above example, n = $\frac{18}{2}$ while β = $\frac{180\ deg}{n}$ = 20 deg

Note: This means that if we consider an induced e.m.f in the conductors which are placed in the slots which are adjacent to each other, there will exist a phase difference of β^0 in between them.



(a) Adjacent slots (b) Indication of phase difference

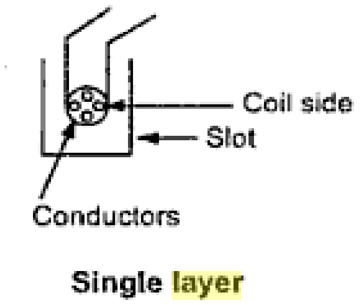
- In general armature winding is calssified as,

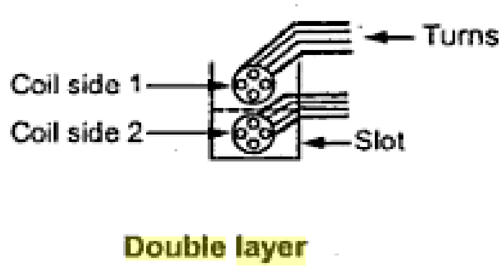
i. Single layer and double layer winding

ii. Full pitch and short pitch winding

iii. Concentrated and distributed winding.

If a slot consists of only one coil side, winding is said to be single layer. This is shown in the Fig. 3. While there are two coil sides per slot, one at the bottom and one at the top the winding is called double layer as shown in the Fig. 4.





Full Pitch Winding :

As seen earlier, one pole pitch is 180^0 electrical. The value of 'n', slots per pole indicates how many slots are contributing $180^{\ 0}$ electrical phase difference.

So if coil side in one slot is connected to a coil side in another slot which is one pole pitch distance away from first slot, the winding is said to be **full pitch winding** and coil is called **full pitch coil.**

For example in 2 pole, 18 slots alternator, the pole pitch is n = 18/2 = 9 slots.

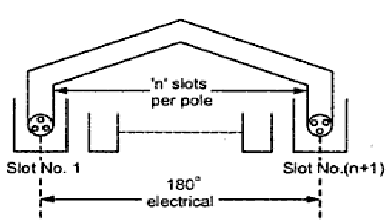
So if coil side in slot No.1 is connected to coil side in slot No. 10 such that two slots No.1 and No. 10 are one pole pitch or n slots or 180^0 electrical apart, the coil is called full pitch coil.

Coil Span :

It is the distance on the periphery of the armature between two coil sides of a coil.

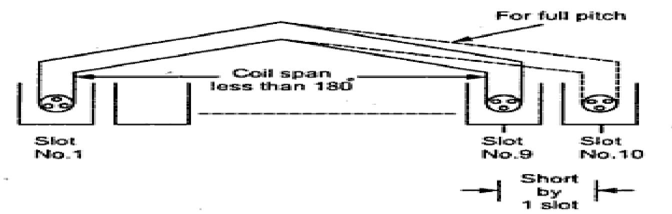
It is usually expressed in terms of number of slots or degrees electrical.

So if coil span is 'n' slots or 180^0 electrical the coil is called full pitch coil. This is shown in the Fig.5



Short Pitch Winding :

- As against this if coils are used in such a way that coil span is slightly less than a pole pitch i.e., less than 180^0 electrical, the coils are called, short pitched coils or fractional pitched coils.
- Generally coils are shorted by one or two slots.



. So in 18 slots, 2 pole alternator instead of connecting a coil side in slot No.1 to slot No.10, it is connected to a coil side in slot No.9 or slot No.8, coil is said to be short pitched coil and winding is called short pitch winding.

Types of double layer winding :

A double layer winding can be of integral or fractional slot type. Further a double layer winding can be lap or wave.

Integral Slot Winding: In an integral slot winding the number of slots/pole/phase 'm', and slots/pole are integer.

Example: $S = 24$, $P = 4$; 3 phase.

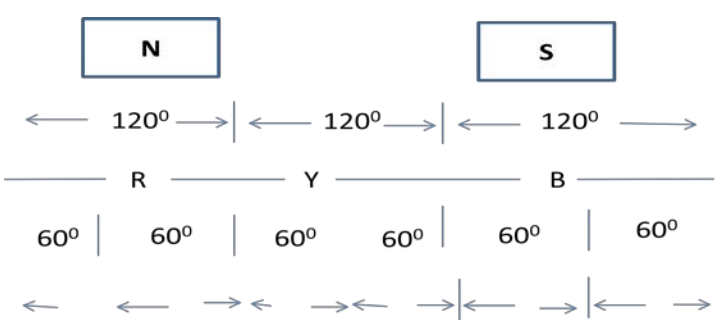
Since. $m = \frac{24}{4*3} = 2$ *and* $s/p = \frac{24}{4} = 6$ are integers, the winding is of integral slot type.

An integral slot winding can be of full or short pitch type.

Fractional slot winding: In an integral slot winding the number of slots/pole/phase 'm', and slots/pole are integer.

i.e., If Slots/Pole/Phase (SPP) is not a whole number (Example: for a 66 slots, 4 pole, 3ph armature, S/P/P = 66/4/3 = 5.5) An fractional slot winding is always short pitch windings.

Phase Spread :



120^0 Phase spread or wide spread winding.

60^0 phase spread or narrow spread winding

In a 120 deg phase spread winding, each phase coils, pole occupies a space equivalent to 120^0 electrical as shown in the Fig.

Thus the space sequence of the phase band or phase winding arrangement sequence is RYB for a phase sequence of RBY.

In a 60^0 phase spread winding, each phase coils occupies a space equivalent to 60^0 under each pole as shown in the Fig.

Thus the space sequence of the phase band or phase winding arrangement sequence is RBY for a phase sequence of RYB.

Between 120^0 and 60^0 phase winding, 60^0 phase spread winding is much used.

As the distribution factor of 60^0 phase spread is greater than 120^0 phase spread.

The minimum value of distribution factor for fundamental is 0.955 for 60^0 phase spread and 0.827 for 120^0 phase spread

Starting of phases :

- To calculate the starting of the phases, consider the phase sequence as reference.
- Angle between R and Y is 120^0, R and B is 240^0
- Let the starting of the R_{phase} be the I slot

Elimination of N^{th} Harmonics :

- ❑ The short pitch winding is more popular compared to full pitch winding as it saves copper at overhang & helps to reduce or eliminate the harmonics.
- ❑ A harmonic is said to be eliminated, i.e., the emf induced due to the harmonics E_n = 4.44 is zero.

K_p = 1 (Full pitch)

K_p 1 (Short pitch)

This happens when the pitch factor of N^{th} Harmonic K_p represents zero.

$$K_{pn} = \cos\frac{n\alpha}{2}$$

$$\frac{n\alpha}{2} = \cos^{-1}(0) = 90^0$$

$$n \propto = 180^0$$

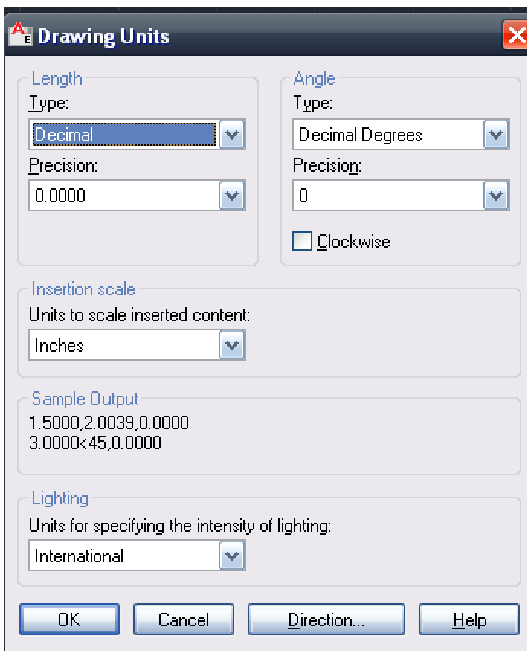
$$\propto = \frac{180^0}{n}$$ where n = No. of harmonics

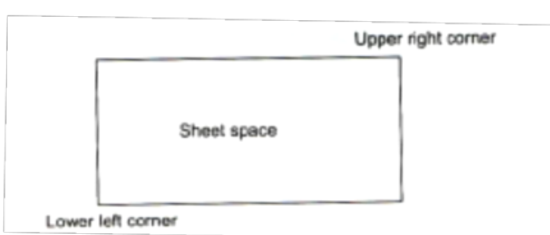
(A) <u>DC Winding Diagrams</u> :

General procedure to draw winding diagrams using CAD : (common to all problems)

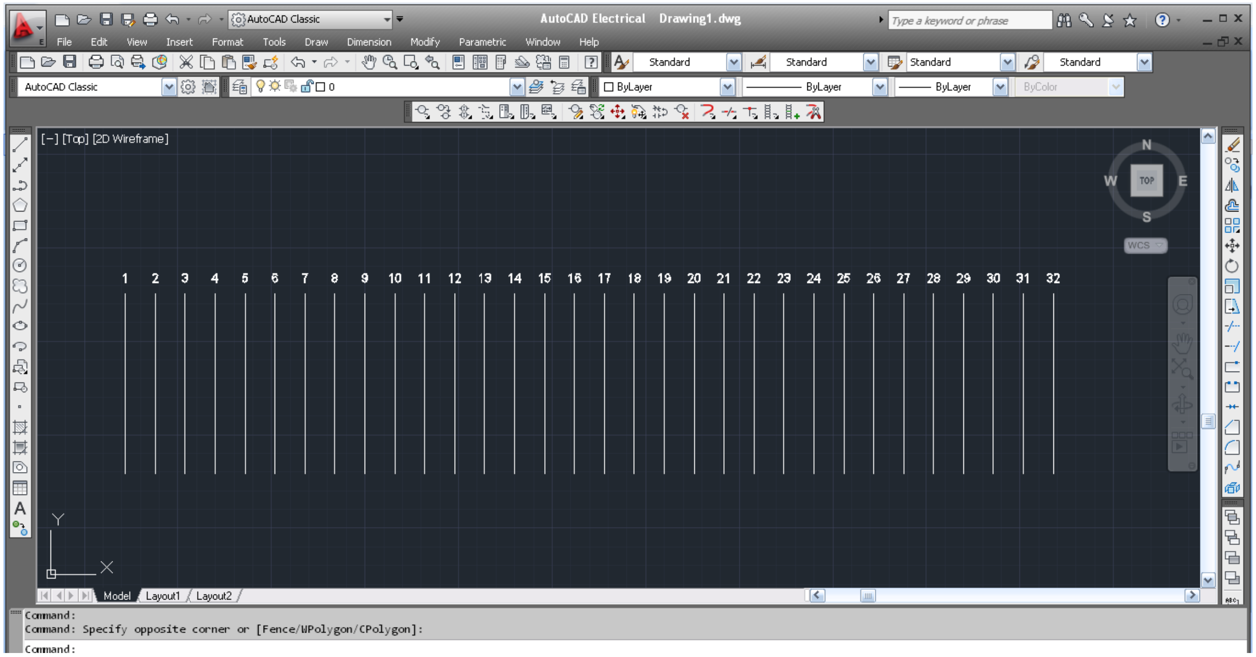
Step 1 : Start AutoCAD . Set drawing units & limits --- Type units in command window to access units & type limits in cw to set limits as shown :

Lower left corner < 0,0 >
Upper right corner < 1500 , 1500 >

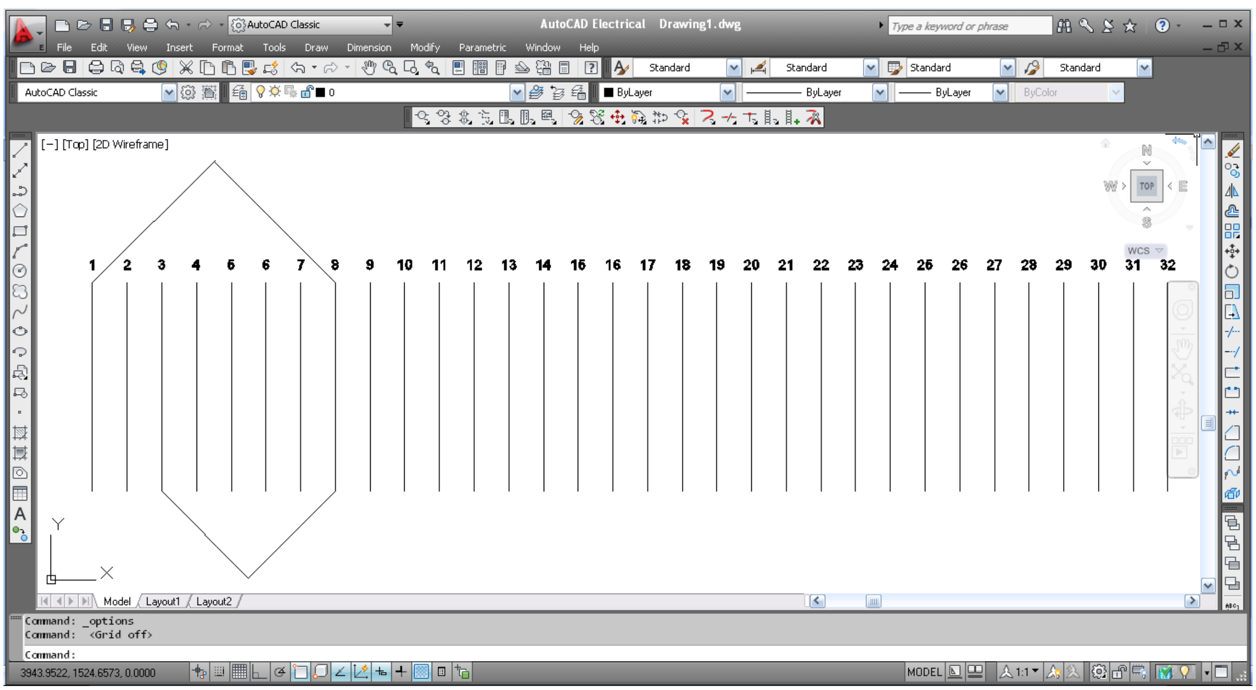




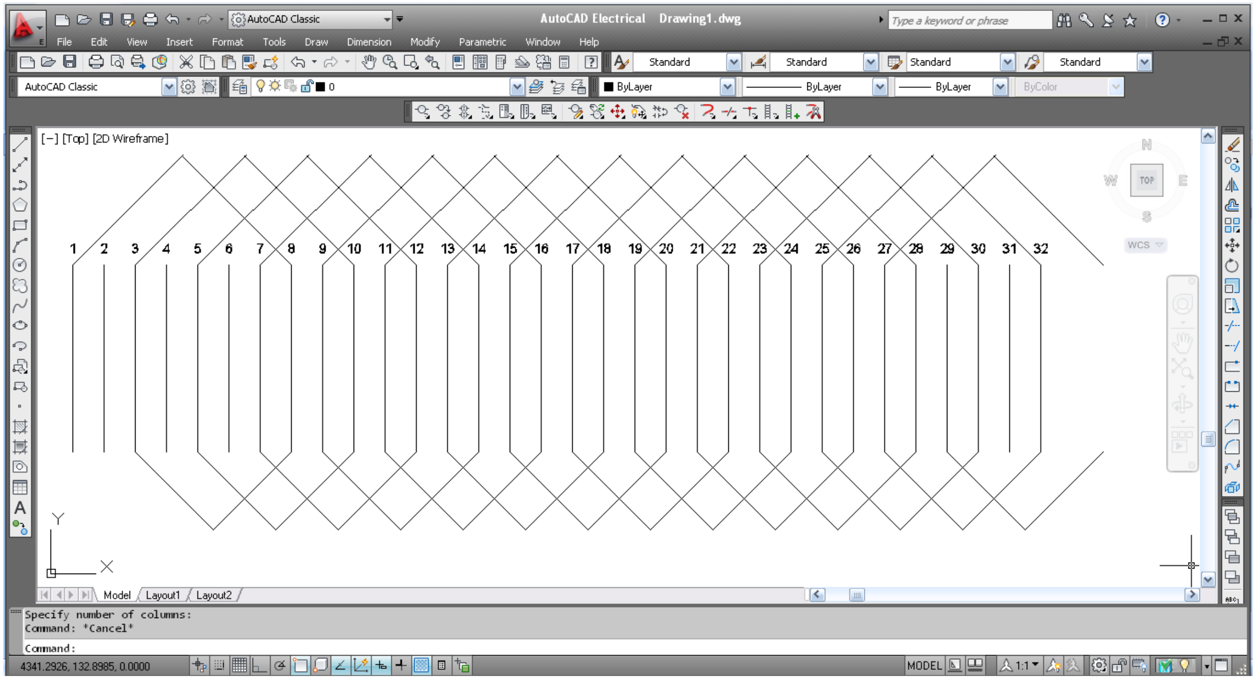
Step 2 : Draw line using line command for required length. Use array command and get the number of lines required (conductors) . Number all the conductors using mtext command.



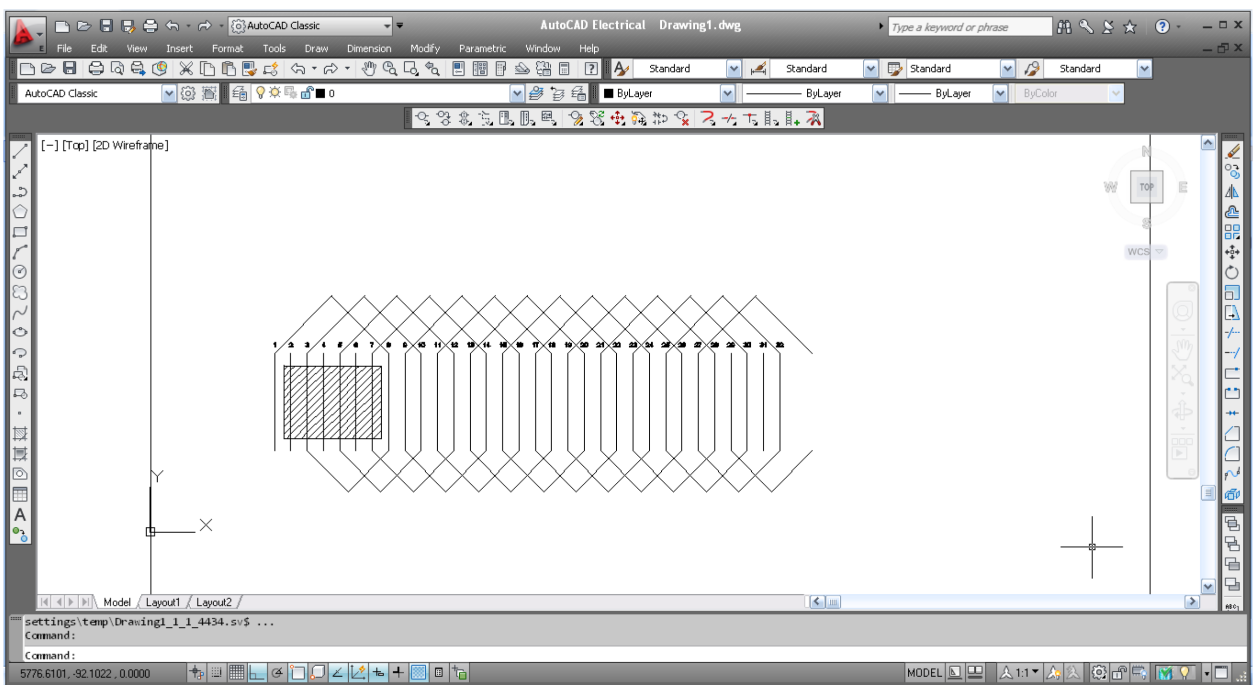
Step 3 : Now , refer winding table & connect the conductors on the front pitch & back pitch By using line command as shown. Use TRIM command if necessary.

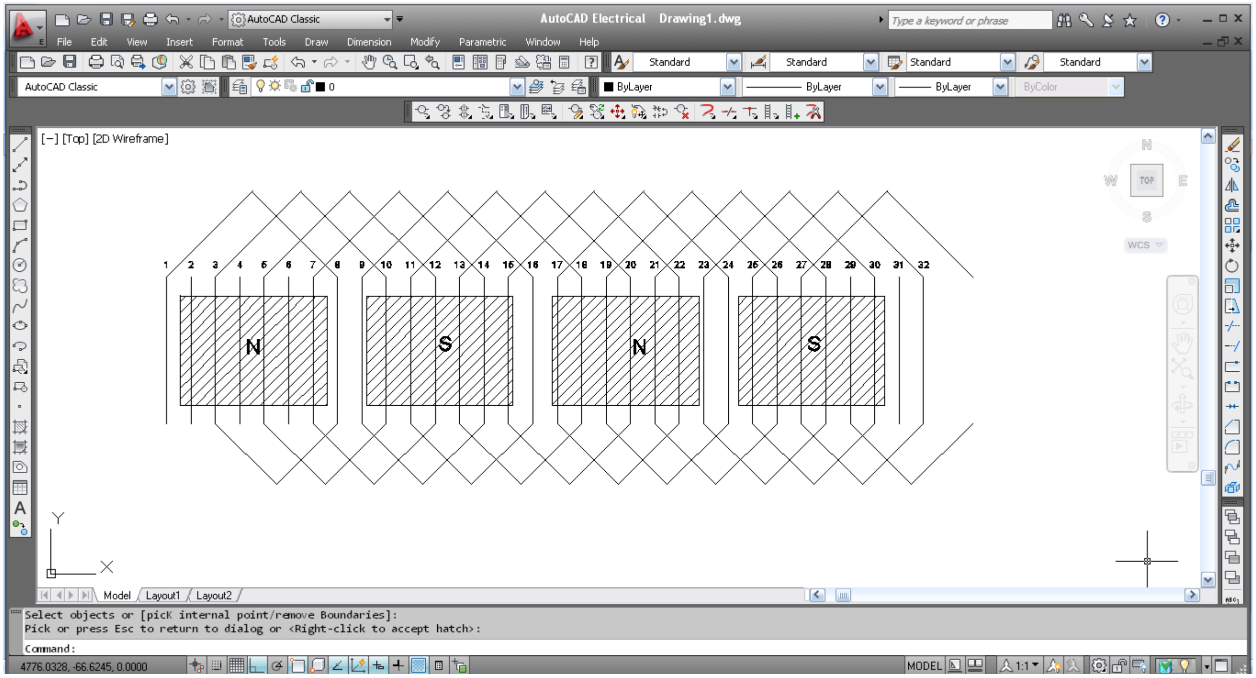


Step 4 : Similarly draw all other end connections as shown :

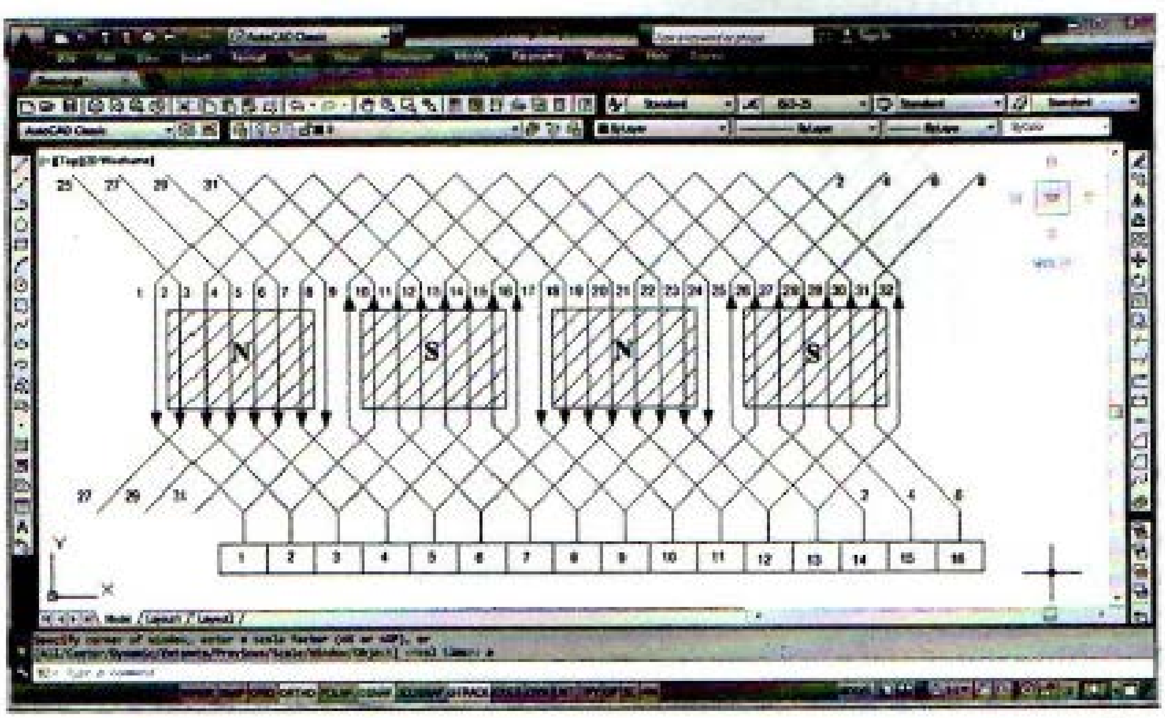


Step 5 : Pole placement : Poles cover 75% of conductor length . Width of pole is 70% of pole pitch .And 30% of pole pitch is the spacing between poles. Hatch poles using hatch command. Mark the poles using text command referring to the details.





