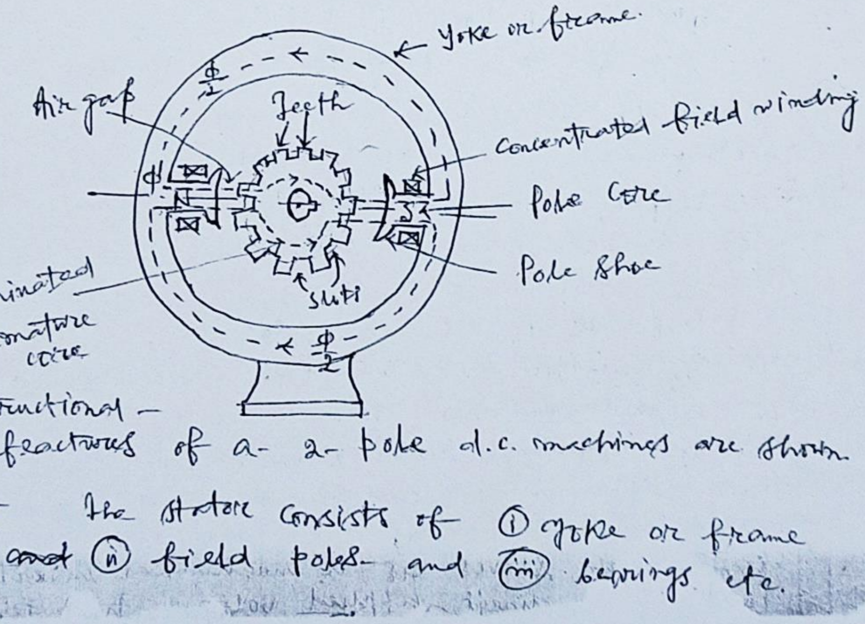
D.C. Machines :-

An electric machine is an electro-mechanical device or a dynamo-electric machine or more briefly dynamo which converts mechanical energy into electrical energy or viceversa. The machine which converts mechanical energy in to electrical energy is known as generator, while the machine converting electrical energy in to mechanical energy is called a motor.

D.C. machine is a highly versatile energy conversion device. It can meet the demand of loads requiring high starting torques, accelerating and decelerating ~~decelerating~~ torques. At the same-time, d.c. machine is easily adaptable for drives requiring wide range speed control and quick reversals.

Construction:- The armature of an electric machine is the part in which e.m.f. is generated in the case of a generator or the part in which the working current interacts to develop mechanical power in the case of a motor. The field member is the part that produces the magnetic field.

In a d.c. machine, the field winding is on the stator and the armature winding is on the rotor.



Constructional features of a 2-pole d.c. machines are shown.

Stator :- The stator consists of (i) yoke or frame ~~and~~ (ii) field poles and (iii) bearings etc.

The yoke or frame of a d.c. machine serves two functions. It forms a portion of the magnetic circuit and supports the poles. Also, it acts as a mechanical support for the entire machine.
Poles carry field windings and when the winding carries a current, the pole becomes an electromagnet and establishes the magnetic field in the machine.

Pole core is usually of smaller crossection than the pole shoe due to the following reasons–

ⓐ The reduced cross section of the pole core requires less copper for the field winding.

ⓑ The large pole shoe area increases the flux per pole entering the armature, due to the reduction in air-gap reluctance.

ⓒ Pole shoes provide mechanical strength and support to the field winding.

Rotor :– The armature of a d.c. machine is the revolving member under the poles and contains the conductors enclosed in slots. As the armature conductors go through N and S- poles alternatively, the voltage induced in the armature coils is an alternating one and has a frequency,

$$f = \frac{PN}{120}$$

where, P = No. of poles

N = Speed of revolution in r.p.m

Armature slots in a d.c. machine are normally rectangular in shape and the conductors, usually of copper, are placed in them in two layers.
The armature and the poles are usually made of silicon steel laminations to reduce hysteresis and eddy current losses in the machine.

In addition to the field and armature windings, a d.c. machine must have a commutator to serve as a mechanical rectifier for converting the alternating e.m.f generated in the armature winding to direct e.m.f at brush terminals. For a d.c. motor, the commutator serves as a mechanical inverter to invert the direct applied voltage to ~~the~~ alternating voltage

Commutator-
is a group of wedge shaped copper segments, insulated from eachother by thin mica sheets.