Step 6 : Mark the directions referring to the sequence diagram and place the brushes using the basic commands and represent the winding diagram .Finally do the dimensioning.



PROBLEM 1: Develop a single layer lap winding diagram for a DC machine having 32 armature conductors and 4 poles. Mark the poles, draw the sequence diagram, indicate the position of the brushes and show the direction of induced emf.

Solution:

Analyse the problem: This particular problem states us to develop a single layer lap winding diagram for a DC machine having 32 armature conductors and 4 poles. Drawing sequence diagram helps us to analyse the flow of current and also helps to locate the brushes.

Given data:

Number of poles (P) = 4

In single layer, number of conductors (Z) = slots = 32

Step 1: First calculate the pole pitch, front pitch Y_f and back pitch Y_b.

Hence, pole pitch = Z/P = 32/4 = 8

But pole pitch = $(Y_b + Y_f)/2$

Hence, $(Y_b + Y_f)/2 = 8$

$$(Y_b + Y_f) = 16 \qquad \text{(i)}$$

But, $Y_b = Y_f \pm 2m$

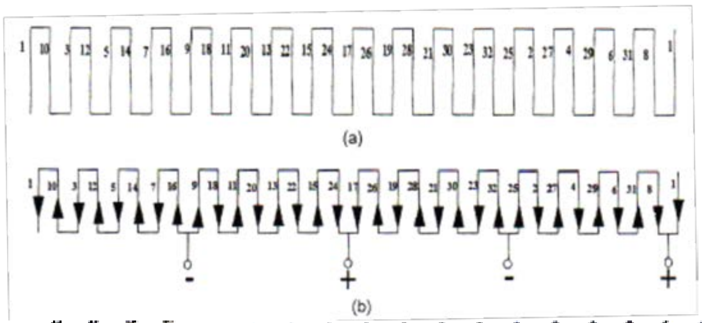
(where, m = 1 for simplex, 2 for duplex and 3 for triplex)

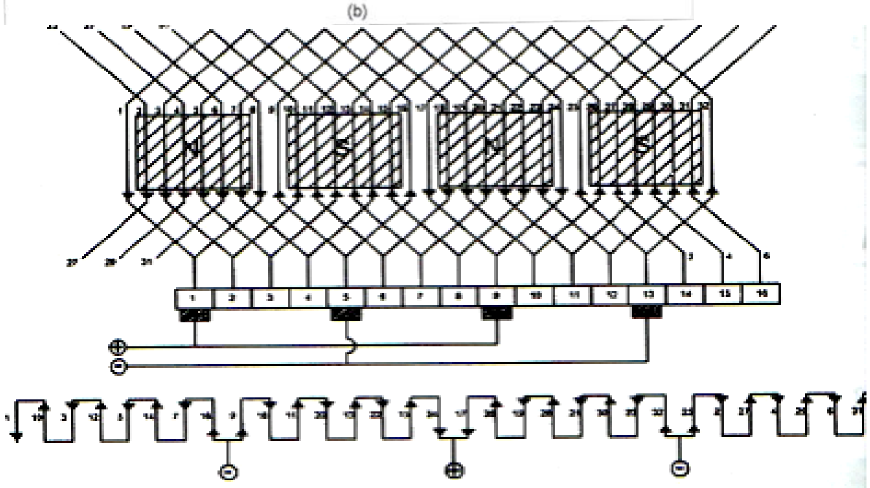
$\boxed{Y_b = 9}$ and $\boxed{Y_f = 7}$

Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 2.1.

TABLE 2.1 Winding Table

At the back $Y_b = 9$	*At the front* $Y_f = 7$	*At the back* $Y_b = 9$	*At the front* $Y_f = 7$
1 + 9 = 10	10 − 7 = 3	17 + 9 = 26	26 − 7 = 19
3 + 9 = 12	12 − 7 = 5	19 + 9 = 28	28 − 7 = 21
5 + 9 = 14	14 − 7 = 7	21 + 9 = 30	30 − 7 = 23
7 + 9 = 16	16 − 7 = 9	23 + 9 = 32	32 − 7 = 25
9 + 9 = 18	18 − 7 = 11	25 + 9 = 34(2)	34 − 7 = 27
11 + 9 = 20	20 − 7 = 13	27 + 9 = 36(4)	36 − 7 = 29
13 + 9 = 22	22 − 7 = 15	29 + 9 = 38(6)	38 − 7 = 31
15 + 9 = 24	24 − 7 = 17	31 + 9 = 40(8)	40 − 7 = 33(1)





PROBLEM 2 : A DC machine as 18 armature slots with 2 conductors per slot and (
Develop a lap winding diagram for the DC machine, mark the poles, draw the sequence d
indicate the position of the brushes and show the direction of induced emf.

Solution:

Analysing the problem: This particular problem states us to develop a double layer lap
diagram for a DC machine having 36 armature conductors and 6 poles. Drawing s
diagram helps us to analyse the flow of current and helps to locate the brushes.

Given data:

Number of poles (P) = 6
Number of armature slots = 18

In double layer number of conductors (Z) = 2 × number of armature slots

$$Z = 2 \times 18 = 36$$

Step 1: First calculate the pole pitch, front pitch Y_f and back pitch Y_b.

Hence, pole pitch = Z/P = 36/6 = 6

But pole pitch = $(Y_b + Y_f)/2$

Hence, $$(Y_b + Y_f)/2 = 6$$

$$(Y_b + Y_f) = 12$$

But $$Y_b = Y_f \pm 2m$$

(where $m = 1$ for simplex, 2 for duplex and 3 for triplex)

$$(Y_b - Y_f) = 2 \quad \text{(ii)}$$

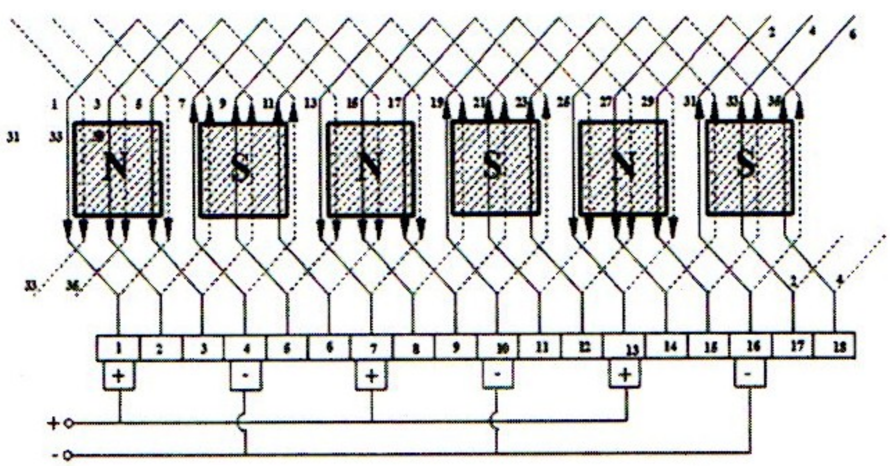
Solving Eq. (i) and (ii), we get

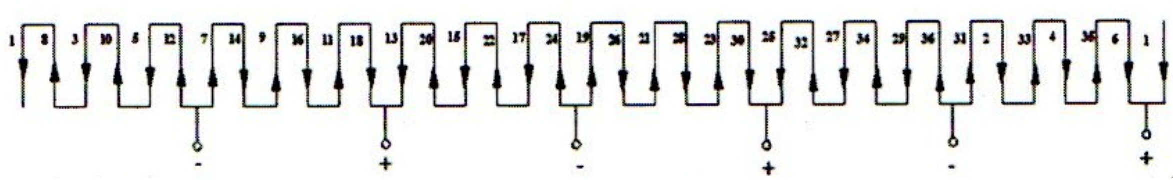
$$\boxed{Y_b = 7} \quad \text{and} \quad \boxed{Y_f = 5}$$

Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 2.2.

TABLE 2.2 Winding table

S. No.	At the back $Y_b = 7$	At the front $Y_f = 5$	S. No.	At the back $Y_b = 7$	At the front $Y_f = 5$
1	1 + 7 = 8	8 − 5 = 3	10	19 + 7 = 26	26 − 5 = 21
2	3 + 7 = 10	10 − 5 = 5	11	21 + 7 = 28	28 − 5 = 23
3	5 + 7 = 12	12 − 5 = 7	12	23 + 7 = 30	30 − 5 = 25
4	7 + 7 = 14	14 − 5 = 9	13	25 + 7 = 32	32 − 5 = 27
5	9 + 7 = 16	16 − 5 = 11	14	27 + 7 = 34	34 − 5 = 29
6	11 + 7 = 18	18 − 5 = 13	15	29 + 7 = 36	36 − 5 = 31
7	13 + 7 = 20	20 − 5 = 15	16	31 + 7 = 38(2)	(2)38 − 5 = 33
8	15 + 7 = 22	22 − 5 = 17	17	33 + 7 = 40(4)	(4)40 − 5 = 35
9	17 + 7 = 24	24 − 5 = 19	18	35 + 7 = 42(6)	(6)42 − 5 = 37(1)





PROBLEM 3 : A DC machine as 28 armature conductors and 4 poles, with one conductor per slot. Develop a progressive simplex lap winding diagram for the DC machine, mark the poles. Also show equaliser ring.

Solution:

Analysing the problem: This particular problem states us to develop a lap winding diagram for a DC machine having 28 armature conductors and 4 poles. Drawing sequence diagram helps us to analyse the flow of current and helps to locate the brushes.

Equalising connection: It is a characteristic of lap winding that all conductors in any parallel path lies under one pair of pole. Each parallel path carries same current when it place exactly under the pole, but due to slight variation in air gap or magnetic property, there is inequalities in flux occurs. Hence, there is always slight imbalance of induced emf in the various parallel paths and also the brushes which carry unequal currents, some brushes will get over loaded. This results in poor commutation and affects the performance of the machine.

In order to overcome the problem of imbalance of induced emf, armature winding must be at equal potential and the difference in brush currents should be diminished. This requires that there should be a whole number of slots per pole pair. For example, if there is a slot under the centre of an N-pole which is connected to the conductor which are in the form of copper rings at the armature back. These rings are called as *equaliser ring*. Hence, the function of equaliser ring is to avoid unequal distribution of the current at the brushes and also helps to get sparkles commutation.

Here, m = number of rings

$$\text{Total number of tapping} = m \times \text{pairs of poles} = \frac{m \times P}{2}$$

$$\text{Distance between adjacent tapping } (T_g) = \frac{\text{Total number of coils}}{\text{Total number of tapping}}$$

Given data:

Number of poles $(P) = 4$

Number of armature slots = number of conductors $(Z) = 28$

Step 1: First calculate the pole pitch, front pitch Y_f and back pitch Y_b.

Hence, pole pitch $= Z/P = 28/4 = 7$

But pole pitch $= (Y_b + Y_f)/2$

Hence,

$$(Y_b + Y_f)/2 = 7$$

$$(Y_b + Y_f) = 14 \quad \text{(i)}$$

$$(Y_b - Y_f) = 2 \quad \text{(ii)}$$

Solving Eqs. (i) and (ii), we get

$$\boxed{Y_b = 8} \quad \text{and} \quad \boxed{Y_f = 6}$$

Here, both Y_b and Y_f are even.

Since, both Y_b and Y_f should be odd for lap winding in this particular problem Y_b and Y_f can be considered as follows:

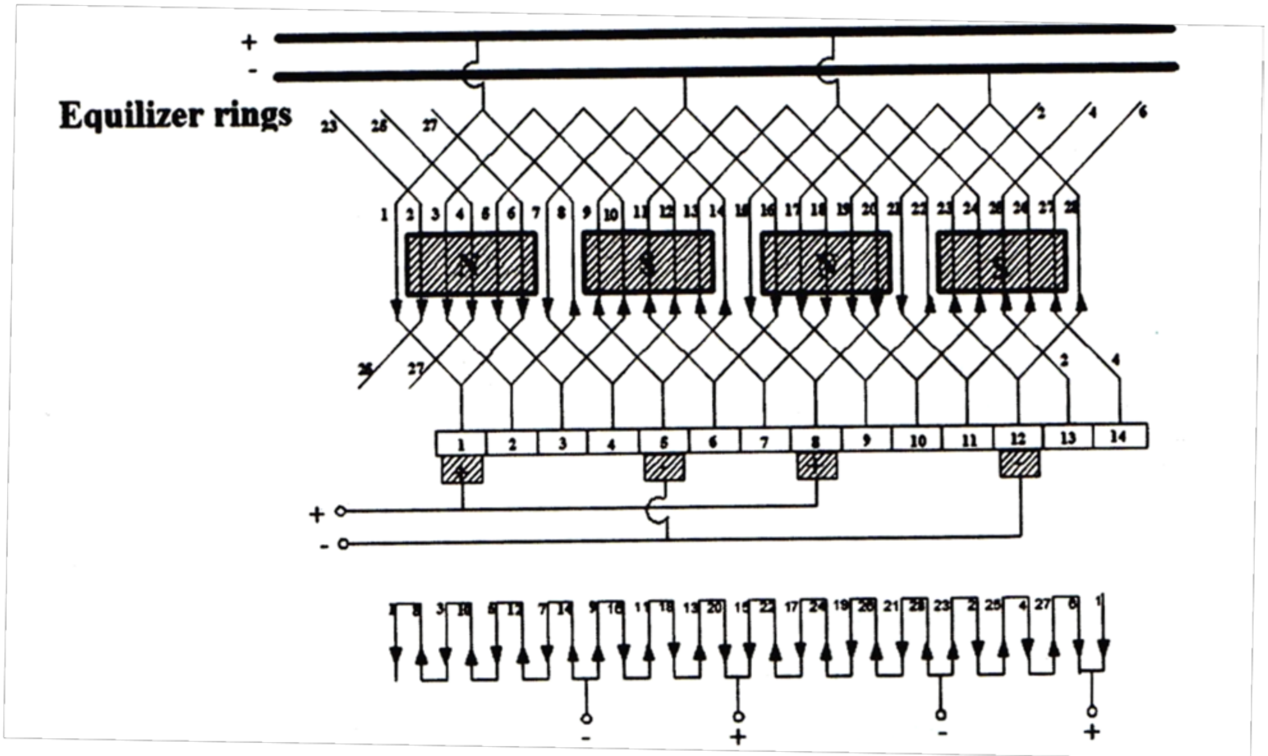
Hence,

$$\boxed{Y_b = 7} \quad \text{and} \quad \boxed{Y_f = 5}$$

Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 2.3.

TABLE 2.3 Winding table

S. No.	*At the back* $Y_b = 7$	*At the front* $Y_f = 5$	*S. No.*	*At the back* $Y_b = 7$	*At the front* $Y_f = 5$
1	1 + 7 = 8	8 − 5 = 3	8	15 + 7 = 22	22 − 5 = 17
2	3 + 7 = 10	10 − 5 = 5	9	17 + 7 = 24	24 − 5 = 19
3	5 + 7 = 12	12 − 5 = 7	10	19 + 7 = 26	26 − 5 = 21
4	7 + 7 = 14	14 − 5 = 9	11	21 + 7 = 28	28 − 5 = 23
5	9 + 7 = 16	16 − 5 = 11	12	23 + 7 = 30(2)	30 − 5 = 25
6	11 + 7 = 18	18 − 5 = 13	13	25 + 7 = 32(4)	32 − 5 = 27
7	13 + 7 = 20	20 − 5 = 15	14	27 + 7 = 34(6)	34 − 5 = 29(1)



PROBLEM 4: A DC machine has 32 armature slots and 4 poles, with one conductor per slot. Develop a progressive duplex lap winding diagram for the DC machine.

Solution:

Analysing the problem: This particular problem states us to develop a duplex lap winding diagram for a DC machine having 32 armature conductors and 4 poles.

Step 1: First calculate the pole pitch, front pitch Y_f and back pitch Y_b.

Hence, pole pitch = $Z/P = 32/4 = 8$

But pole pitch = $(Y_b + Y_f)/2$

Hence, $(Y_b + Y_f)/2 = 8$

Calculating Y_b as per the general procedure:

$$(Y_b + Y_f) = 16 \quad \text{(i)}$$

$$(Y_b - Y_f) = 2 \quad \text{(ii)}$$

Solving equations (i) and (ii), we get

$$\boxed{Y_b = 9}$$

But $Y_b = Y_f \pm 2m$

(where m = 1 for simplex, 2 for duplex and 3 for triplex)

$$(Y_b - Y_f) = 2 \times 2 = 4 \tag{iii}$$

Now, substituting the value of Y_b in equation (iii)

Hence

$$\boxed{Y_b = 9} \quad \text{and} \quad \boxed{Y_f = 5}$$

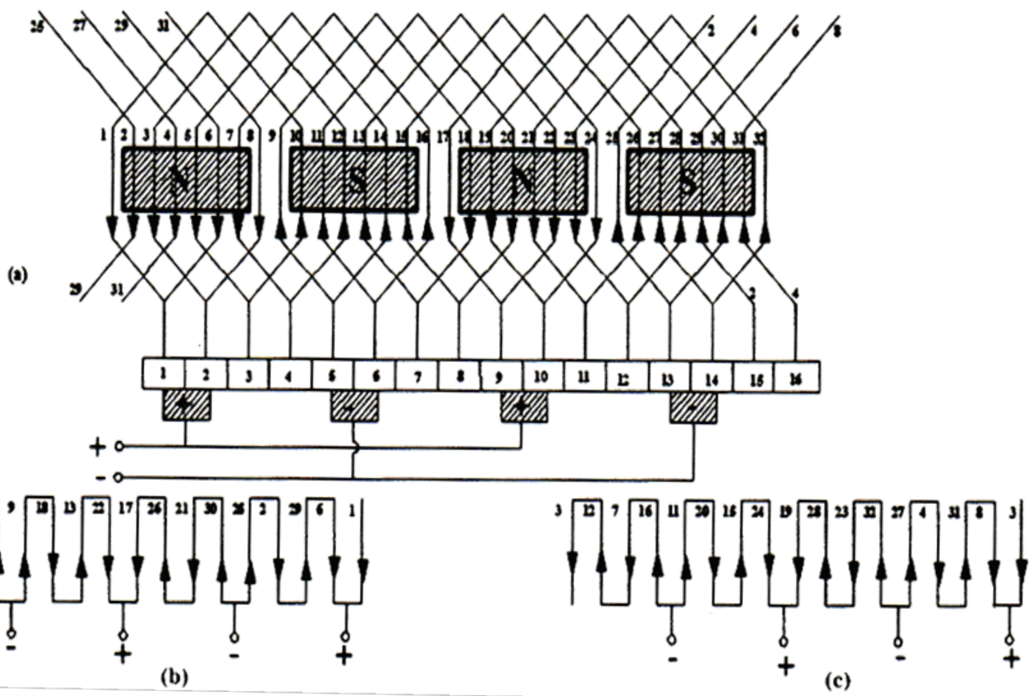
Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 2.4.

TABLE 2.4 Winding table

At the back $Y_b = 9$	*At the front* $Y_f = 5$	*At the back* $Y_b = 9$	*At the front* $Y_f = 5$
1 + 9 = 10	10 − 5 = 5	3 + 9 = 12	12 − 5 = 7
5 + 9 = 14	14 − 5 = 9	7 + 9 = 16	16 − 5 = 11
9 + 9 = 18	18 − 5 = 13	11 + 9 = 20	20 − 5 = 15
13 + 9 = 22	22 − 5 = 17	15 + 9 = 24	24 − 5 = 19
17 + 9 = 26	26 − 5 = 21	19 + 9 = 28	28 − 5 = 23
21 + 9 = 30	30 − 5 = 25	23 + 9 = 32	32 − 5 = 27
25 + 9 = 34(2)	34 − 5 = 29	27 + 9 = 36(4)	36 − 5 = 31
29 + 9 = 38(6)	38 − 5 = 33(1)	31 + 9 = 40(8)	40 − 5 = 35(3)

Now, this winding table shows the connection of coils on both front and back pitches.

Repeat the steps 1 to 20 as stated in solution of problem to draw the winding diagram. Figure 2.30 shows the developed winding diagram for this particular problem.



PROBLEM 5: Develop a double layer winding for a DC machine having 16 slots and 4 poles. Draw the sequence diagram and indicate the position of the brushes. Show the direction of induced emf and give equaliser connection. (VTU, June 2013)

Solution:

Given data:

Type of winding = Progressive lap

Number of slots (S) = 16

Number of conductors (Z) = 32

Number of poles (P) = 4

Number of circuits (m) = 1

Number of layers = 2

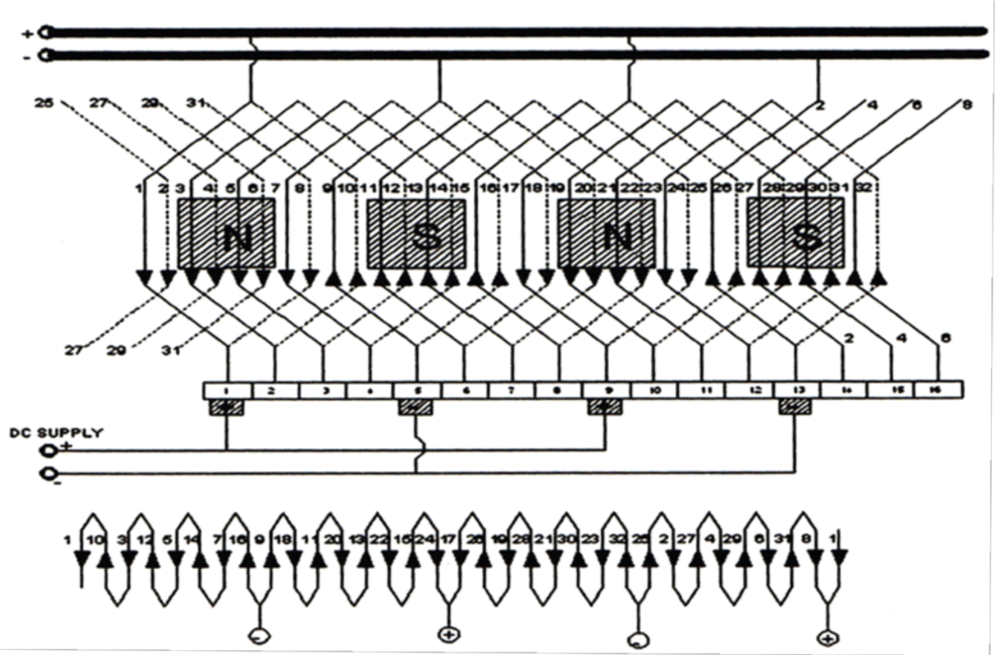
Calculation:

Pole pitch (Z/P) = 8

$Y_b = 9$

$Y_f = 7$

At the back $Y_b = 9$	*At the front* $Y_f = 7$	*At the back* $Y_b = 9$	*At the front* $Y_f = 7$
1 + 9 =10	10 − 7 = 3	17+ 9 = 26	26 − 7 = 19
3 + 9 = 12	12 − 7 = 5	19 + 9 = 28	28 − 7 = 21
5 + 9 = 14	14 − 7 = 7	21 + 9 = 30	30 − 7 = 23
7 + 9 = 16	16 − 7 = 9	23 + 9 = 32	32 − 7 = 25
9 + 9 = 18	18 − 7 = 11	25 + 9 = 34(2)	34 − 7 = 27
11 + 9 = 20	20 − 7 = 13	27 + 9 = 36(4)	36 − 7 = 29
13 + 9 = 22	22 − 7 = 15	29 + 9 = 38(6)	38 − 7 = 31
15 + 9 = 24	24 − 7 = 17	31 + 9 = 40(8)	40 − 7 = 33(1)



PROBLEM 6: Draw the armature winding of a DC machine with 2 poles, 18 slots and single layer retrogressive wave. Draw the sequence diagram and show the position of brush and direction of induced emf. (VTU, June 2013)

Solution:

Given data:

Type of winding = Retrogressive wave
Number of slots = 18
Number of conductor (Z) = 18
Number of poles (P) = 2
Number of circuits (m) = 1
Number of layers = 1

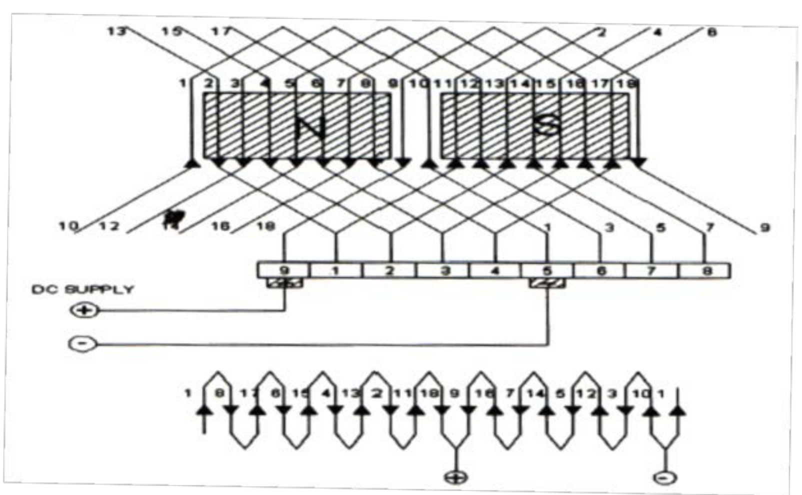
Calculation:

Pole pitch (Z/P) = 9
$Y_b = 7$
$Y_f = 9$

Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 3.2.

TABLE 3.2 Winding table

At the back $Y_b = 7$	*At the front* $Y_f = 9$	*At the back* $Y_b = 7$	*At the front* $Y_f = 9$
1 + 7 = 8	8 + 9 = 17	9 + 7 = 16	16 + 9 = 25(7)
17 + 7 = 24(6)	6 + 9 = 15	7 + 7 = 14	14 + 9 = 23(5)
15 + 7 = 22(4)	4 + 9 = 13	5 + 7 = 12	12 + 9 = 21(3)
13 + 7 = 20(2)	2 + 9 = 11	3 + 7 = 10	10 + 9 = 19(1)
11 + 7 = 18	18 + 9 = 27(9)		



PROBLEM 7 : Draw the armature winding of a DC machine with 4 poles, 18 slots and double layer simplex retrogressive wave. Show the position of brush and direction of induced emf. (VTU, June 2013)

Given data:

Type of winding = Retrogressive wave

Number of slots = 18

Number of conductor (Z) = 36

Number of poles (P) = 4

Number of circuits (m) = 1

Number of layers = 2

Calculation:

Pole pitch (Z/P) = 9

Y_b = 9

Y_f = 9

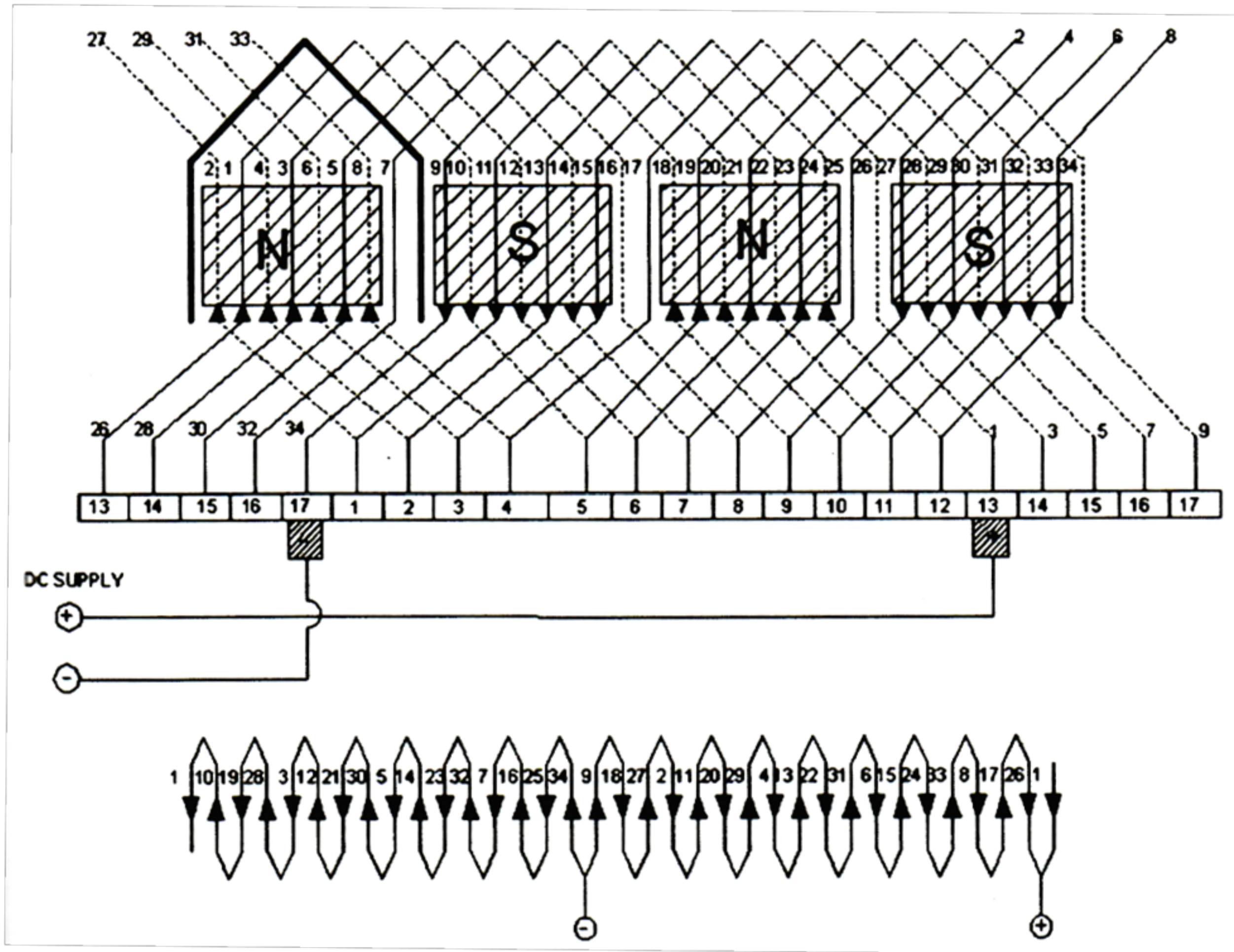
Note: Here, in this problem the commutator pitch is fraction which results a coil to be made electrical dummy, i.e., a coil will be connected at the back end and left open in the front end connection.

Therefore, the number of conductors to be considered is 34(Z = 34).

Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 3.4.

TABLE 3.4 Winding table

At the back $Y_b = 9$	*At the front* $Y_f = 9$	*At the back* $Y_b = 9$	*At the front* $Y_f = 9$
1 + 9 = 10	10 + 9 = 19	27 + 9 = 36(2)	2 + 9 = 11
19 + 9 = 28	28 + 9 = 37(3)	11 + 9 = 20	20 + 9 = 29
3 + 9 = 12	12 + 9 = 21	29 + 9 = 38(4)	4 + 9 = 13
21 + 9 = 30	30 + 9 = 39(5)	13 + 9 = 22	22 + 9 = 31
5 + 9 = 14	14 + 9 = 23	31 + 9 = 40(6)	6 + 9 = 15
23 + 9 = 32	32 + 9 = 41(7)	15 + 9 = 24	24 + 9 = 33
7 + 9 = 16	16 + 9 = 25	33 + 9 = 42(8)	8 + 9 = 17
25 + 9 = 34	34 + 9 = 43(9)	17 + 9 = 26	26 + 9 = 35(1)
9 + 9 = 18	18 + 9 = 27		



PROBLEM 8 : Develop a single layer simplex progressive wave winding for a dc machine with 4 poles and 24 slots. Show the position of brush and direction of induced emf. Draw the sequence diagram.

Analysing the problem: This particular problem states us to develop a single layer progressive wave winding diagram for a DC machine having 24 armature conductors and 4 poles. Drawing sequence diagram helps us to analyse the flow of current and helps to locate the brushes.

Given data:

Number of poles (P) = 4
In single layer, number of conductors (Z) = slots = 24

Step 1: First calculate the pole pitch, front pitch Y_f and back pitch Y_b.

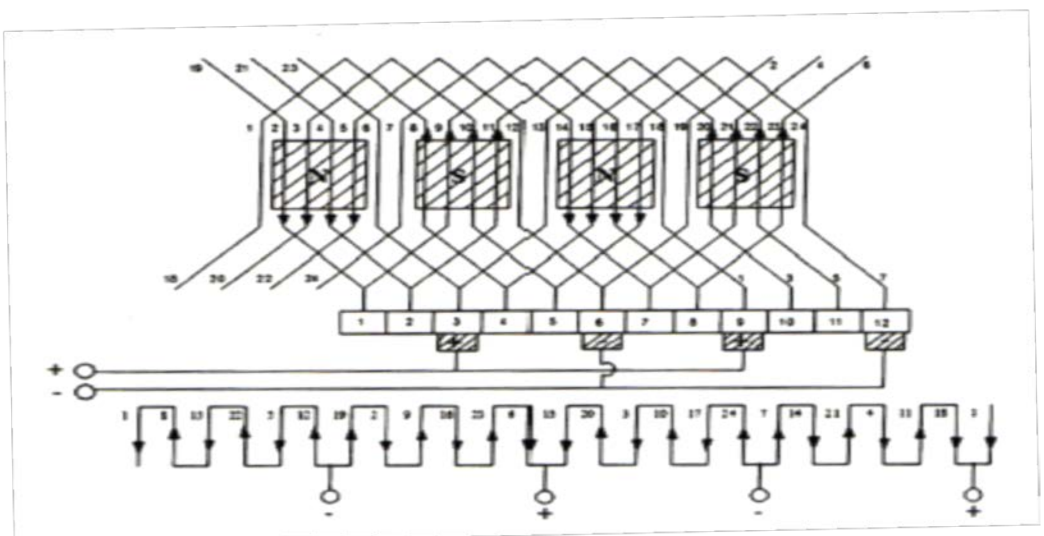
Hence, pole pitch $(Z/P) = 24/4 = 6$.

Therefore,

$$\boxed{Y_b = 7} \quad \text{and} \quad \boxed{Y_f = 7}$$

Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 3.1.

At the back $Y_b = 7$	*At the front* $Y_f = 7$	*At the back* $Y_b = 7$	*At the front* $Y_f = 7$
1 + 7 = 8	8 + 7 = 15	13 + 7 = 20	20 + 7 = 27(3)
15 + 7 = 22	22 + 7 = 29	3 + 7 = 10	10 + 7 = 17
5 + 7 = 12	12 + 7 = 19	17 + 7 = 24	24 + 7 = 31(7)
19 + 7 = 26(2)	2 + 7 = 9	7 + 7 = 14	14 + 7 = 21
9 + 7 = 16	16 + 7 = 23	21 + 7 = 28(4)	4 + 7 = 11
23 + 7 = 30(6)	6 + 7 = 13	11 + 7 = 18	18 + 7 = 25

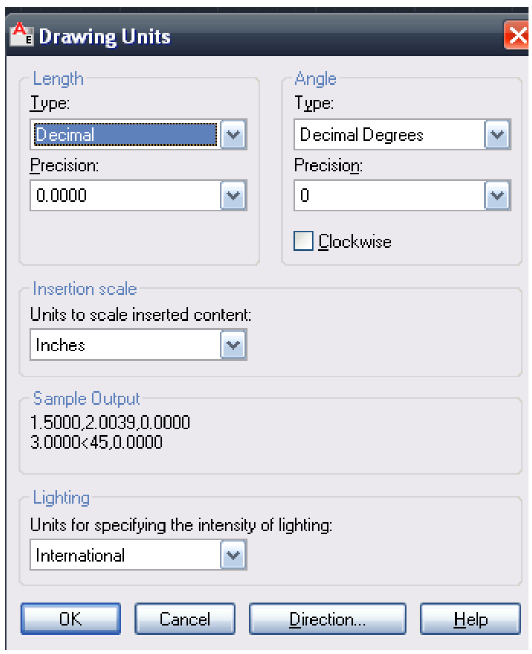


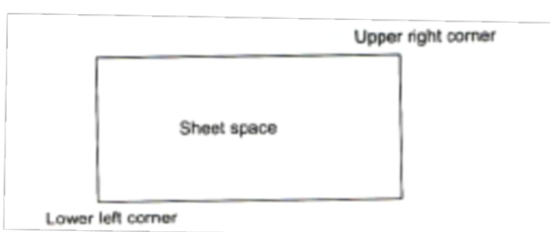
(B) AC Winding Diagrams :

General procedure to draw winding diagrams using CAD : (common to all problems)

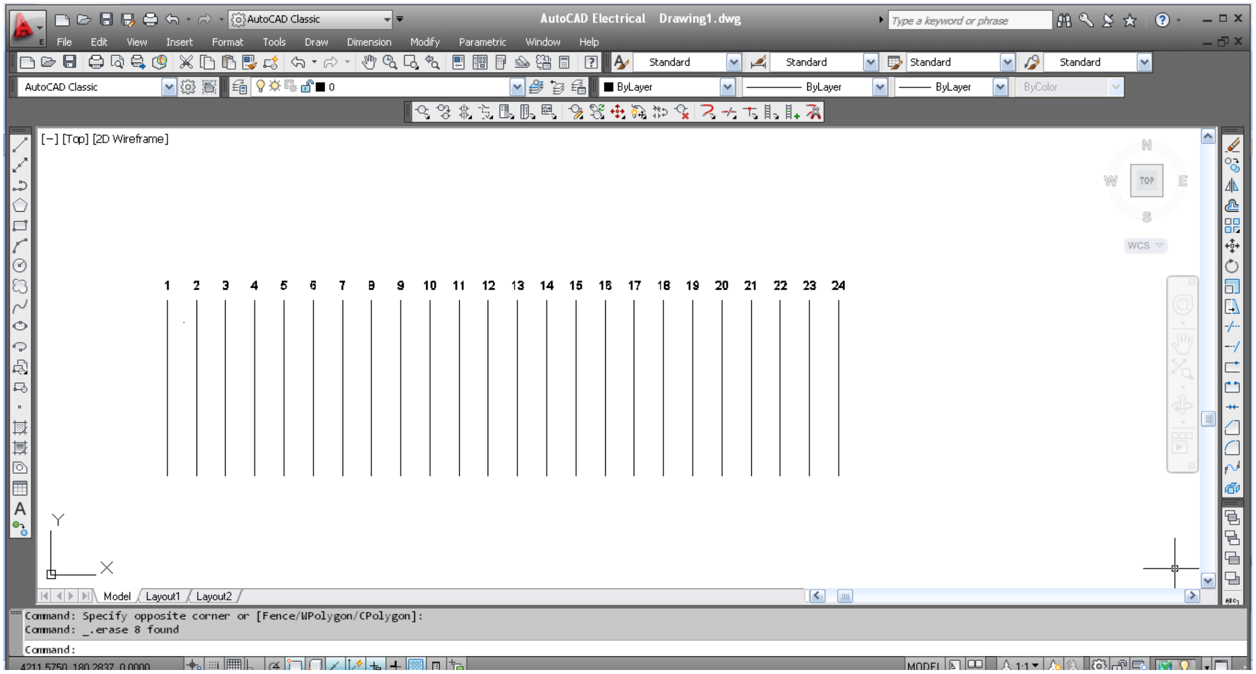
Step 1 : Start AutoCAD . Set drawing units & limits --- Type units in command window to access units & type limits in cw to set limits as shown :

Lower left corner < 0,0 >
Upper right corner < 1500 , 1500 >

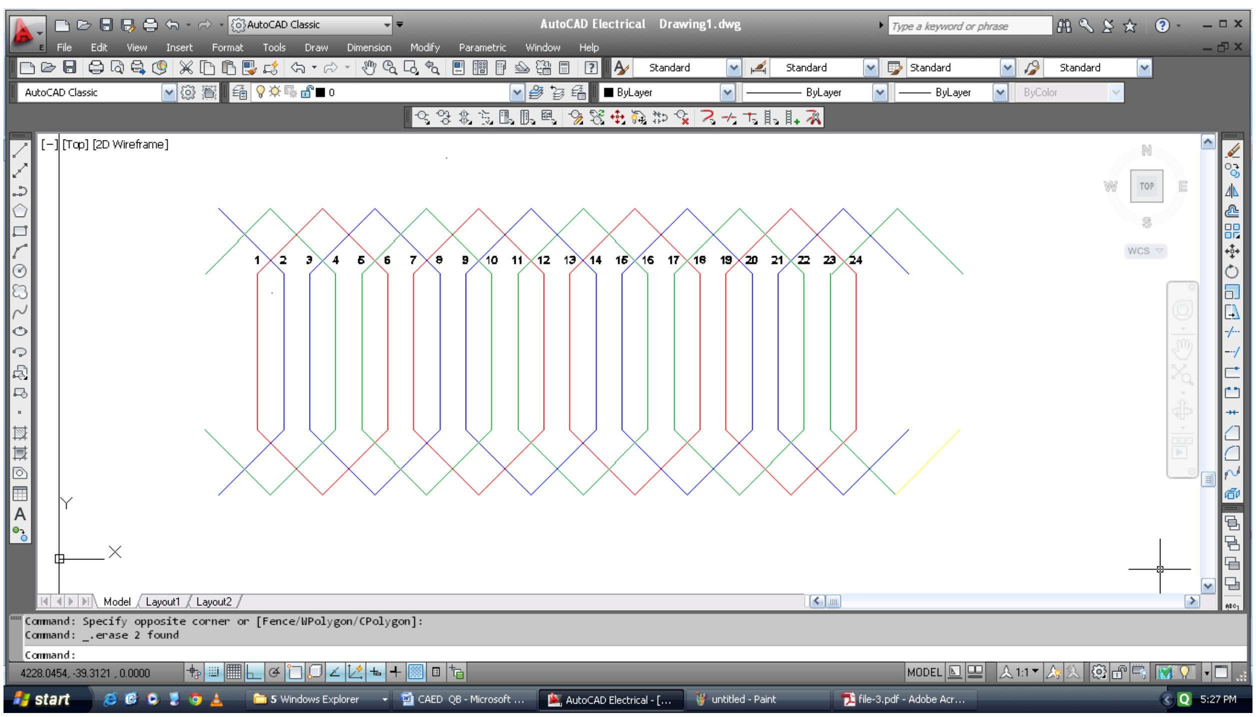




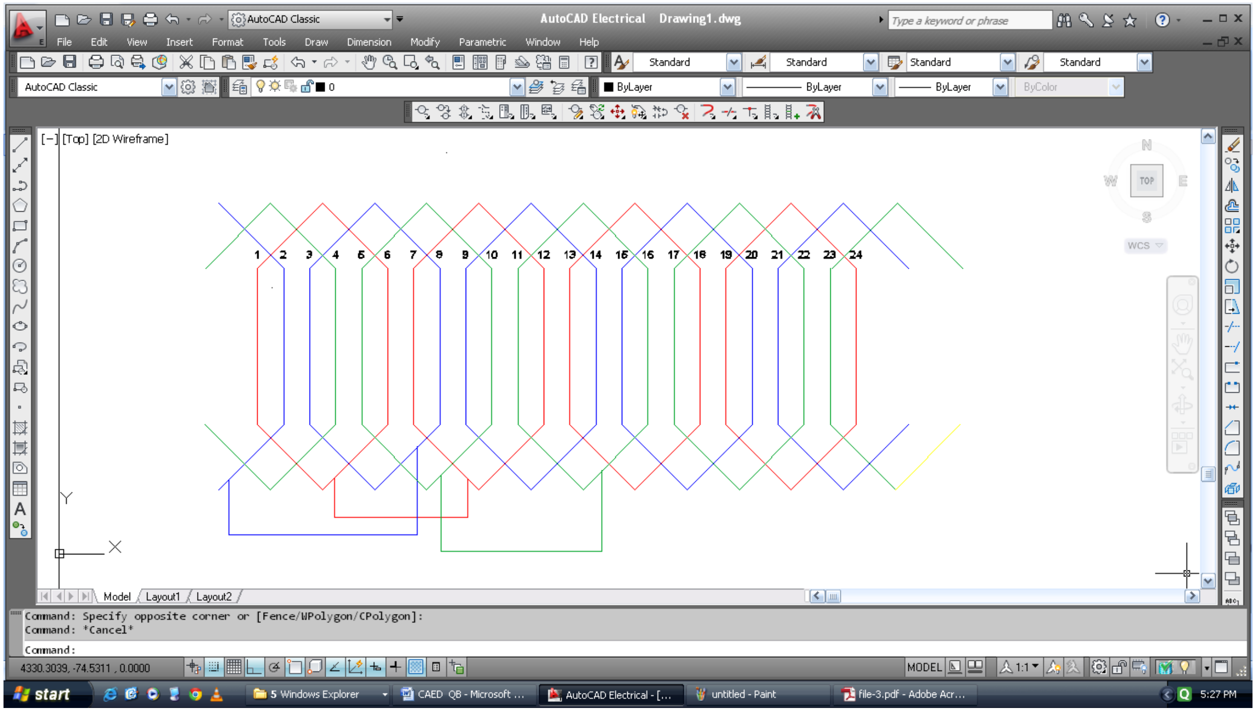
Step 2 : Draw line using line command for required length. Use array command and get the number of lines required (conductors) . Number all the conductors using mtext command.



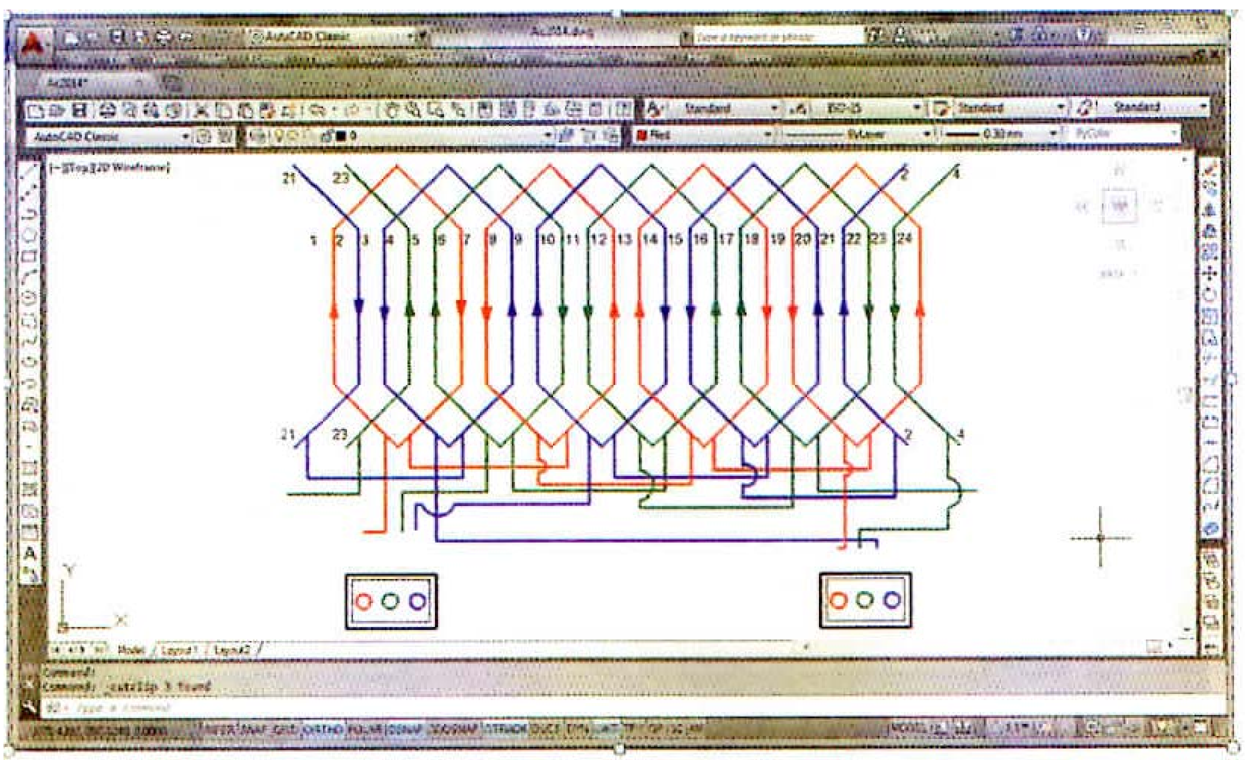
Step 3 : Apply color attribute to the windings to represent 3 phases , R,Y,B using format commands with layer and make appropriate connections referring the winding table.