Direction of induced emf. — Fleming's right hand rules-

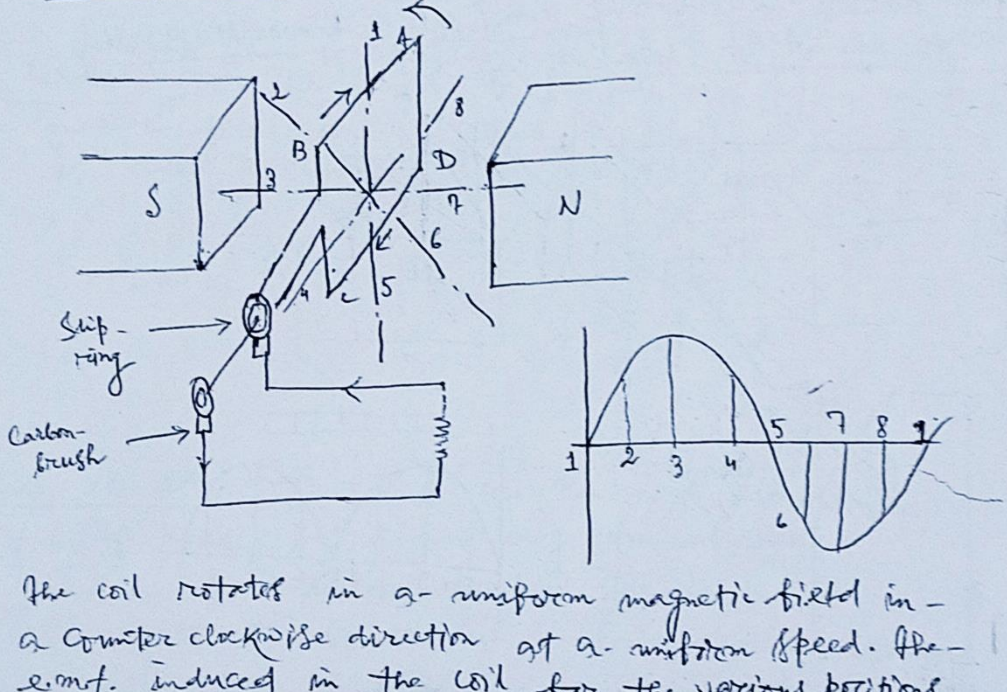
If the forefinger points along the line of flux and the thumb in the direction of motion of the conductor, the middle finger will point in the direction of induced emf..

The emf. induced e by a conductor of length l- metre cutting a flux density B wb./m² at a velocity v m/sec, is given by

$$e = Blv \text{ volts},$$

provided that B, l and v are mutually perpendicular.

Emf. generated by rotation of a coil:-



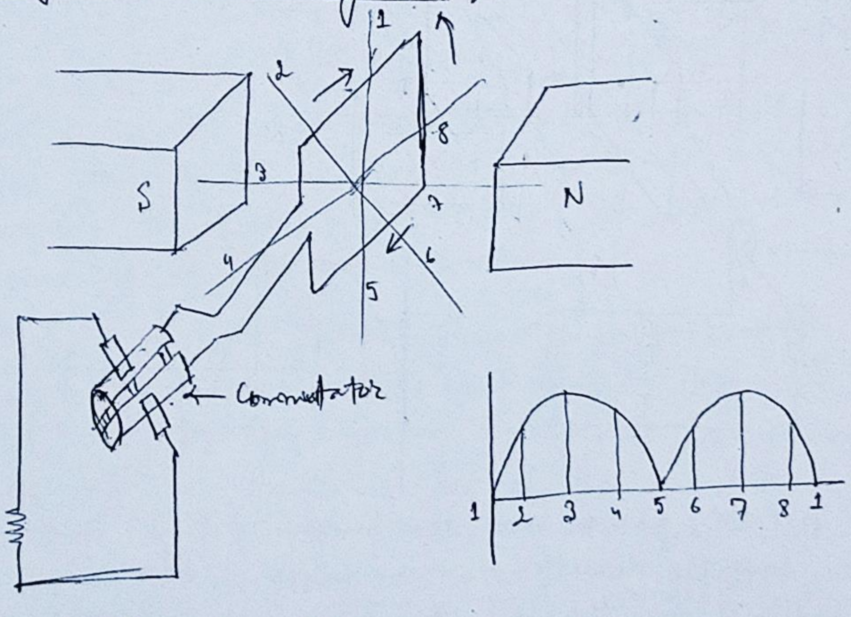
The coil rotates in a uniform magnetic field in a counter clockwise direction at a uniform speed. The emf. induced in the coil for the various positions 1 to 8, 9 is shown in the figure.