Step 4 : Interconnect the coils of the same group as shown .



Step 5 : Mark the direction of current flow and draw the terminal plates and name them by phases and connect them as shown.



Step 6 : Terminate the winding connections based on the given configuration : star or delta to complete the diagram. Finally do the dimensioning.

PROBLEM 1: Draw the developed single layer lap winding diagram of a 3 phase star connected AC machine with 4 poles and 24 conductors. The winding is to be short pitched by one slot.

Solution:

Analysing the problem: This particular problem states us to develop a single layer lap winding diagram for an AC machine having 24 conductors and 4 poles.

Given data:

Number of poles = 4

Number of slots = S = Z = number of conductors = 24

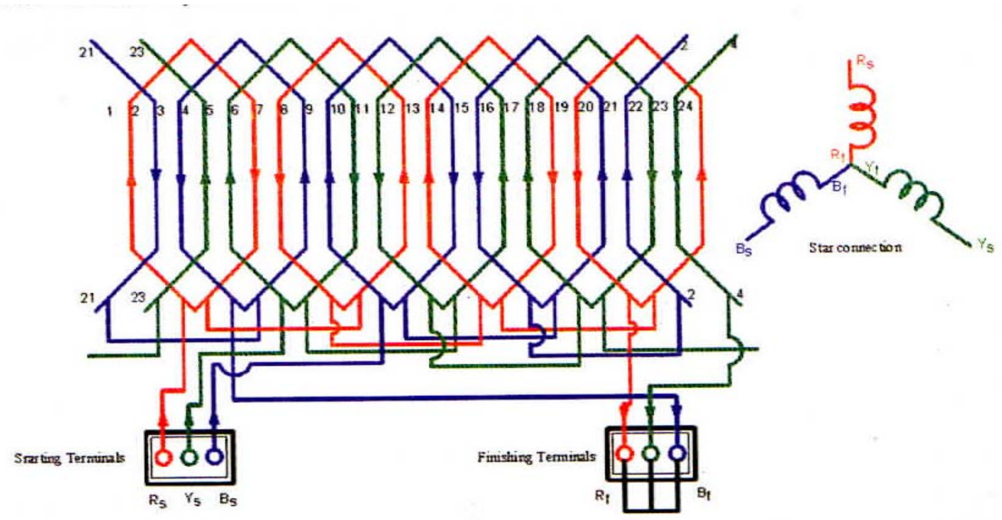
Step 1: First calculate all the necessary details like pole pitch, slots/pole, slots/pole/phase, coil span, etc. as given below:

- Pole pitch = number of slots/pole = (24/4) = 6
- Number of slots/pole/phase = (6/3) = 2
- Number of coils/pole/phase = 12/12 = 1 (hence winding is balanced)
- Slot angle = (180/pole pitch) = (180/6) = 30°
- Winding pitch = 180 – (number of slots shorted × slot angle) = 180 – (1 × 30) = 150
- Coil span = (winding pitch/slot angle) = (150/30) = 5
- The winding is balanced and one coil is fitted in each pole per phase. Hence, 1st conductor is connected to 6th conductor (1 + 5 = 6).
- The phase R starts from slot number 1, i.e., $R_S = 1$.
- The phase Y starts after 120°, i.e., $Y_S = 1 + (120/\text{slot angle}) = 1 + (120/30) = 5$.
- The phase B starts after 240°, i.e., $B_S = 1 + (240/\text{slot angle}) = 1 + (240/30) = 9$.

Step 2: Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 4.1.

TABLE 4.1 Winding table

	1st pole	2nd pole	3rd pole	4th pole
R phase	1 + 5 = 6	7 + 5 = 12	13 + 5 = 18	19 + 5 = 24
B phase	3 + 5 = 8	9 + 5 = 14	15 + 5 = 20	21 + 5 = 26(2)
Y phase	5 + 5 = 10	11 + 5 = 16	17 + 5 = 22	23 + 5 = 28(4)



PROBLEM 2 : Draw the developed winding diagram for the following details:

3 phase AC double layer lap winding, slots = 12, poles = 4 and phase sequence = R Y B.

(VTU, June 2013)

Solution:

Pole pitch = S/P = 3

Slots per pole per phase = pole pitch/phase = 1

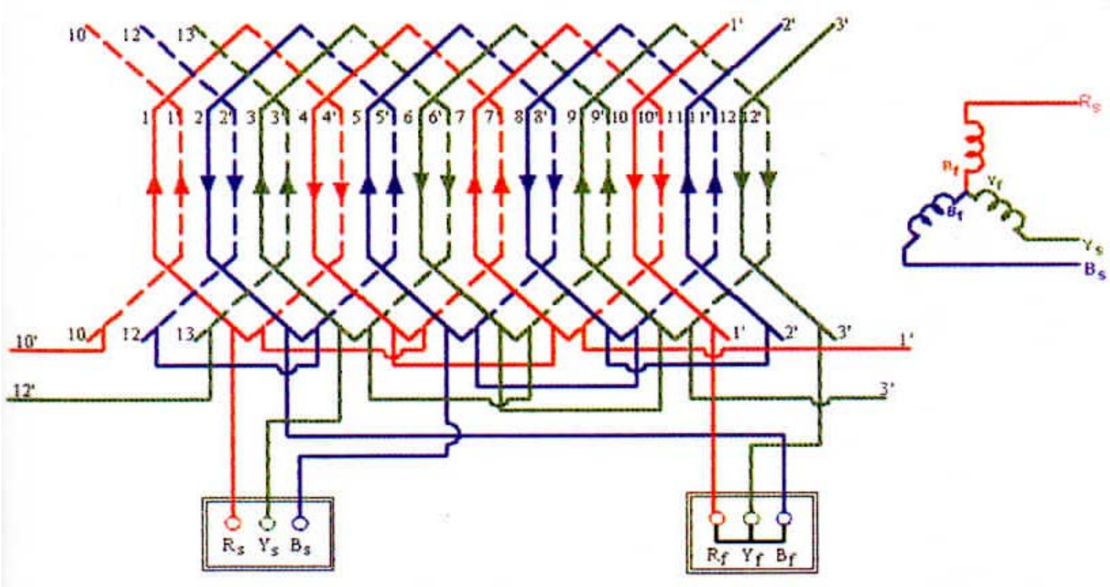
Slot angle = 180°/pole pitch = 60°

$R_S = 1^{TCS}$ (TCS = Top Coil Side in particular slot)

$Y_S = 1 + (120°/60°) = 3^{TCS}$

$B_S = 1 + (240°/60°) = 5^{TCS}$

Poles/phases	*R phase*	*B phase*	*Y phase*
P1	$(R_S)1 + 3 = 4'$	$(B_F)2 + 3 = 5'$	$(Y_S)3 + 3 = 6'$
P2	$4 + 3 = 7'$	$(B_S)5 + 3 = 8'$	$6 + 3 = 9'$
P3	$7 + 3 = 10'$	$8 + 3 = 11'$	$9 + 3 = 12'$
P4	$(R_F)10 + 3 = 13'$	$11 + 3 = 14'$	$(Y_F)12 + 3 = 15'$



PROBLEM 3: Develop the winding diagram for a 3 phase AC machine with 18 slots and 6 poles. Assume it is star connected and phase sequence is RYB. (VTU, June 2013)

Solution:

Pole pitch = S/P = 18/6 = 3

Slots per pole per phase = pole pitch/phase = 1

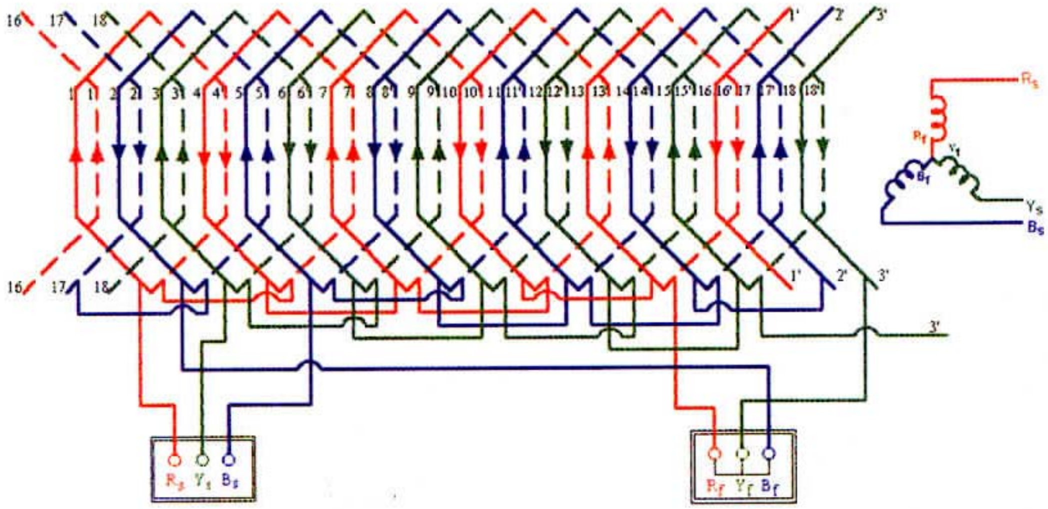
Slot angle = 180°/pole pitch = 60°

$R_S = 1^{TCS}$ (TCS = Top Coil Side in particular slot)

$Y_S = 1 + (120°/60°) = 3^{TCS}$

$B_S = 1 + (240°/60°) = 5^{TCS}$

Poles/phases	*R phase*	*B phase*	*Y phase*
P1	$(R_S)1 + 3 = 4'$	$(B_F)2 + 3 = 5'$	$(Y_S)3 + 3 = 6'$
P2	$4 + 3 = 7'$	$(B_S)5 + 3 = 8'$	$6 + 3 = 9'$
P3	$7 + 3 = 10'$	$8 + 3 = 11'$	$9 + 3 = 12'$
P4	$10 + 3 = 13'$	$11 + 3 = 14'$	$12 + 3 = 15'$
P5	$13 + 3 = 16'$	$14 + 3 = 17'$	$15 + 3 = 18'$
P6	$(R_F)16 + 3 = 1'$	$17 + 3 = 2'$	$(Y_F)18 + 3 = 3'$



PROBLEM 4: Design and draw the developed 3 phase AC lap winding diagram for 24 slots, double layer lap connected, 4 poles and one slot to be chorded. Also show the winding in star connection.

Solution:

Pole pitch = $S/P = 6$

Slots per pole per phase = pole pitch/phase = 2

Slot angle = 180°/pole pitch = 30°

$R_S = 1^{\text{TCS}}$ (TCS = Top Coil Side in particular slot)

$Y_S = 1 + (120°/30°) = 5^{\text{TCS}}$

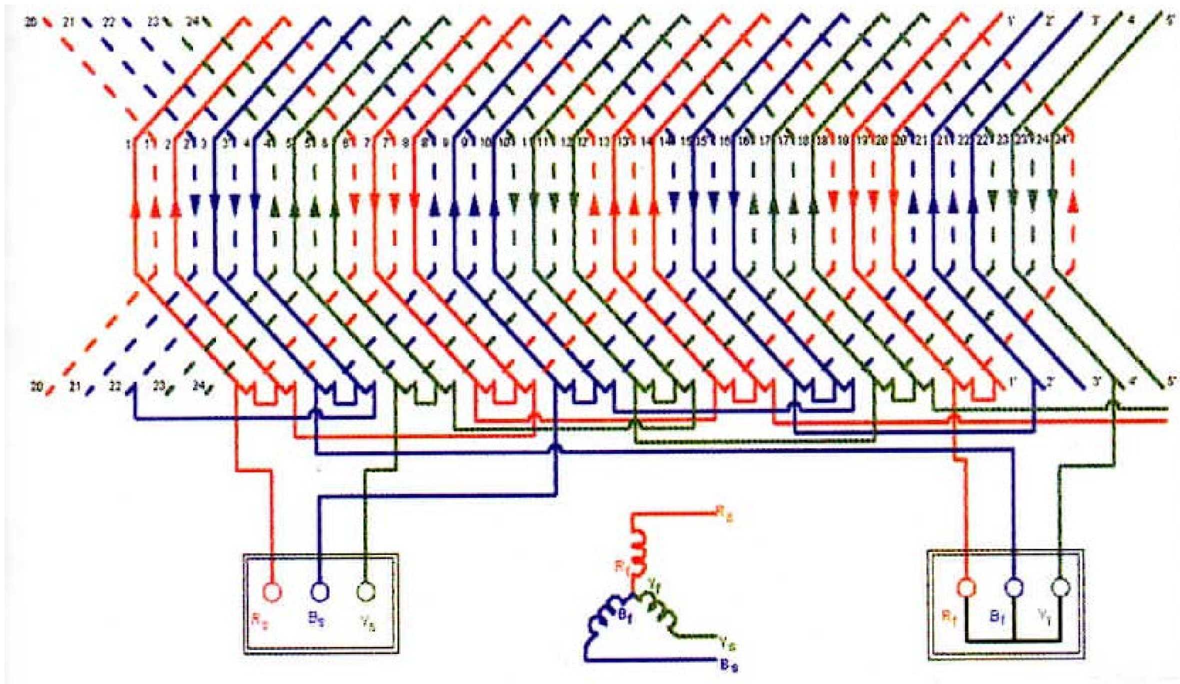
$B_S = 1 + (240°/30°) = 9^{\text{TCS}}$

Actual coil span = pole pitch – number of coils to be chorded = 6 – 1 = 5

Now, develop the winding table so as to establish the coil connection in various slots as shown in Table 4.4.

TABLE 4.4 Winding table

Poles/phases	*R phase*	*B phase*	*Y phase*
P1	$(R_S)1 + 5 = 6'$ $2 + 5 = 7'$	$3 + 5 = 8'$ $4 + 5 = 9'$	$5 + 5 = 10'$ $6 + 5 = 11'$
P2	$7 + 5 = 12'$ $8 + 5 = 13'$	$9 + 5 = 14'$ $10 + 5 = 15'$	$11 + 5 = 16'$ $12 + 5 = 17'$
P3	$13 + 5 = 18'$ $14 + 5 = 19'$	$15 + 5 = 20'$ $16 + 5 = 21'$	$17 + 5 = 22'$ $18 + 5 = 23'$
P4	$19 + 5 = 24'$ $20 + 5 = 25'(1')$	$21 + 5 = 26'(2')$ $22 + 5 = 27'(3')$	$23 + 5 = 28'(4')$ $24 + 5 = 29'(5')$



PROBLEM 5: Develop and draw the wave winding diagram for the following details: Slots = 12, poles = 4, single layer, phase sequence is RYB and delta connected.

Solution:

Pole pitch = S/P = 3

Slots per pole per phase = pole pitch /phase = 1

Slot angle = 180°/ pole pitch = 60°

$R_S = 1^{TCS}$

$Y_S = 1 + (120°/60°) = 3^{TCS}$

$B_S = 1 + (240°/60°) = 5^{TCS}$

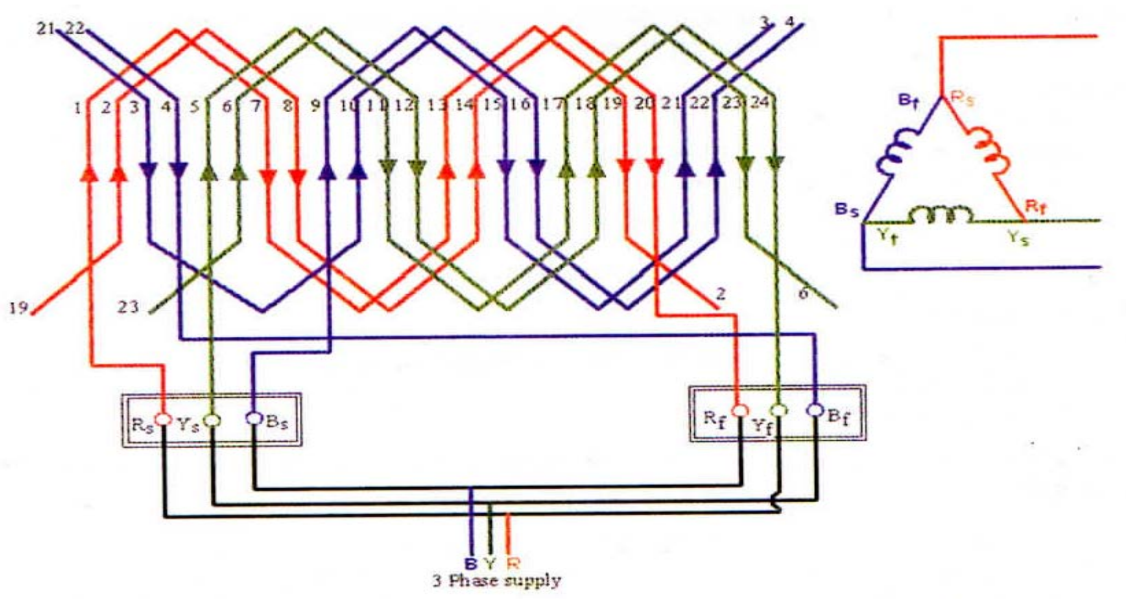
The coil span is 6, hence the Y_B and $Y_F = 6$

R_S conductor in $1^{TCS} = 1$ (TCS = Top Coil Side in particular slot)

Y_S conductor in $3^{TCS} = 5$

B_S conductor in $5^{TCS} = 9$

R_S 1 + 6 = 7	7 + 6 = 13	13 + 6 = 19	19 + 6 = 25(1)
2 + 6 = 8	8 + 6 = 14	14 + 6 = 20	R_F 20 + 6 = 26(2)
Y_S 5 + 6 = 11	11 + 6 = 17	17 + 6 = 23	23 + 6 = 29(5)
6 + 6 = 12	12 + 6 = 18	18 + 6 = 24	Y_F 24 + 6 = 30(6)
B_S 9 + 6 = 15	15 + 6 = 21	21 + 6 = 27(3)	3 + 6 = 9
10 + 6 = 16	16 + 6 = 22	22 + 6 = 28(4)	B_F 4 + 6 = 10



PROBLEM 6 : Develop the wave winding for the stator of an induction motor having 24 slots, 4 poles, RYB phase sequence and double layer.

Solution:

Pole pitch = S/P = 6

Slots per pole per phase = pole pitch/phase = 2

Slot angle = 180°/pole pitch = 30°

$R_S = 1^{TCS}$ (TCS = Top Coil Side in particular slot)

$Y_S = 1 + (120°/30°) = 5^{TCS}$

$B_S = 1 + (240°/30°) = 9^{TCS}$

The total winding pitch $Y = Y_B + Y_F = 12 \times 2 = 24$ coil

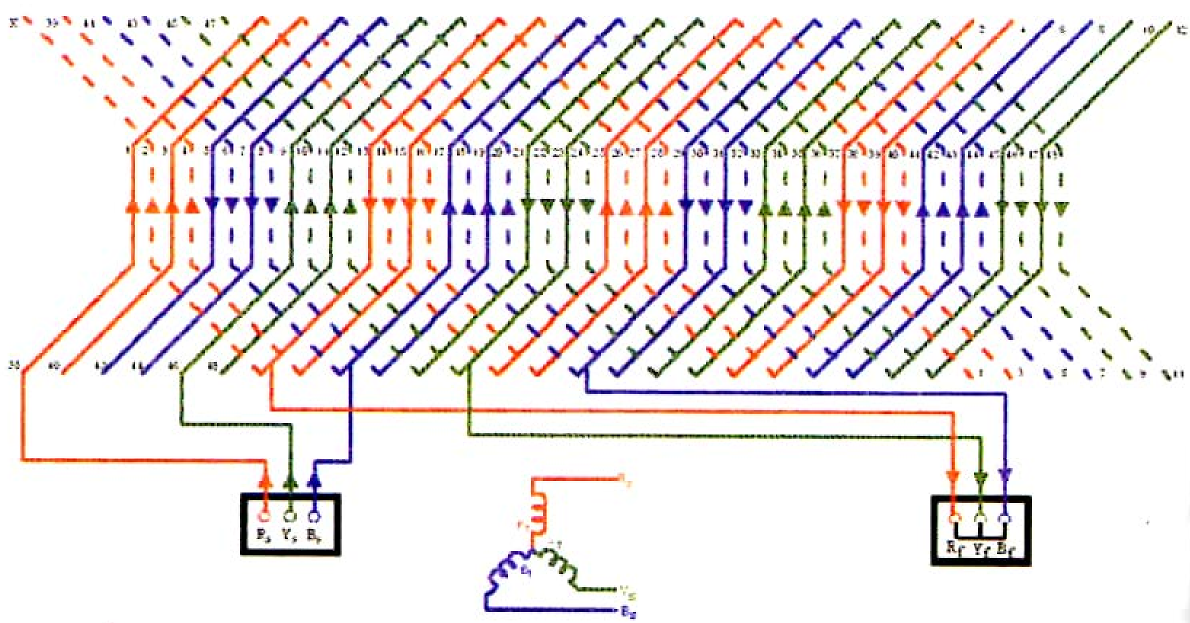
$Y_B = 13$ and $Y_F = 11$

R_S conductor in $1^{TCS} = 1$ (TCS = Top coil side in particular slot)

Y_S conductor in $5^{TCS} = 9$

B_S conductor in $9^{TCS} = 17$

R_S 1 + 13 = 14	14 + 11 = 25	25 + 13 = 38	38 + 11 = 49(1)
3 + 13 = 16	16 + 11 = 27	27 + 13 = 40	40 + 11 = 51(3)
4 – 13 = 39	39 – 11 = 28	28 – 13 = 15	15 – 11 = 4
2 – 13 = 37	37 – 11 = 26	26 – 13 = 13	**R_F 13 – 11 = 2**
Y_S 9 + 13 = 22	22 + 11 = 33	33 + 13 = 46	46 + 11 = 57(9)
11 + 13 = 24	24 + 11 = 35	35 + 13 = 48	48 + 11 = 59(11)
12 – 13 = 47	47 – 11 = 36	36 – 13 = 23	23 – 11 = 12
10 – 13 = 45	45 – 11 = 34	34 – 13 = 21	**Y_F 21 – 11 = 10**
B_S 17 + 13 = 30	30 + 11 = 41	41 + 13 = 54(6)	6 + 11 = 17
19 + 13 = 32	32 + 11 = 43	43 + 13 = 56(8)	8 + 11 = 19
20 – 13 = 7	7 – 11 = 44	44 – 13 = 31	31 – 11 = 20
18 – 13 = 5	5 – 11 = 42	42 – 13 = 29	**B_F 29 – 11 = 18**



MODULE II : <u>SINGLE LINE DIAGRAMS OF SUBSTATIONS</u> :

Usually, the power is generated in a remote place away from residential or industrial areas or urban places. For example, hydroelectric power station is located at a place where there is availability of water to generate power and this power generated in such station is to be transmitted to other residential or industrial areas or urban places in order to fulfil the energy demand.

The power generated in the generating stations cannot be directly transmitted to meet the consumer's needs. Hence, the power generated will be first stepped up depending on the requirement then transmitted and this power is received in a power station where, again it is stepped up or down and later it is distributed to the consumers. This station, where the power is stepped up or down is called as *substation*.

Right from the generating station to receiving station and to the consumers, there are numerous electrical apparatus involved in order to cater to the energy demand of the consumers. It is always necessary to have a pictorial representation of the flow of power from generating station to the consumers but drawing all the components becomes difficult and hasty. Hence, a diagram with only the representations of the symbols can be drawn and this sort of a diagram which gives the complete information is called as a '*single line diagram*'.

Generating station :

Generating station refers to the place where the electricity is generated. For examples, hydroelectric generating station, nuclear station, thermal, diesel, etc., usually these stations are located away from urban or densely populated areas and where the resources are available in plenty. Usually, the electricity generated is around 11 kV in a hydroelectric generating station. This generated electricity is to be transmitted to the urban areas or to the consumers. When this generated voltage of 11 kV is transmitted, then due to transmission losses, at the receiving end we might not receive the suitable voltage and the very same might not be used by all the consumers. Henceforth as soon as the power is generated, the voltage thus generated should be stepped up.

Substation :

Substation refers to the place where the electricity generated in the generating station is stepped up or down for transmission purpose depending upon the requirement. The station or the location where the electricity is stepped down for distribution purpose to the consumer is known as *distribution substation*. Figure 5.1 gives the classification of substation.

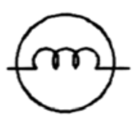
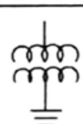
Classification of substation

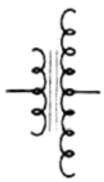
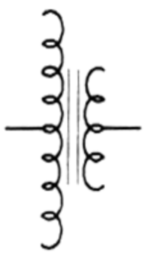
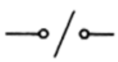
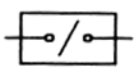
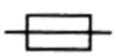
According to service	According to construction
Industrial	Indoor
Frequency changing	Outdoor
Isolating	Pole mounted
Transformer	Under ground
P.F. correction	

Receiving station :

Receiving station refers to the place which is usually located in an urban area or a place which is nearer to the consumer. The power generated from the generating station is stepped up in a substation and is then transmitted via transmission lines; this power is received in the receiving stations. The consumer requirement differs from consumer to consumer. Consumers are mainly of two kinds, they are domestic and commercial consumers. A commercial consumer refers to industries and domestic consumers refer to household purposes. Thus, receiving stations are mainly responsible to receive power from a generating station and then depending on requirement transmit it to distribution substations for distribution of power to the consumers.

Representation of various electrical apparatus :

S.No.	*Representation*	*Description*
1		*AC generator*: It is responsible for generating sinusoidal or alternating voltage.
2		*Lightning arrestor* (LA) with grounded: Where all the transmission line is exposed to sunlight, at such places lightning arrestors should be provided compulsorily.
3		*Wave trap* (WT): This is used to eliminate any unwanted radiations like the radio frequency and electromagnetic radiations abrupting the transmission process.
4		*Current transformer* (CT): This is used to measure the current flowing in the transmission line and is always connected in series with the transmission line.
5		*Potential transformer* (PT): This is used to check the voltage flowing in the transmission line and is always connected in parallel with the transmission line.
6		*Coupling condenser* (CC):

S.No.	Representation	Description
7		*Earthing switch* (ES): This is a normal switch but when connected along with ground then it is called as earthing switch. It is used to eliminate stray charges.
8		*Step up transformer*: It is used to step up the voltage.
9		*Step down transformer*: It is used to step down the voltage.
10		*Isolator*: This is nothing but a switch.
11		*Bus coupler* (BC): It is used to couple 2 bus bars.
12		*Oil circuit breaker* (OCB): It is used in places where the voltage level is high.
13		*Low tension oil circuit breaker* (LT OCB): It is used in places where the voltage level is low.
14		*Transformer with delta star connection*: In a star delta transformer the primary is connected in star connection and secondary in delta connection and vice versa.
15		*Feeder*: A feeder is structure resembling bus bar responsible for feeding or providing power to consumers.
16		*Bus bar*: This is a thick conductor. It can be used either vertically or horizontally. It is used to distribute power.

PROBLEM 1: Draw a neat single line diagram using I.S.I. symbols for a 110 kV/11 kV M.U.S.S. with the following details:

- Incoming lines: Two, 110 kV
- Lines: Two, OCB 110 kV
- Transformers: Two, step down 110 kV/11 kV
- LT OCBs for transformers: Two
- Duplicate bus bars on high tension (HT) and low tension (LT) sides to be indicated
- Bus coupler on HT side only
- Feeders: Six, 11 kV at LT bus
- LT circuit breakers for feeders: Six
- Station supply transformer: 11 kV/415 V to be shown at LT side

Indicate earthing switch, coupling condensers, lightning arrestors, wave traps, PTs and CTs at appropriate places.

PROBLEM 2: Draw the single line diagram of a substation having the following equipment:

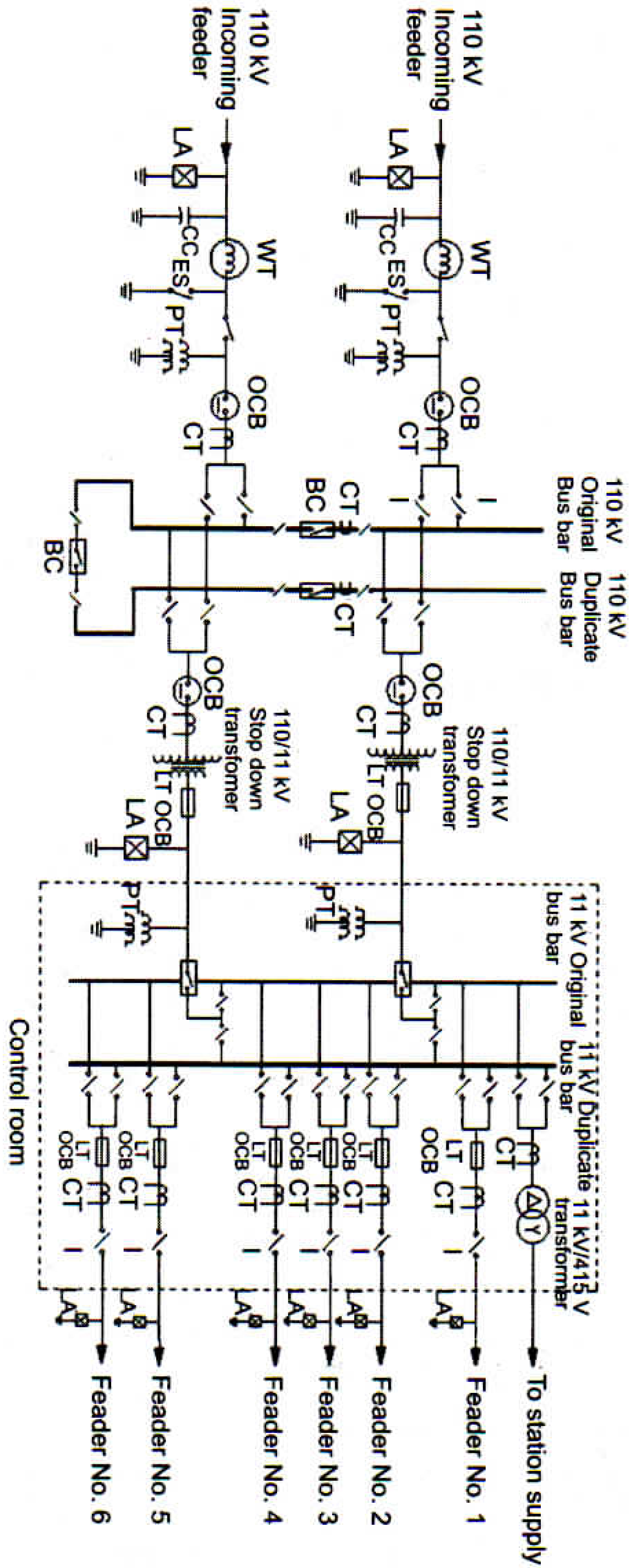
(i) Incoming lines: Two, 110 kV, 50 Hz
(ii) Outgoing lines: One, 110 kV, 50 Hz
Three, 11 kV, 50 Hz
(iii) Transformers: Two, 5 MVA, 110 kV/11 kV, 3 phase, Δ/Δ
One, 15 MVA, 110/220 kV, 3 phase, Δ/Δ
(iv) Auxiliary station transformer: One, 500 kVA, 11 kV/400 V, 3 phase, Δ/Y
(v) The station is connected to another substation through the 15 MVA transformer of 110/220 kV.

Show the positions of CT, PT, isolating switches, lightning arrestors and circuit breakers.

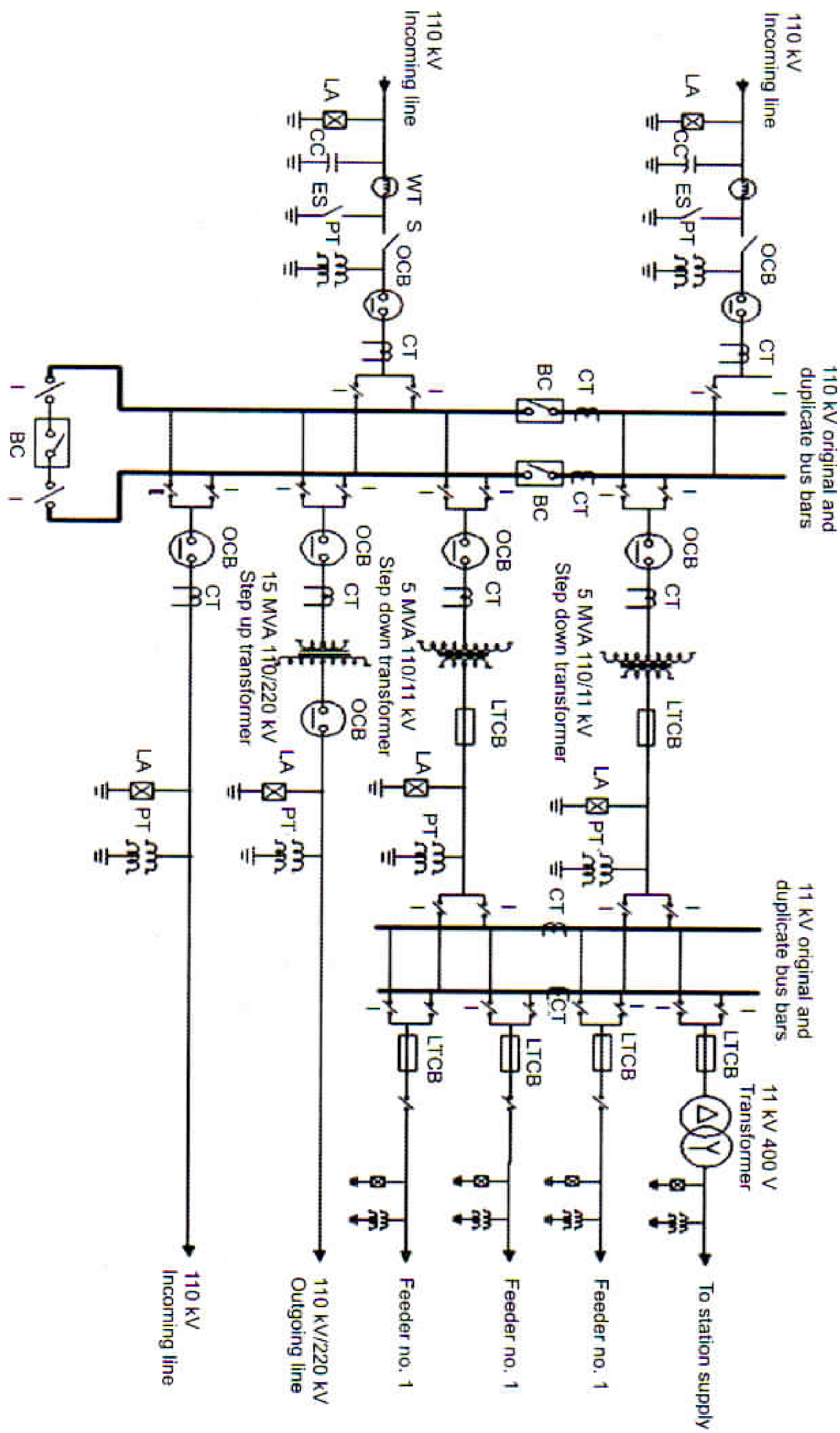
Sol :

CAD : Use the required commands and draw the single line diagrams. Highlight the symbols used by naming them using text command . Use layers and blocks if necessary.

The single line diagrams of problems 1 & 2 are drawn respectively in next pages.



110 kV Incoming feeder
110 kV Incoming feeder
LA
WT
CC
ES
PT
OCB
CT
110 kV Original Bus bar
110 kV Duplicate Bus bar
BC
CT
110/11 kV Stop down transfomer
LT OCB
11 kV Original bus bar
11 kV Duplicate bus bar
11 kV/415 V transformer
Control room
To station supply
Feeder No. 1
Feeder No. 2
Feeder No. 3
Feeder No. 4
Feeder No. 5
Feeder No. 6


110 kV
Incoming line
LA
CCT
WT
ES
PT
OCB
CT
110 kV original and
duplicate bus bars
BC
5 MVA 110/11 kV
Step down transformer
15 MVA 110/220 kV
Step up transformer
LTCB
11 kV original and
duplicate bus bars
11 kV 400 V
Transformer
To station supply
Feeder no. 1
110 kV/220 kV
Outgoing line
110 kV
Incoming line

PART – B

MODULE III : ASSEMBLY DRAWINGS :

(A) Transformer Assembly :

Introduction :

A *transformer* is a static electrical apparatus which transfers power from one circuit to the other which are electrically not connected but mutually coupled.

Transformer is considered as the heart of the power system as it is the main device in the process of transmission and distribution. A power system can never exist without a transformer. Depending on the usage, transformers are basically classified into two types namely:

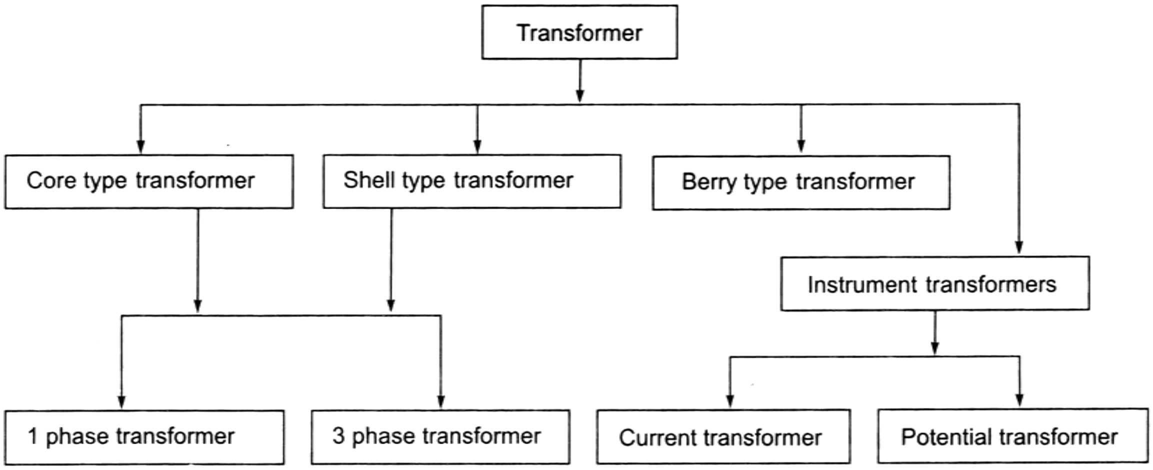
- ***Power transformer**:* These are the transformers used for transmission purposes.
- ***Distribution transformer**:* These are the transformers used for distribution purposes, i.e., distribution of power to the consumer.

Transformer is a job specific (tailor made) product and requires effort in its design and drafting, even if a single parameter is changed. Standardisation of the specification and design parameters of this vital equipment of energy transport will not only help in ensuring optimal deployment of available resources but also go a long way in economising the capital costs.

The efficiency of a transformer is usually very high when compared to other electrical machines and is of the range 90–95%, as the losses are minimal in the transformer. Theoretically, there exists a transformer which provides 100% efficiency and is known as *ideal transformer*.

Assembly refers to the detailed complete view of an object with all its parts assembled together. Assembly drawing is also known as detailed drafting and is necessary for fitting all the parts or assembling different parts of the item or machine together. Assembly is the area which deals with the complete dimension of the machine and its parts, which in turn helps to produce the various parts which constitutes the machine. It also gives a clear idea of which part is to be connected to which part, where and how so that it results in a complete faultless machine. It is always necessary to give the complete information to the lay man so as to obtain the machine.

Classification of transformers :



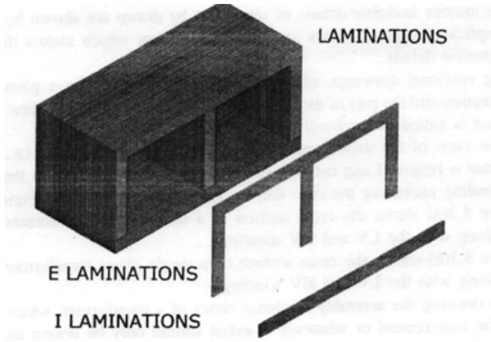
Core :

When voltage is applied to the exciting or primary winding of the transformer, a magnetising current flows in the primary winding. This current produces the flux in the core. The flow of flux in magnetic circuits is analogous to the flow of current in electrical circuits.

When the flux flows in the steel core, losses are occur. There are two components of this loss, which are termed 'eddy' and 'hysteresis' losses. *Hysteresis loss* is caused by the cyclic reversal of flux in the magnetic circuit and can be reduced by metallurgical control of the steel. *Eddy loss* is caused by eddy currents circulating within the steel induced by the flow of magnetic flux normal to the width of the core and it can be controlled by reducing the thickness of the steel lamination or by applying a thin insulating coating.

If a solid core were used in a power transformer, the losses would be very high and the temperature would be excessive. For this reason, cores are laminated from very thin sheets, such as 0.23 mm and 0.28 mm sheets, to reduce the thickness of the individual sheets of steel normal to the flux and thereby reducing the losses. Each sheet is coated with a very thin material to prevent shorts between the laminations.

Core steel can be hot or cold rolled, grain oriented or non-grain oriented, and even laser scribed for additional performance. The core cross section can be circular or rectangular, with circular cores commonly referred to as cruciform construction. Rectangular cores are used for smaller ratings and as auxiliary transformers used within a power transformer. Rectangular cores use a single width of strip steel, while circular cores use a combination of different strip widths to approximate a circular cross section. Just like other components in the transformer, the heat generated by the core must be adequately dissipated. While the steel and coating may be capable of withstanding higher temperatures, it will come in contact with insulating materials with limited temperature capabilities. In larger units, cooling ducts are used inside the core for additional convective surface area, and sections of laminations may be split to reduce localised losses.



There are two basic types of core construction used in power transformer: (i) core form and (ii) shell form.

(i) In *core form* construction, there is a single path for the magnetic circuit. For single phase applications, the windings are typically divided on both core legs. In three phase applications, the windings of a particular phase are typically on the same core leg. Figure 8.2 shows what is referred to as the 'E' and 'I' assembly of a three phase core form core during assembly.

(ii) In *shell form* construction, the core provides multiple paths for the magnetic circuit. Variations of three phase shell form construction include five and seven legged cores, depending on size and application.

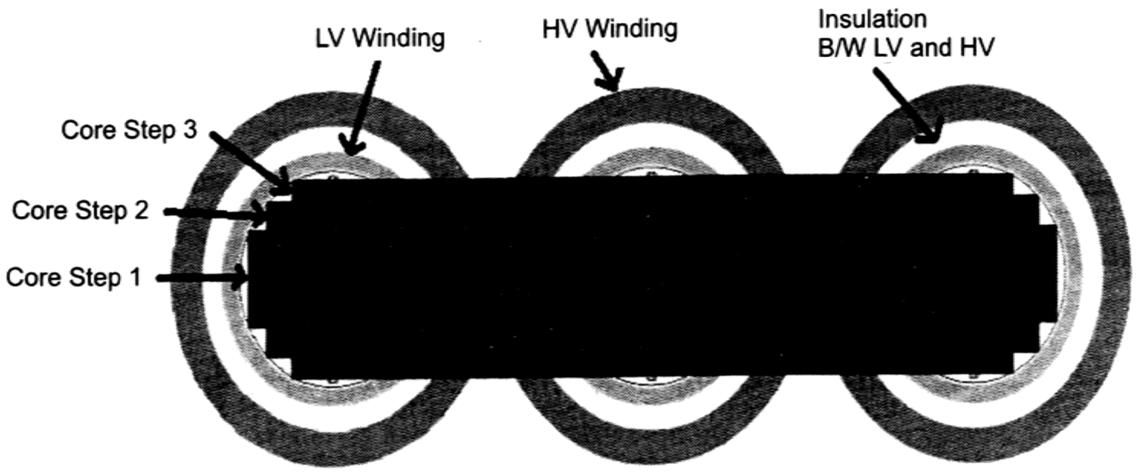
Sectional view :

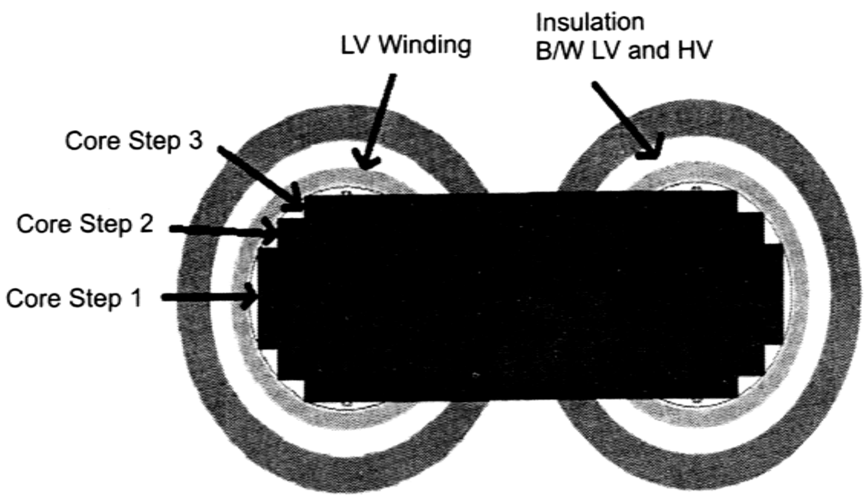
In drawing, the interior invisible details of objects to be drawn are shown by dotted lines but in case of complicated objects, views are drawn in section which makes the drawing more clear with its interior details.

In making sectional drawings, object is imagined to be cut by a plane in a particular position and direction and the part of the object is removed. The projected view of the remaining part of the object is called as *sectional view*.

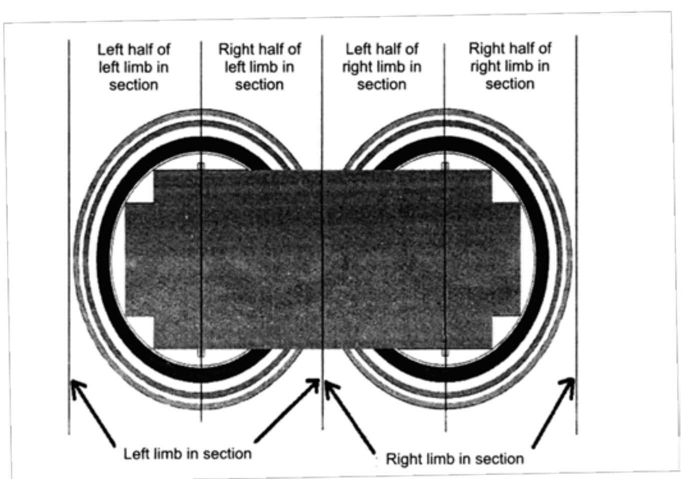
This is the view of the transformer that can be seen from the top, i.e., when the yoke of the transformer is removed and the transformer is seen from the top. In this view, only the core and the winding encircling the core will be visible as shown in the Figure 8.3(a).

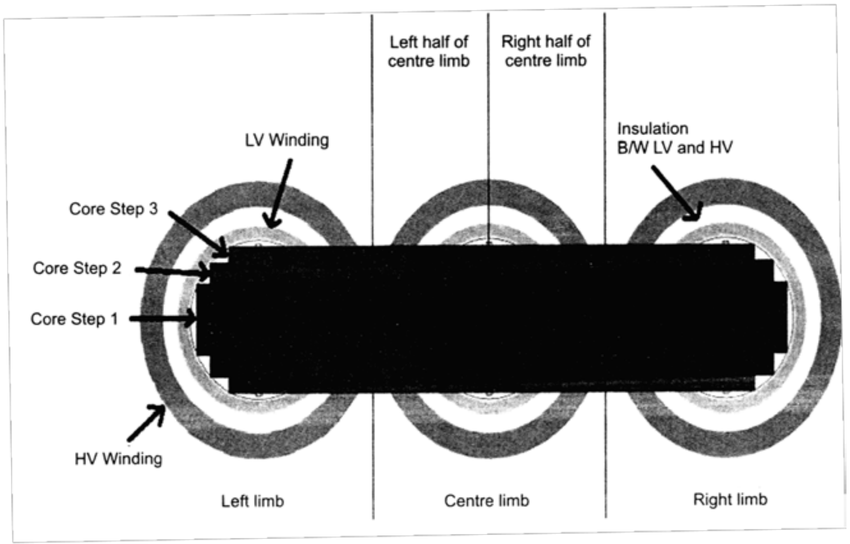
Cross Section of three phase & single phase transformer with 3 stepped core with LV & HV windings :





Elevation :

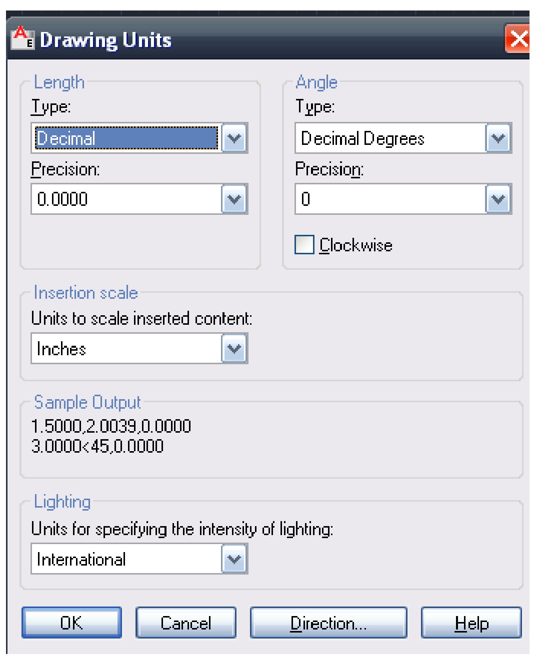


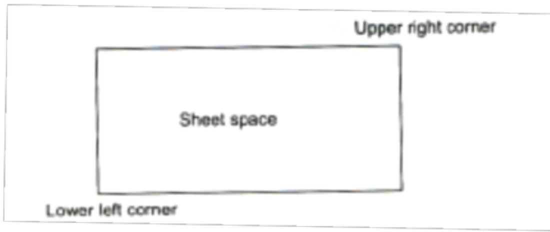


General procedure to draw assembly diagrams using CAD : (common to all problems)

Step 1 : Start AutoCAD . Set drawing units & limits --- Type units in command window to access units & type limits in cw to set limits as shown :

Lower left corner < 0,0 >
Upper right corner < 1500 , 1500 >





Step 2 : Use circle & line commands. Use modifiers when required and finally dimension the sketch.

PROBLEM 1: Design and draw the assembly of single phase core type transformer with the following details:

Core details:

3 stepped core
Distance between core centres = 48 cm
Diameter of circumscribing circle = 24 cm
Height of the core = 50 cm

Winding details:

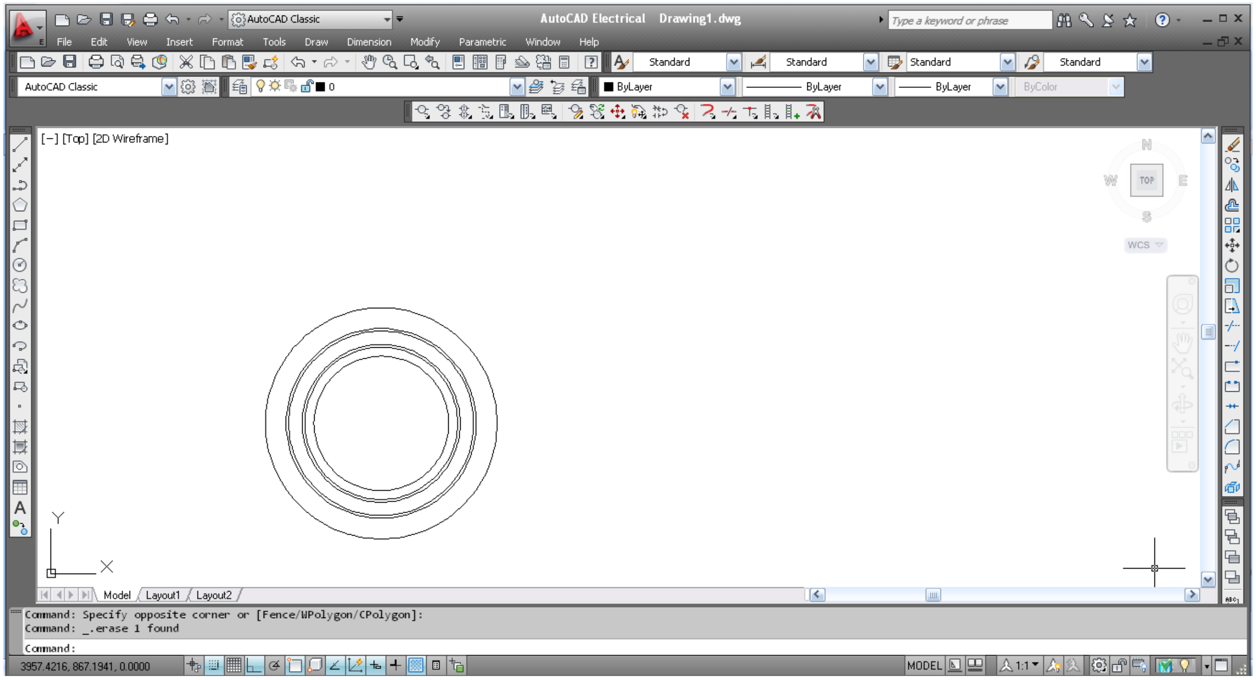
LV winding:

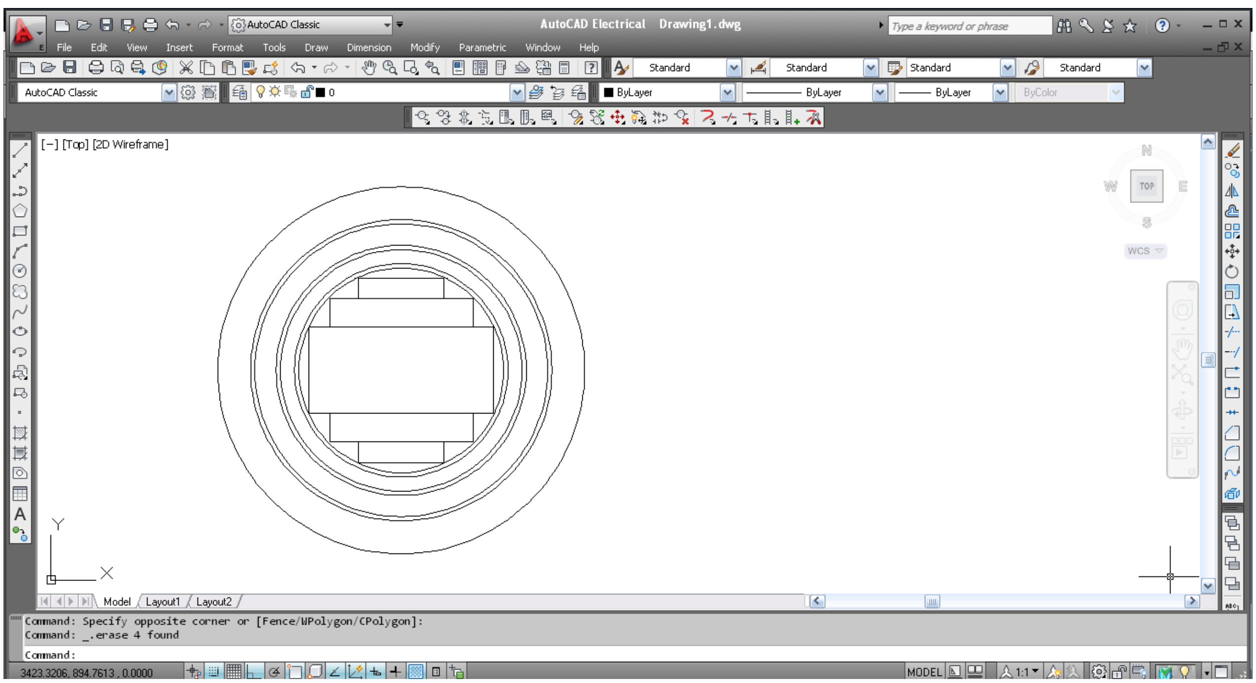
Outer diameter of first LV layer = 28.3 cm
Inner diameter of first LV layer = 25 cm
Outer diameter of second LV layer = 34.3 cm
Inner diameter of second LV layer = 29.3 cm

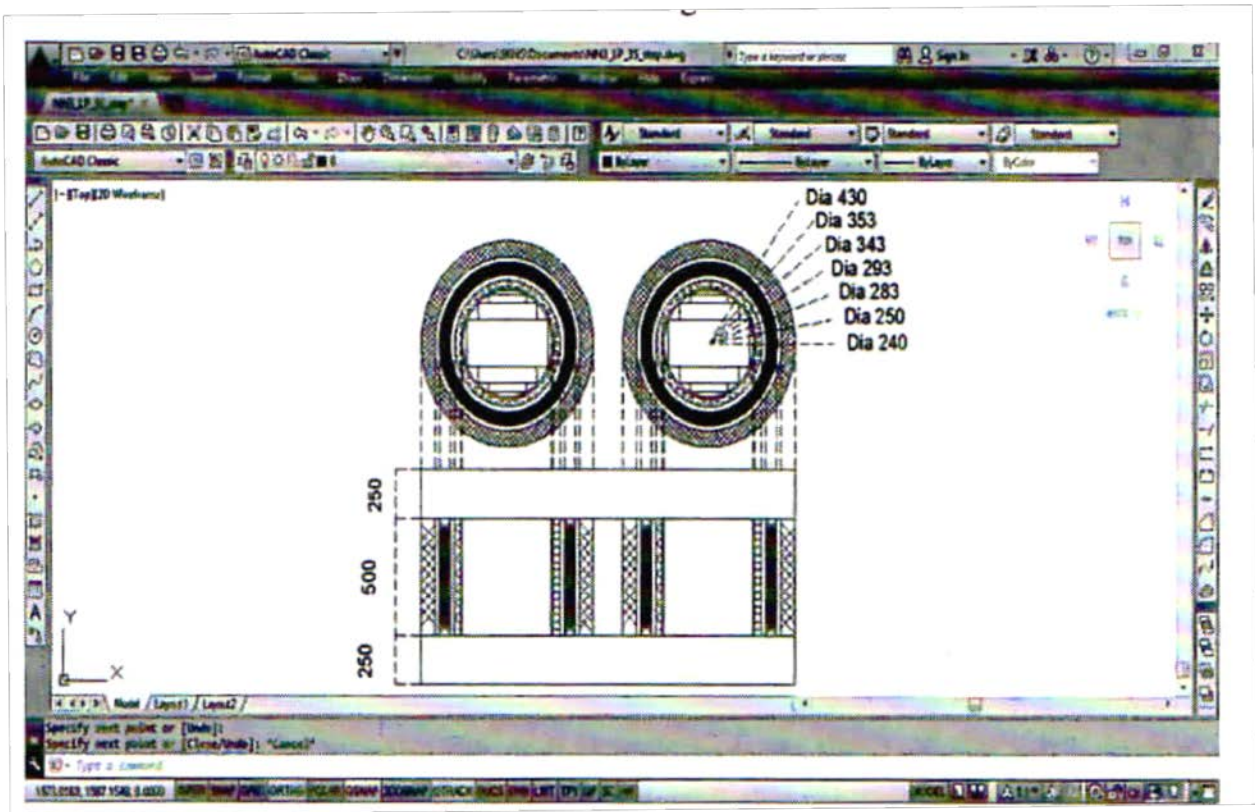
HV winding:

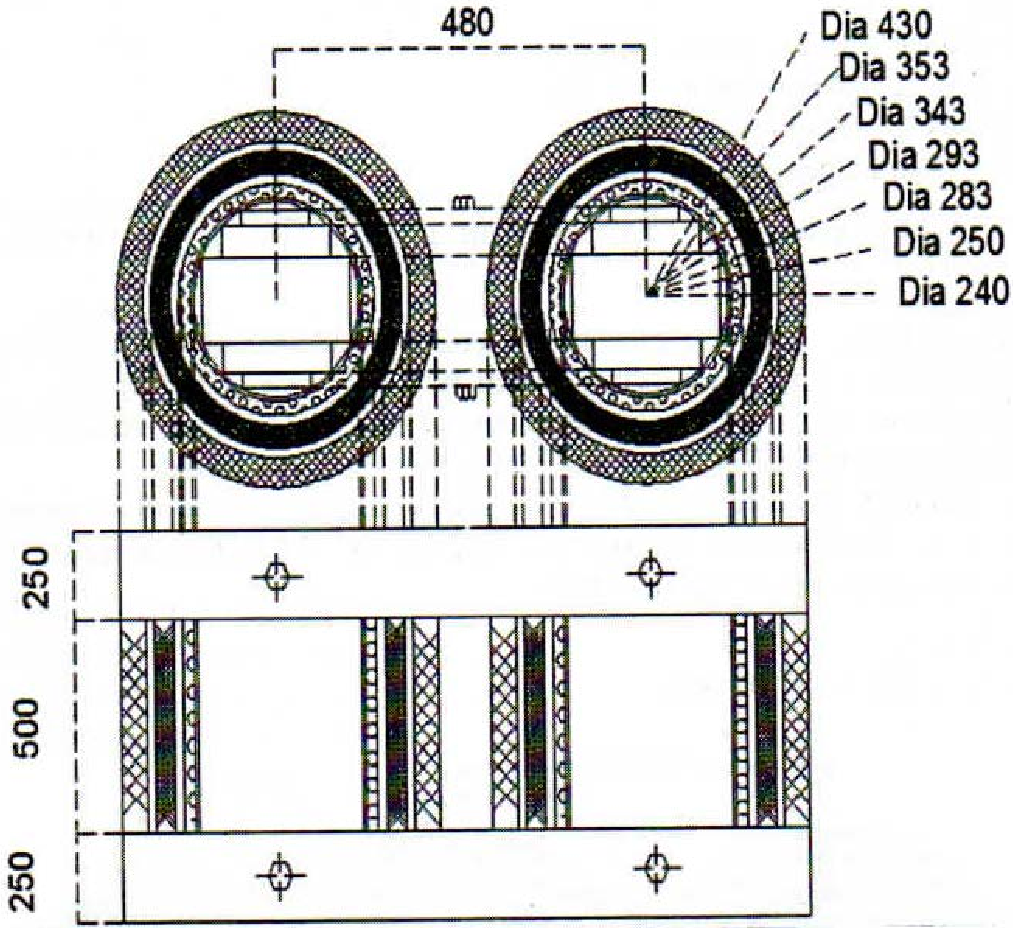
Outer diameter of HV layer = 43 cm
Inner diameter of HV layer = 35.3 cm

$a = 0.9 \times D$
$a = 0.9 \times 240 = 216$ mm
$b = 0.42 \times D$
$b = 0.42 \times 240 = 108$ mm


AutoCAD Electrical Drawing1.dwg
[−] [Top] [2D Wireframe]
Command: Specify opposite corner or [Fence/WPolygon/CPolygon]:
Command: _.erase 1 found
Command:


AutoCAD Electrical Drawing1.dwg
[−] [Top] [2D Wireframe]
Command: Specify opposite corner or [Fence/WPolygon/CPolygon]:
Command: _.erase 4 found
Command:


Dia 430
Dia 353
Dia 343
Dia 293
Dia 283
Dia 250
Dia 240
250
500
250


480
Dia 430
Dia 353
Dia 343
Dia 293
Dia 283
Dia 250
Dia 240
250
500
250

PROBLEM 2 : Draw the following views of a 1 phase, core type, 5 kVA, 380V/220V transformer with a frequency 50 Hz.

- Front elevation full in section
- Plan in full section

Dimension of various parts are given below:

Core:

Cross section of the core = 2 stepped core

Diameter of circumscribing circle = 14 cm

Distance between adjacent core centres = 33 cm

Yoke:

Height of the yoke = 8 cm

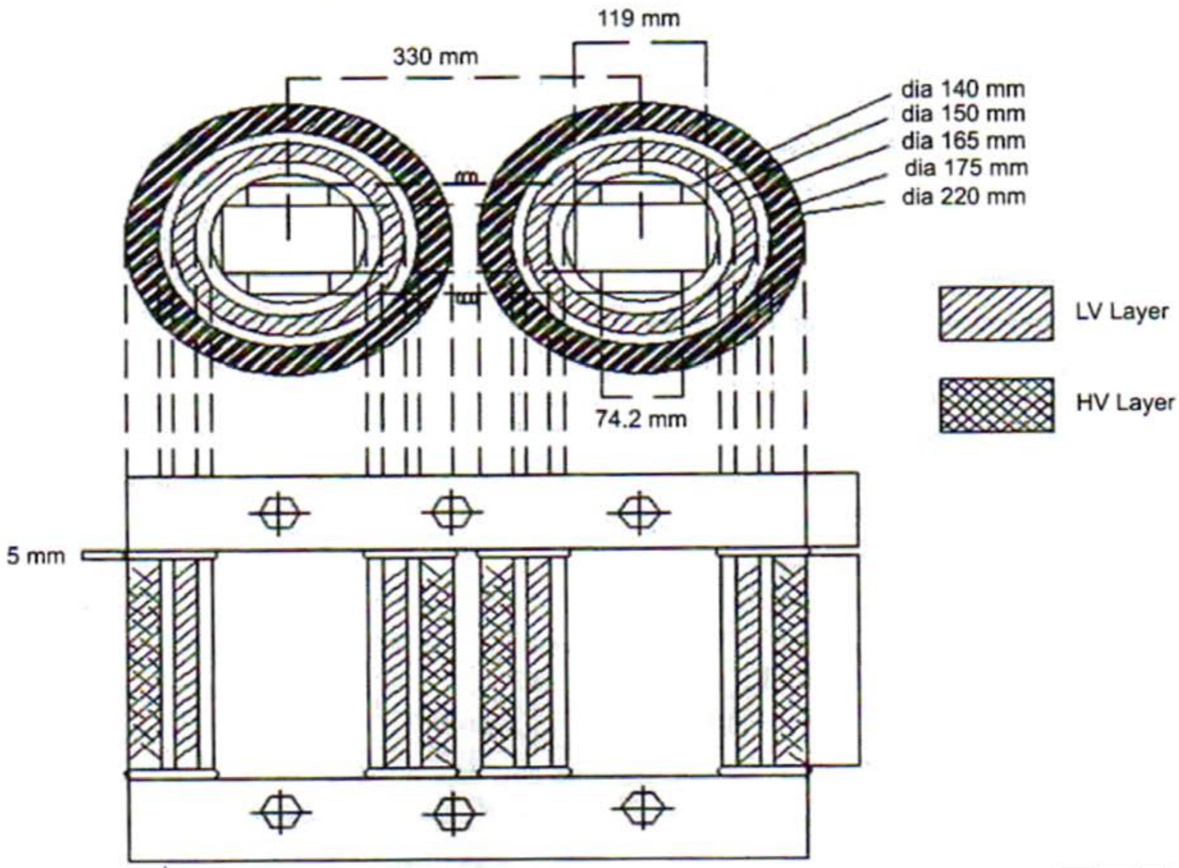
LV winding:

Outer diameter of LV coil = 21 cm

Inner diameter of LV coil = 17 cm

Height of LV winding = 23 cm

Number of turns per phase = 34



PROBLEM 3 : Draw the following views of a 3 phase, core type, 30 kVA, 2200V/400V transformer:

- Front elevation full in section
- Plan in full section

Dimension of various parts are given below:

Core:

Cross section of the core = 1 stepped core
Diameter of circumscribing circle = 250 mm
Distance between adjacent core centres = 465 mm

Yoke:

Height of the yoke = 200 m

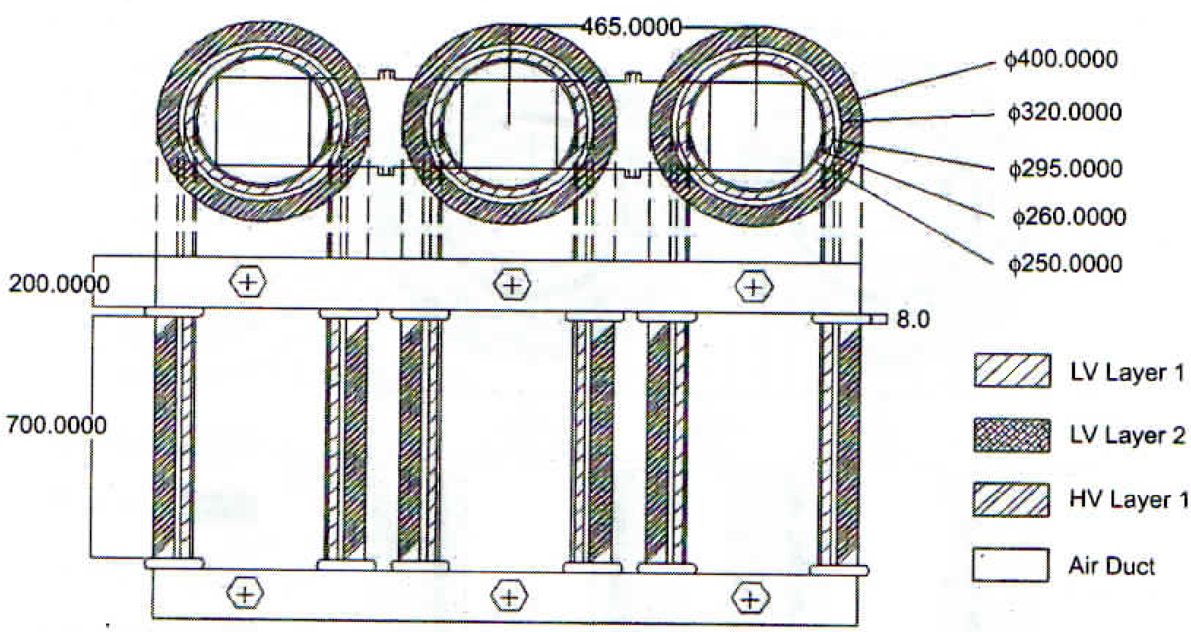
HV winding:

Outer diameter of HV coil = 400 mm
Inner diameter of HV coil = 320 mm
Height of HV winding = 700 mm
Number of turns per phase = 92

Total height of the transformer is 1150 mm. Assume any data missing.

Solution:

$a = 0.71 \times D$
$a = 0.71 \times 250 = 177.5$ mm



PROBLEM 4 : Draw the following views of a 3 phase, core type, 500 kVA, 6600V/415V transformer:

- Front elevation full in section
- Plan in full section

Dimension of various parts are given below:

Core:

Cross section of the core = 3 stepped core
Diameter of circumscribing circle = 25 cm
Distance between adjacent core centres = 70 cm

Yoke:

Height of the yoke = 14 cm

LV winding:

Outer diameter of LV1 coil = 29.5 cm
Inner diameter of LV1 coil = 26 cm
Outer diameter of LV2 coil = 38 cm
Inner diameter of LV2 coil = 34 cm
Height of LV winding = 48.5 cm

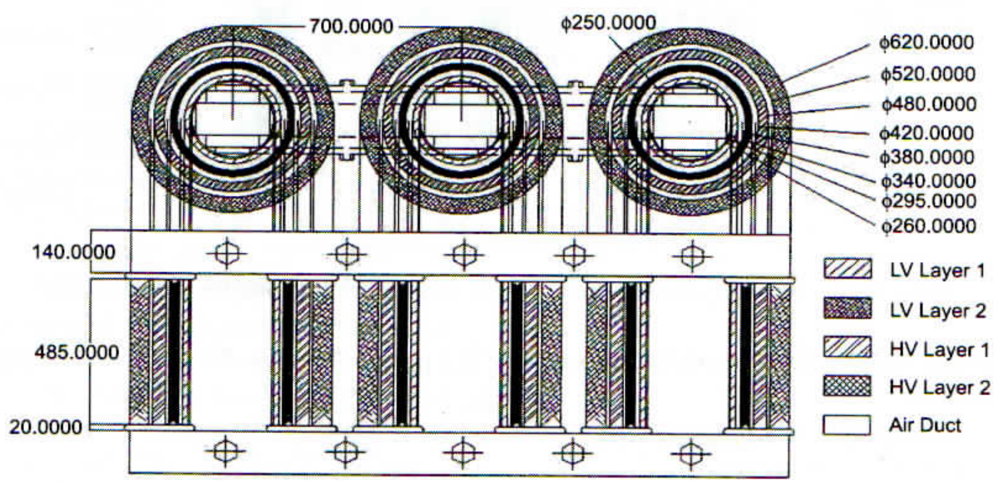
HV winding:

Outer diameter of HV1 coil = 48 cm
Inner diameter of HV1 coil = 42 cm
Outer diameter of HV2 coil = 62 cm
Inner diameter of HV2 coil = 52 cm
Height of HV winding = 48.5 cm

Total height of the transformer is 80.1 cm. Assume any data missing.

Solution:

$a = 0.9 \times D$
$a = 0.9 \times 250 = 225$ mm
$b = 0.42 \times D$
$b = 0.42 \times 250 = 105$ mm



PROBLEM 5 : Draw to suitable scale, the half sectional elevation and plan of a 10 kVA, 50 Hz, single phase, shell type transformer with following data:

Central leg = 280 mm
Outer leg = 140 mm
Yoke = 140 mm
Window = 800 mm

HV winding:

Number of turns = 1000
Number of layers = 12
Insulation of conductors = 0.5 mm

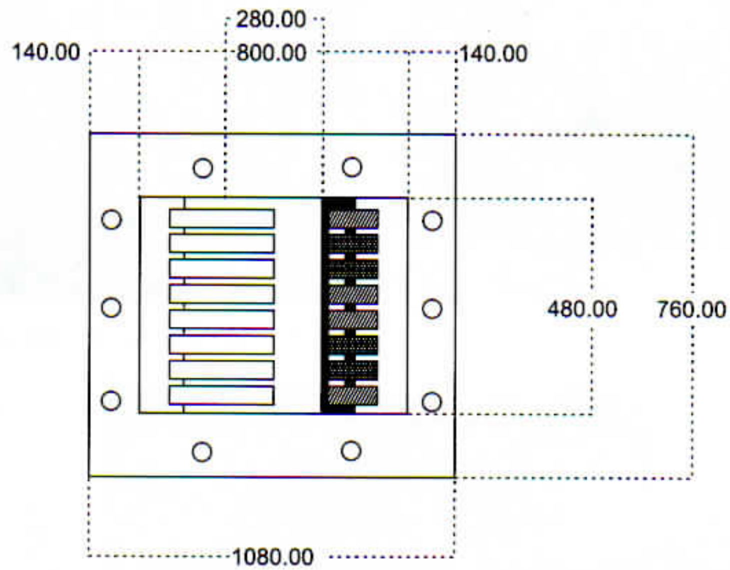
LV winding:

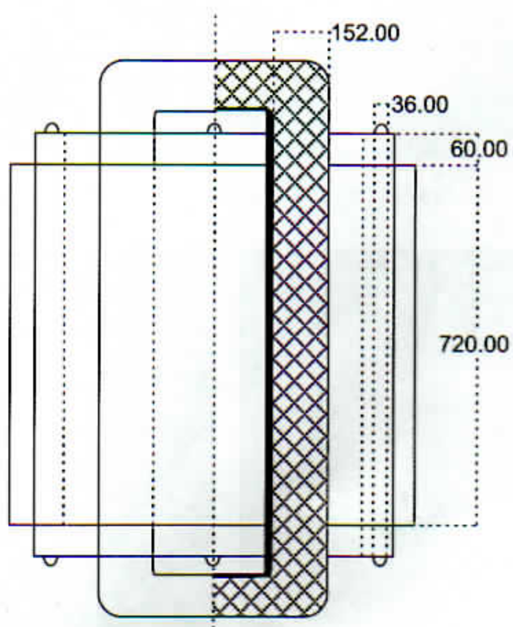
Number of turns = 100
Number of layers = 2
Insulation of conductors = 0.3 mm

Insulation:

Between the layers = 0.5 mm
Between core and LV winding = 2.5 mm
Between HV and LV winding = 3 mm

Assume any missing data.





MODULE - 4

(B) DC Machine Assembly :

Introduction :

DC machines are known for their uniqueness. Although the DC supply is not readily available, many industries and applications employ DC machines. Just by connecting the field winding to the armature in various combinations, DC machines can be operated as shunt, series and compound machines. They provide a wide range of voltage and current ratios along with a smooth control of speed.

DC machines are characterised by their versatility. By means of various combinations of shunt, series and separately-excited field windings, they can be designed to display a wide variety of volt-ampere or speed-torque characteristics for both dynamic and steady state operation. Because of the ease with which they can be controlled, systems of DC machines have been frequently used in applications requiring a wide range of motor speeds or precise control of motor output.

There are mainly two basic circuits used in any DC motor, the *armature* (the device that rotates sometimes referred to as a rotor) and the *field* (the stationary part, sometimes referred to as a stator). The two components magnetically interact with one another to produce rotation.

The armature rotates as a result of the repelling motion created by the magnetic flux of the armature, in opposition to the magnetic flux created by the field winding. The windings are placed in the slots of the armature.

There are many coils (windings) around the armature to allow for maximum generation of torque. The polarity of the armature coils must be reversed at the precise time to ensure that the repelling action continues. This action is called *commutation* and takes place when properly aligned brushes are contacting the commutator.

The parts of a DC machine may look slightly different, depending on manufacturer but all DC motors will have following components:

A DC Machine consists of:

Stator: Stationary part of the machine.

It consists of:

(a) Yoke/Frame
(b) Pole cores and pole shoes
(c) Field coils

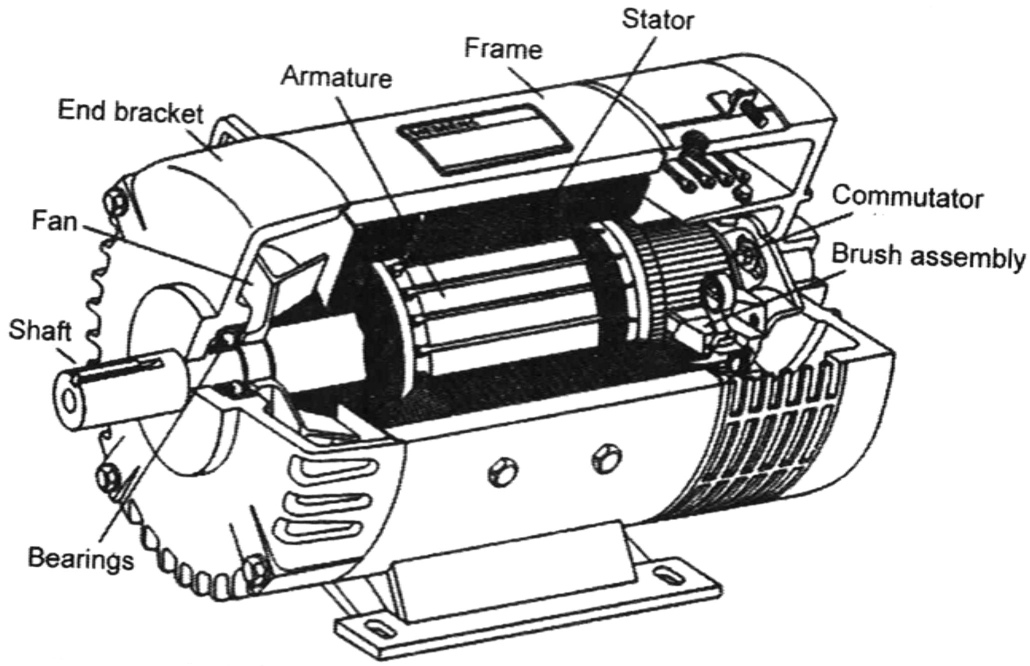
Rotor: Rotating part of the machine.

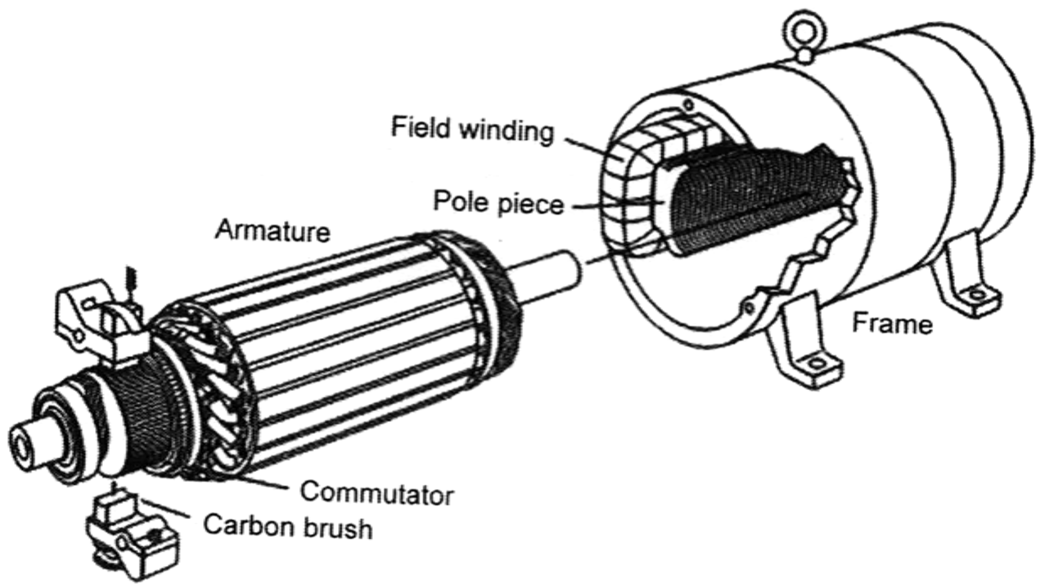
It consists of:

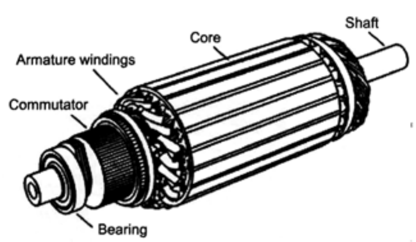
(a) Armature core and windings
(b) Commutator
(c) Carbon brushes

Other than that there are following several subsidiary parts:

1. *Armature core*: Central mass of iron on which windings are mounted.
2. *Armature slots*: Hollow spaces on core in which windings are placed.
3. *Shaft*: Circular supporting structure on which the entire armature section is balanced.
4. *Spider*: A metallic frame upon which armature laminations are assembled or mounted.
5. *Collar*: A metallic supporting structure which holds end plates supporting the laminations intact.
6. *Hexagonal nut*: Another metallic structure which holds the second end plate.
7. *Flange*: A metallic structure which secures the laminations intact which is bolted on either side.







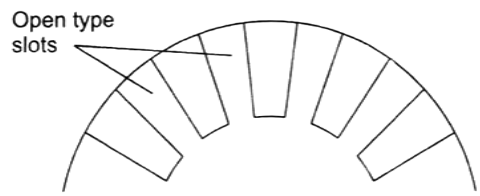
Construction of dc machine :

Slots :

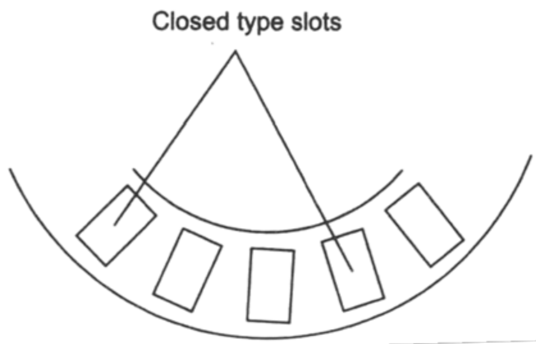
Slots are the paths or places in the armature where the conductors are placed to form the armature winding. They are mainly classified based on their appearance on the armature core and their application.

The slots in a machine are mainly of the following types:

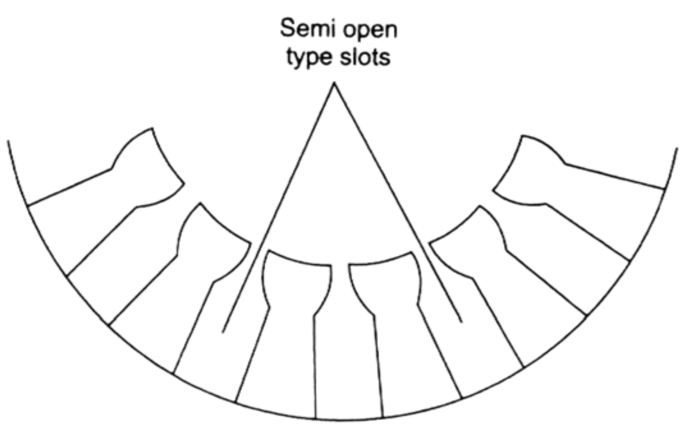
1. ***Open type*:** In this type of slots, the slots are open as shown in the Figure 6.5(a). The conductors are placed in these windings.



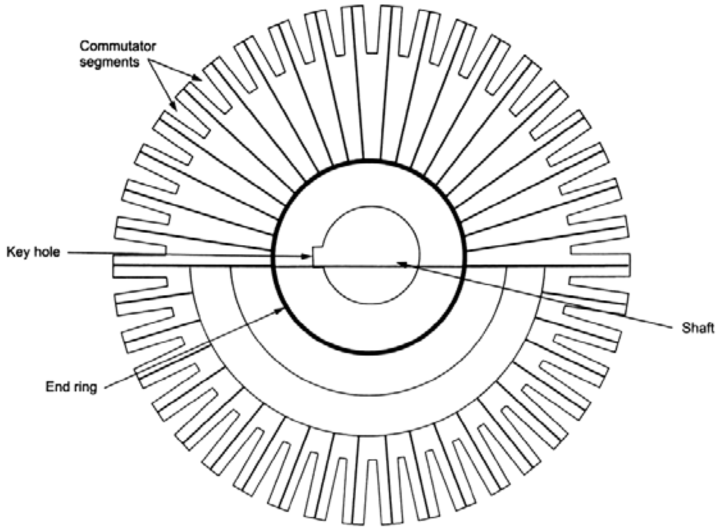
2. ***Closed type:*** In these kinds of slots, they are totally enclosed in the armature and the conductors are placed in the hollow paths as shown in the Figure 6.5(b).



3. ***Semi-enclosed or semi-open type:*** In these kinds of slots, they are neither completely open nor closed as shown in the Figure 6.5(c).



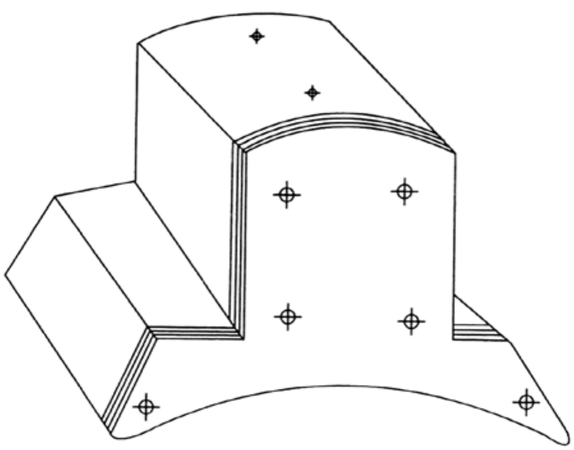
Commutator :



The armature has an integral part, called a *commutator*. The commutator acts as an electrical switch, always switching the polarity of the magnetic flux to ensure that a 'repelling' force taking place. Commutator of a DC machine is shown in Figure 6.6.

Pole :

The poles are wound with preformed copper, which is typically of rectangular shape, although round shaped coils are also used. In both cases, varnishing is the most common insulation method. First, a layer of insulation is assembled on the pole and then the winding is wound on it. The cross section of the field winding conductor may be round or rectangular.



General procedure to draw assembly diagrams using CAD : (common to all problems)

Step 1 : Start AutoCAD . Set drawing units & limits --- Type units in command window to access units & type limits in cw to set limits as shown :

Lower left corner < 0,0 >
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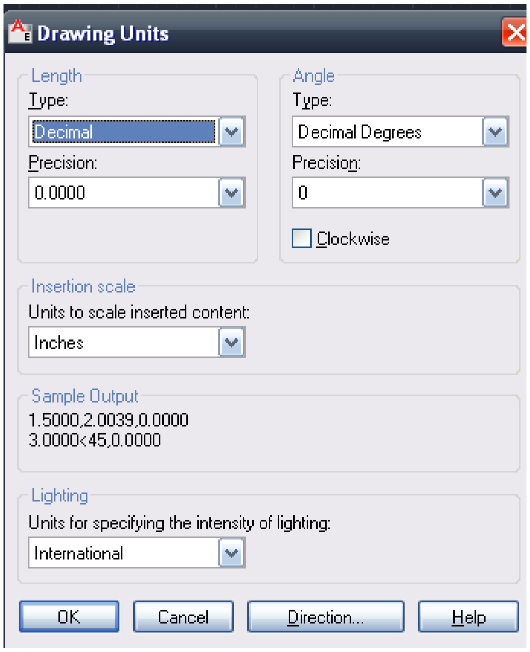
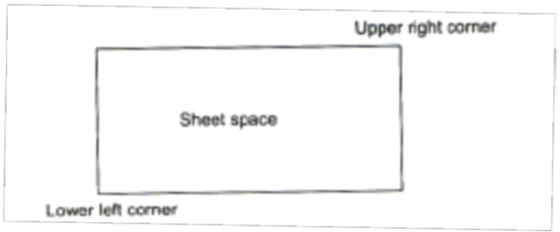




Step 2 : Use circle & line commands. Use modifiers when required and finally dimension the sketch.

PROBLEM 1: Draw a suitable scale end view elevation with top half in section of a DC machine, with the following details:

Yoke:

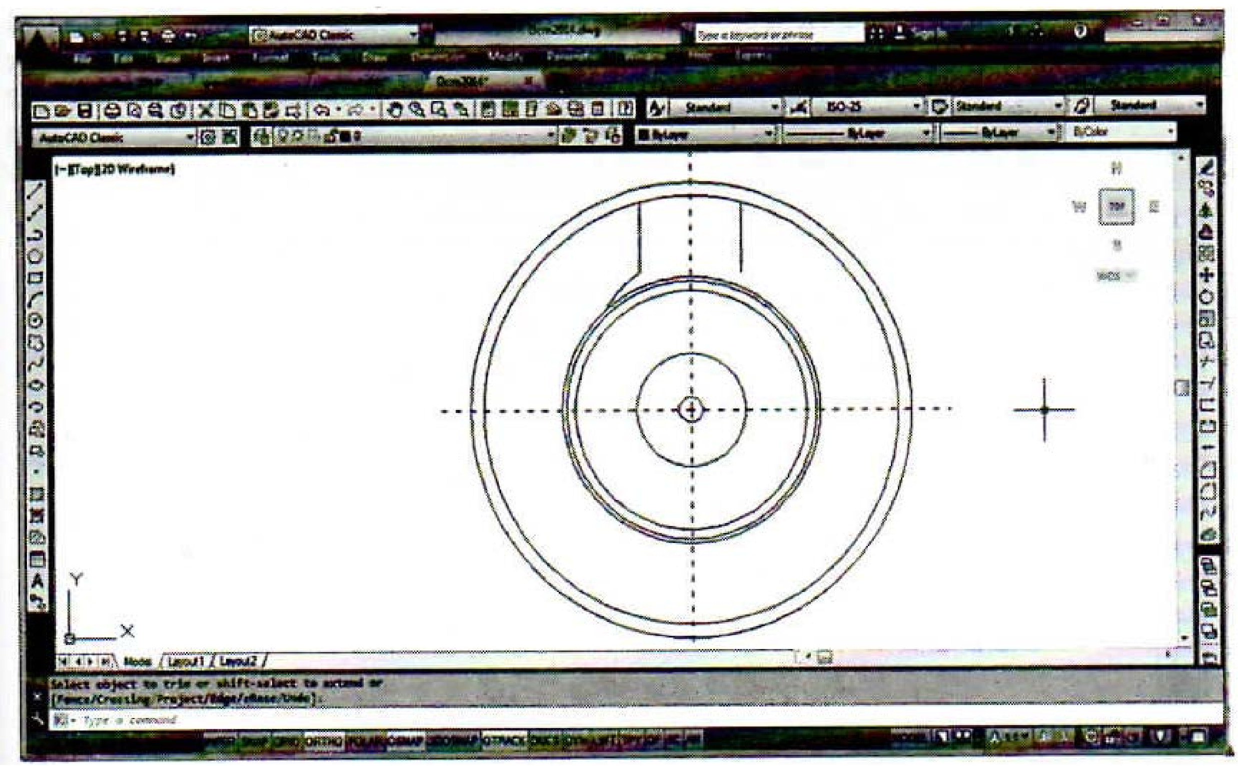
Outside diameter = 92 cm
Inner diameter = 86.5 cm
Axial length = 600 cm

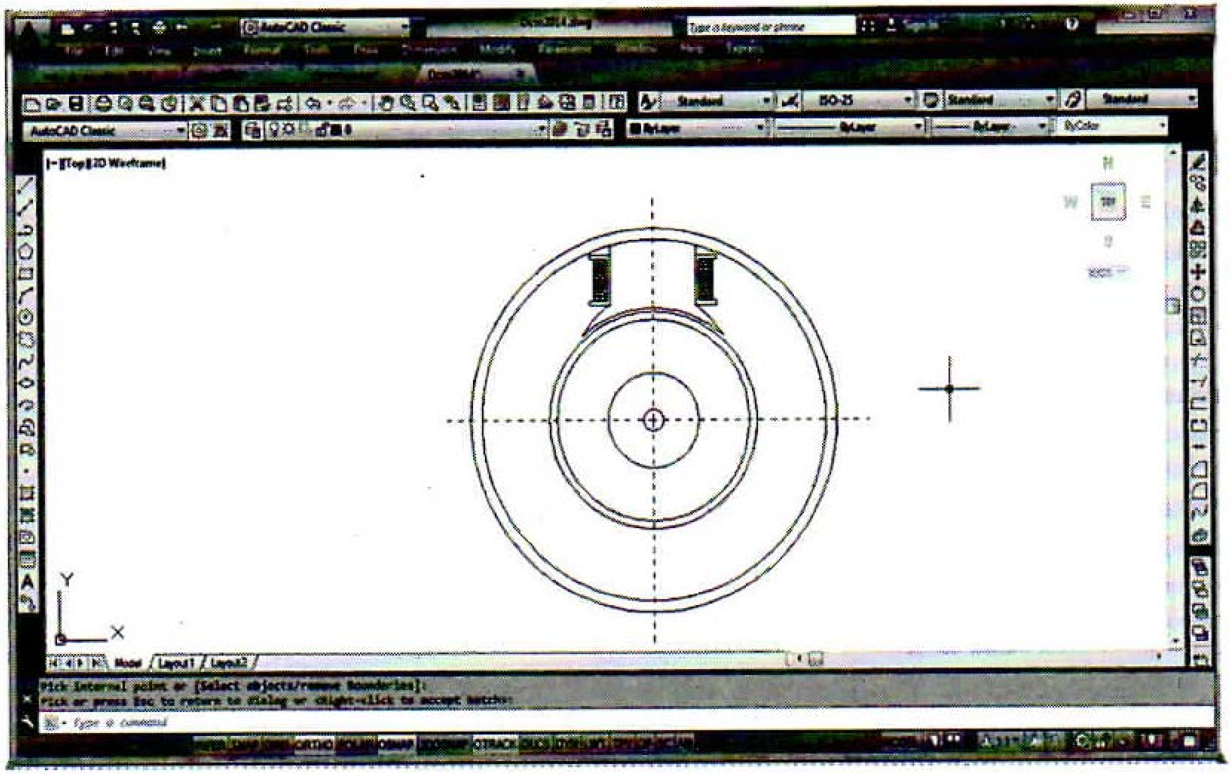
Armature:

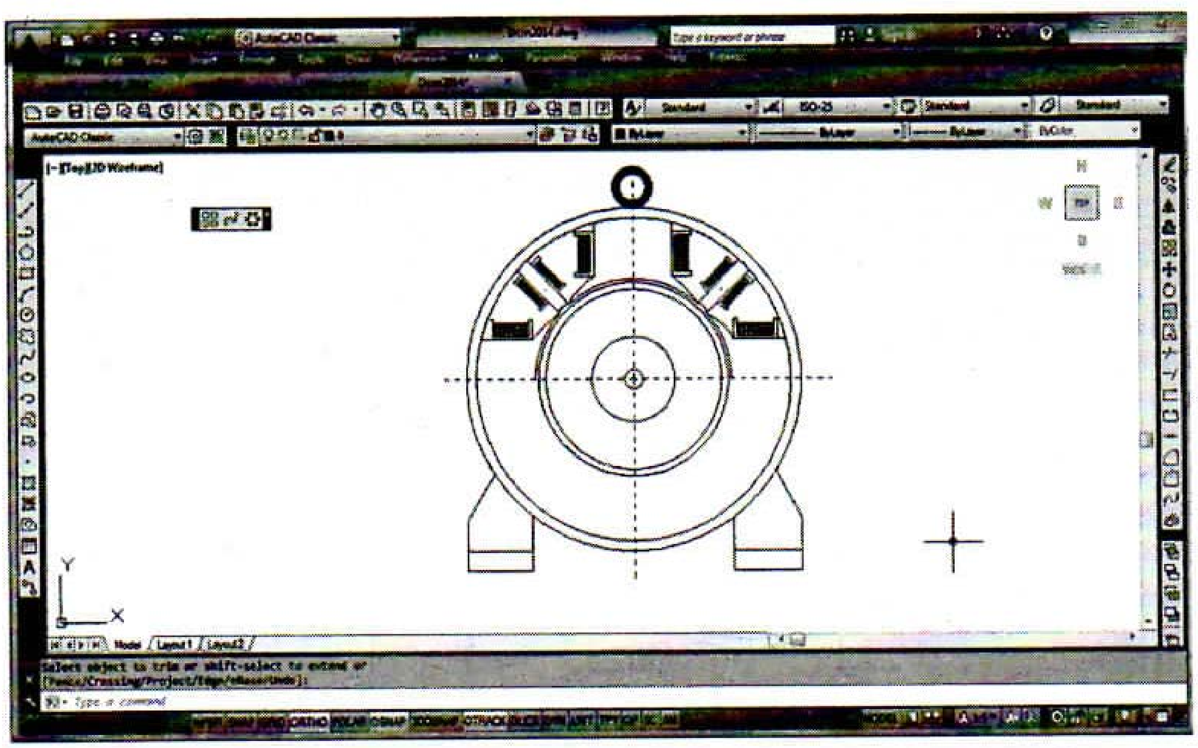
Diameter = 52.1 cm
Slot type = Open type
Slot dimension = 20 × 38 mm

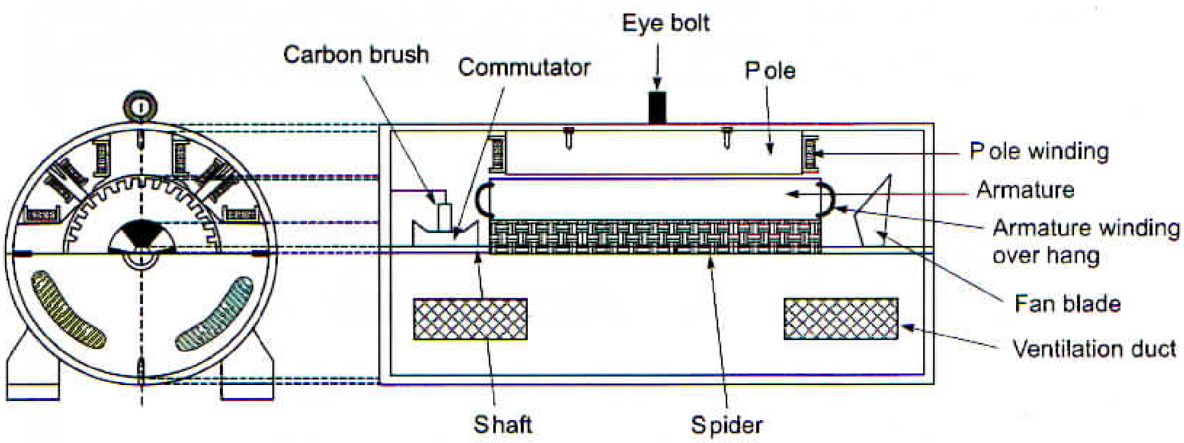
Main pole:

Number of poles = 4
Total height = 15.5 cm
Width = 21.4 cm
Air gap = 3 mm







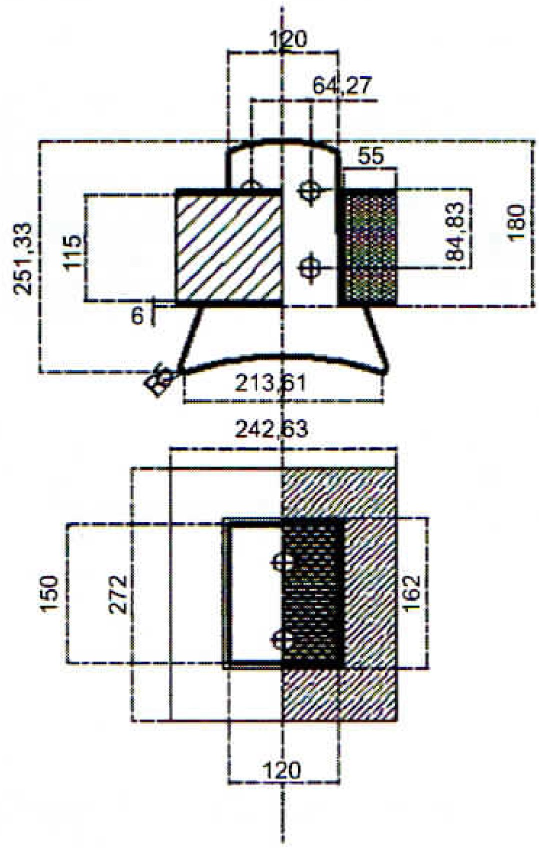


PROBLEM 2: Draw to suitable scale:

(a) Elevation with right half in section.
(b) Plan with right half in section.

Following are the details of a main pole of a DC machine:

(i) Number of poles = 4
(ii) Height of pole = 180 mm
(iii) Width of the pole = 120 mm
(iv) Length of the pole = 150 mm
(v) Armature diameter = 400 mm
(vi) Pole arc/pole pitch = 0.67
(vii) Number of turns/pole = 1890
(viii) Conductor area = 1.77 mm^2
(ix) Depth of the winding = 55 mm
(x) Height of the winding = 115 mm


120
64,27
55
251,33
115
84,83
180
6
213,61
242,63
150
272
162
120

PROBLEM 3: Draw to scale

(a) Half sectional end view and

(b) Front view of alternator with the following data:

(i) Diameter of shaft = 1.6 cm

(ii) Height of pole = 11 cm

(iii) Diameter of frame (outer) = 92 cm

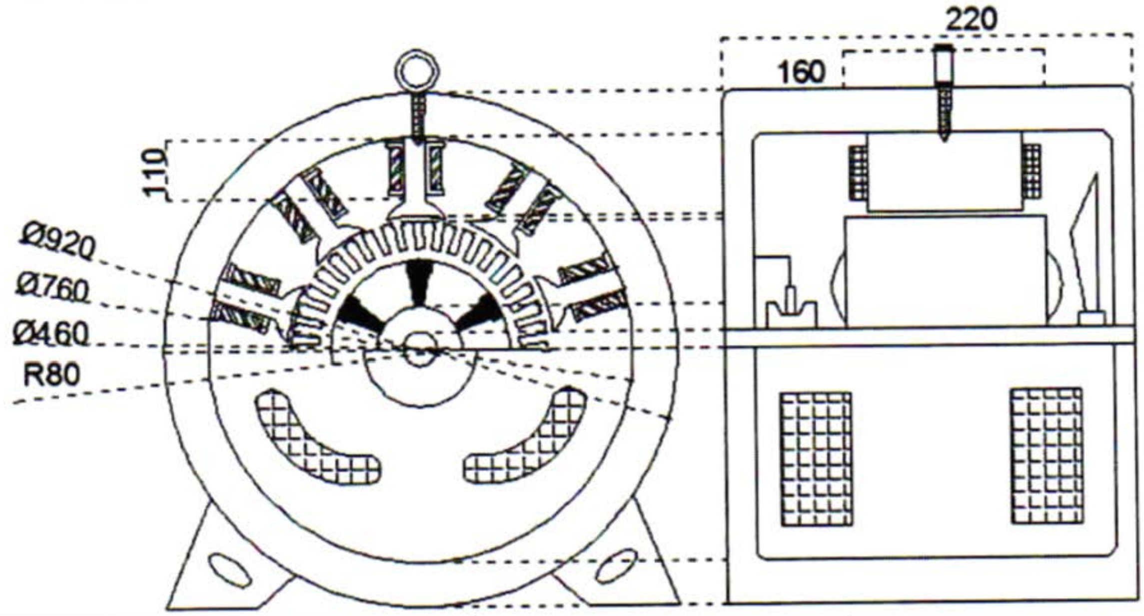
(iv) Length of yoke = 22 cm

(v) Diameter of the rotor = 46 cm

(vi) Outer diameter of the stator = 76 cm

(vii) Number of poles = 10

(viii) Length of stator = 16 cm



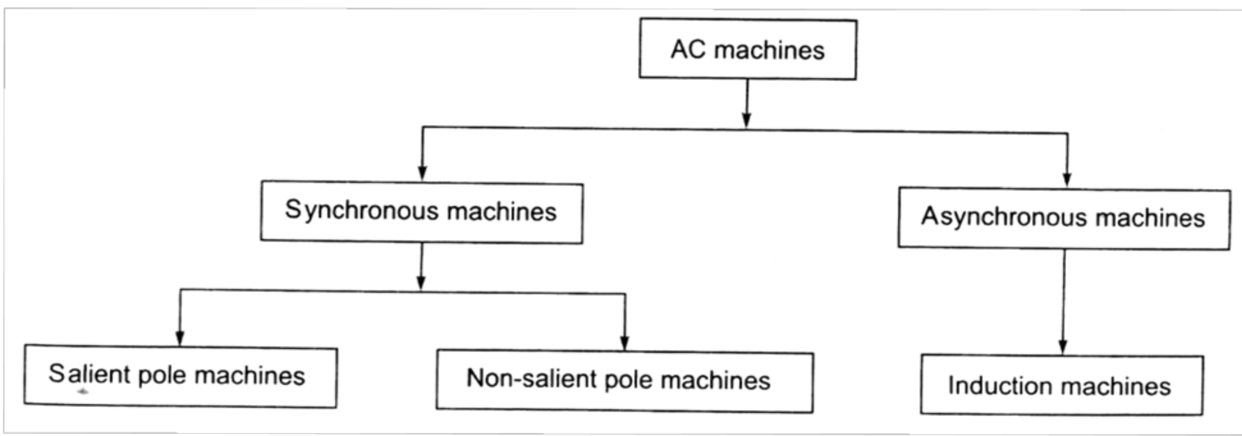
MODULE - 5

(C) AC Machine Assembly :

Introduction:

AC machines are widely used in almost all the places right from our houses to each and every industry. The design, structure, characteristics, cost, maintenance, speed control and flexibility of the machine to suit any environment, efficiency and reliability have made these machines to replace the DC machines in the industrial sector. The mode of power transmission in our nation is in AC; hence this reason also makes it the best choice when compared to DC machines since the AC power is not required to be converted into DC to operate AC machines.

Classification :



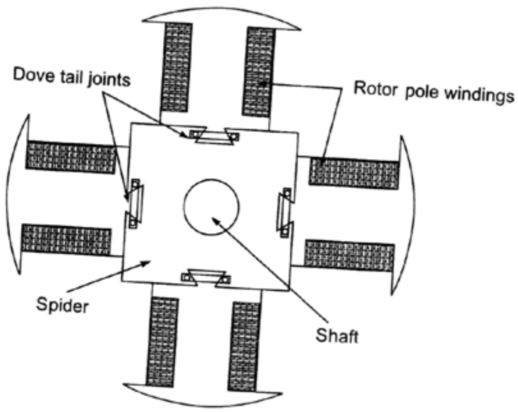
Synchronous machines :

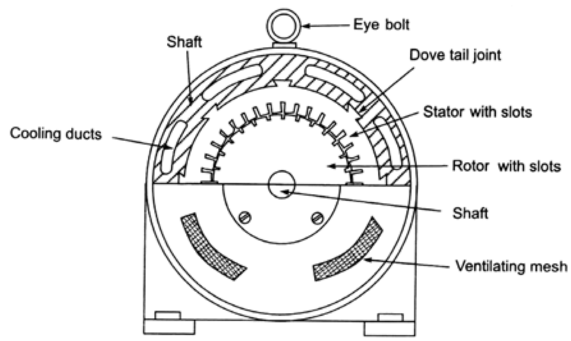
In these kinds of machines, the currents to the rotor winding are supplied directly from the stationary frame through a rotating contact.

In synchronous motors, the torque can be produced at synchronous speed by a field winding which is generally wound on the rotor and is excited by a DC supply such that it produces a rotor flux which is relatively static to the rotor. Hence, this results in the rotation of the rotor at synchronous speed Ns such that its field travels in step with the stator field axis. At speeds other than Ns, the rotor pole will approach alternately a stator 'north' pole field, then a 'south' pole field, changing the resulting torque from a positive to a negative value at a frequency related to the speed difference, the mean torque being zero.

Synchronous machines can be broadly classified into two kinds depending upon its rotor construction as salient pole machines and non-salient pole machines.

Salient and non salient pole synchronous machines :





The operating speed of the asynchronous machine is slightly less than the synchronous speed henceforth it is called as an *asynchronous machine*, because of its rigid characteristics in almost all the cases, these machines are used as induction motors for different applications.

Induction machines are considered as a boon to the industrial sector. The machine gains its name as induction machine as it works on the same principle as a transformer. These machines are also addressed as *rotating transformers*. In these machines, the rotor currents get induced in the rotor windings by a combination of the time-variation of the stator currents and the motion of the rotor relative to the stator. Rotor is not at all connected to any electrical supply but the rotor current is a result of induction effect. Only the stator is fed with the electrical supply in an induction machine.

Depending upon the rotor construction, induction machines can be classified into 2 different kinds, namely:

- Squirrel cage rotor
- Phase wound rotor or slip ring rotor

Squirrel cage rotor :

Induction machines which employ squirrel cage rotors, the speed variation is not possible since the rotor winding is completely shorted and accessing the rotor at any point of time is impossible. Here, the rotor windings are solid aluminium bars which are placed and moulded into the slots of the rotor and are shorted together on both the ends by cast aluminium rings.

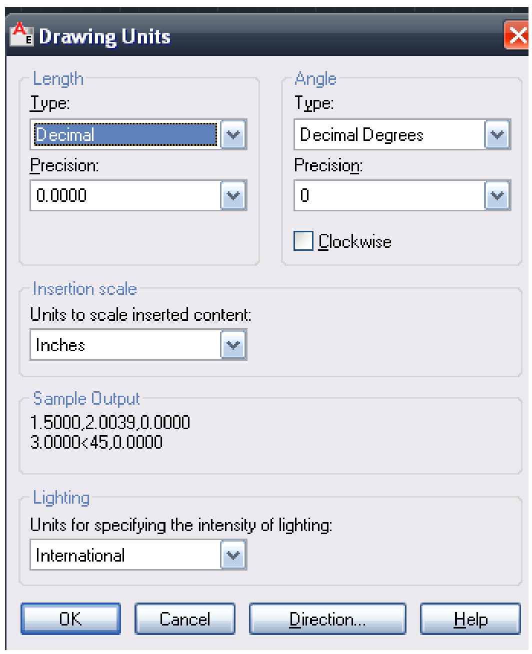
Slip ring induction machine :

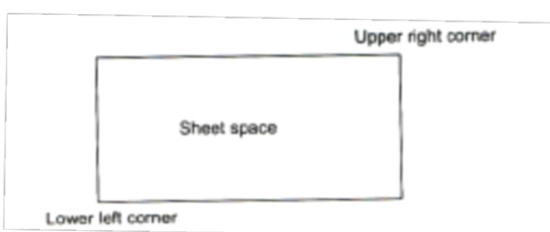
In slip ring induction machine, the connection in the rotor is star connected such that one end is completely shorted and at the other end it is connected to the Cu rings placed on the shaft of the machine to which external resistance can be conducted and the speed of the induction

General procedure to draw assembly diagrams using CAD : (common to all problems)

Step 1 : Start AutoCAD . Set drawing units & limits --- Type units in command window to access units & type limits in cw to set limits as shown :

Lower left corner < 0,0 >
Upper right corner < 1500 , 1500 >





Step 2 : Use circle & line commands. Use modifiers when required and finally dimension the sketch.

PROBLEM 1: Draw the following view of a 7 HP, 400 V, 50 Hz, 3 phase, 1440 RPM slip ring induction motor:

- Half section front elevation.
- Half section end view.

The main dimensions have been given below:

Outer diameter of the stator stamping is 28.8 cm
Stator core length is 10 cm
Thickness of the stator frame is 2.5 cm

Slot:

Type-open type
Number of slots is 36
Size is 14 mm × 6 mm
Air gap is 4 mm

Outer diameter of the rotor stampings is 21.2 cm
Inside diameter of the rotor stamping is 3.6 cm
Rotor core length 10 cm

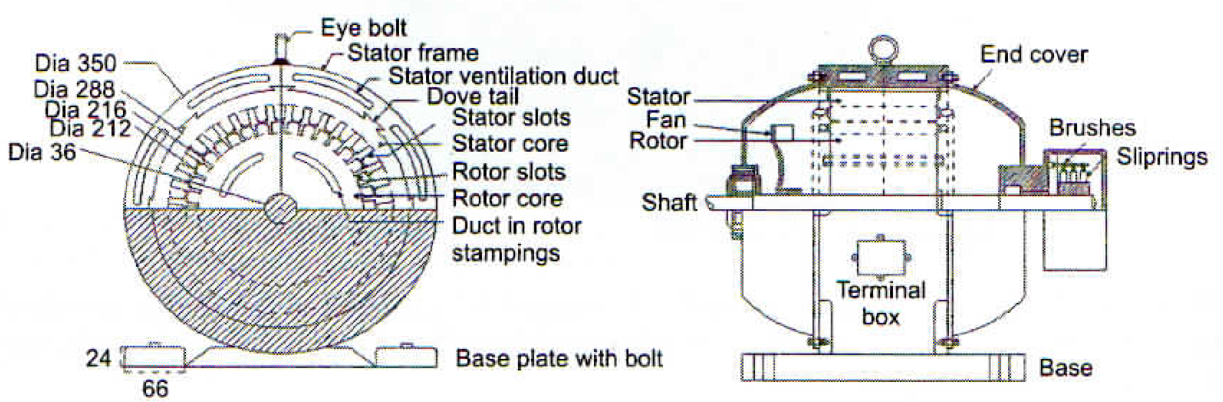
Slot:

Type-open type
Number of slots is 36
Size is 14 mm × 5 mm

Shaft diameter is 3.6 cm

Base plate thickness is 5 mm, with bolt dimension 24 mm × 66 mm.
The stator frame has eight and rotor stamping have four equally spaced ducts for ventilation.
Inside diameter of the stator stamping is 21.6 cm. (VTU June 2013)

Solution: Figure 7.6 shows the top half in section end view and elevated view of slip ring induction machine with the dimensions given above.



PROBLEM 2: Draw the following view of a 2 HP, 400 V, 50 Hz, 3 phase, 1440 RPM squirrel cage induction motor:

- Half section front elevation.
- Half section end view.

The main dimensions have been given below:

Outer diameter of the stator stamping is 17 cm
Inside diameter of the stator stamping is 14.2 cm
Stator core length is 8 cm
Thickness of the stator frame is 2 cm

Slot:

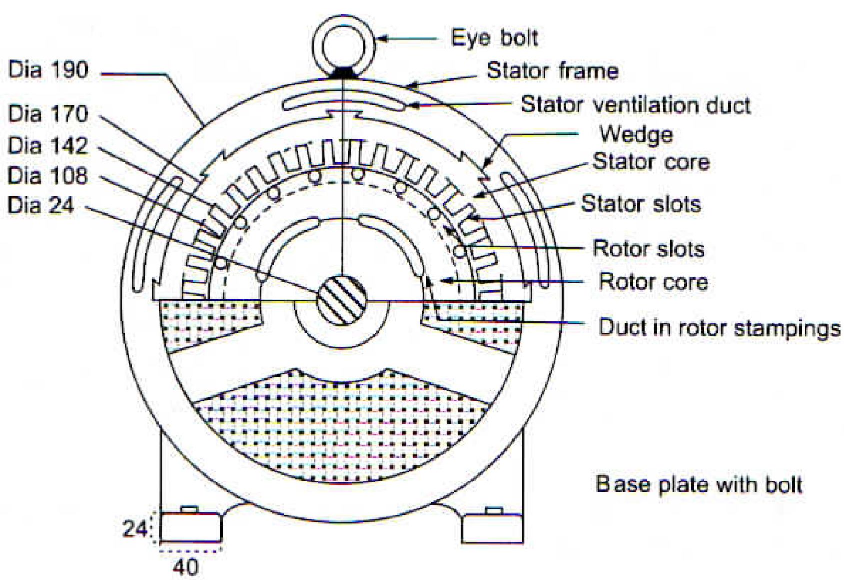
Type-open type
Number of slots is 36
Size is 10 mm × 6 mm
Air gap is 1.75 mm

Outer diameter of the rotor stampings is 10.8 cm
Inside diameter of the rotor stamping is 2.4 cm
Number of rotor slots is 16
Shaft diameter is 1.8 cm

The rotor has totally closed type slots and contains bare conductors which are short circuited at both sides.

Base plate thickness is 5 mm, with bolt dimension 24 mm × 40 mm.

Solution: Figure 7.10 shows the top half in section end view of squirrel cage induction machine with the dimensions given above.



PROBLEM 3: Draw the following view of a 3.5 HP, 400 V, 50 Hz, 3 phase, 1440 RPM squirrel cage induction motor:

- Half section front elevation.
- Half section end view.

The main dimensions have been given below:

Outer diameter of the stator stamping is 38 cm
Inside diameter of the stator stamping is 32.4 cm
Stator core length is 14 cm
Thickness of the stator frame is 2.5 cm

Slot:

Type-open type
Number of slots is 36
Size is 18 mm × 10 mm
Air gap is 7 mm

Outer diameter of the rotor stampings is 18.4 cm
Inside diameter of the rotor stamping is 4 cm
Number of rotor slots is 18
Shaft diameter is 2 cm

The rotor has totally closed type slots and contains bare conductors which are short circuited at both sides.

Base plate thickness is 5 mm, with bolt dimension 20 mm × 60 mm.

Solution: Figure 7.8 shows the top half in section end view and elevated view of squirrel cage induction machine with the dimensions given above.