Emf. induced $e = N\frac{d\phi}{dt}$

When the plane of the coil is at right angles to lines of flux i.e, when it is in position 1, then flux linked with the coil is maximum but rate of change of flux linkages is minimum. Because, in this position, the coil sides AB and CD slides and they move parallel (rod 4) to them. Hence, there is no induced e.m.f. in the coil.

At position 3, coil plane is horizontal, i.e., parallel to the lines of flux. The flux linked with the coil is minimum, but rate of change of flux linkage is maximum. Hence, maximum e.m.f. is induced in the coil. It is seen that the e.m.f. induced is an alternating e.m.f. and is varying sinusoidally. This alternating e.m.f. can be impressed on an external circuit by means of two slip-rings. Each ring is continuous and is insulated from the other ring and from the shaft. A metal or carbon brush rests on each ring and conducts the current from the coil to the external circuit.

<u>Conversion of alternating e.m.f. to unidirectional voltage using commutator segments:-</u>



The rectification of alternating voltage to a direct voltage can be accomplished by using split ring i.e., commutator segments. Instead of two slip rings only one ring or commutator is used. The commutator is split in to two segments (each segment insulated from the other) and the ends of coil are connected to the segments produced.

make contact alternatively to a particular segment moving under a given pole flux and hence, the voltage in the external circuit becomes unidirectional. Even though the voltage becomes unidirectional, it is not of a constant magnitude. This can be achieved by connecting more no. of coils and hence, with more no. of commutator segments.

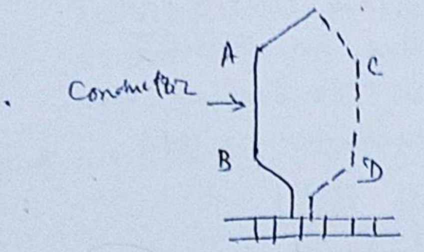
Armature Windings :-

Pole Pitch :- It may be defined as -

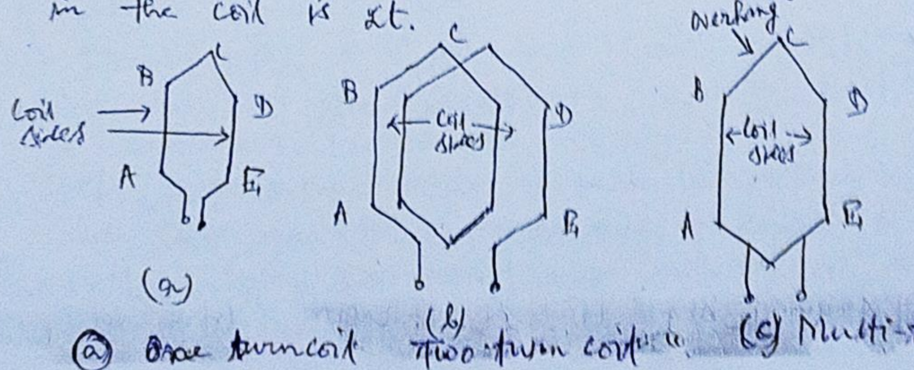
(i) the peripheral distance between two adjacent poles, i.e., the periphery of the armature divided by the no. of poles.

(ii) It is equal to the no. of armature conductors or armature slots per pole. If there are 48 conductors and 4 poles, then pole pitch $= \frac{48}{4} = 12$.
Pole pitch is always equal to 180° electrical.

Conductor :- The length of a wire lying in the magnetic field and in which an e.m.f. is induced, is called a conductor. For example, length AB or CD.



Coil, coil side, Turn :- A coil can have one or more no. of turns, but it has only two coil sides.
The no. of conductors per coil side is t if t is the no. of turns per coil and the no. of conductors in the coil is 2t.

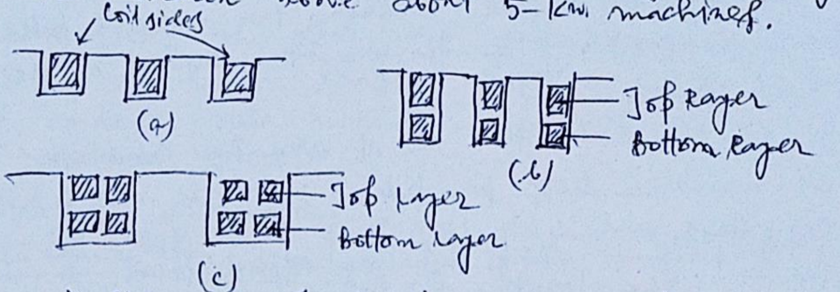


(b)
(a) One turn coil   Two turn coil   (c) Multi-turn coil

BCD - is called the end connection or overhang.

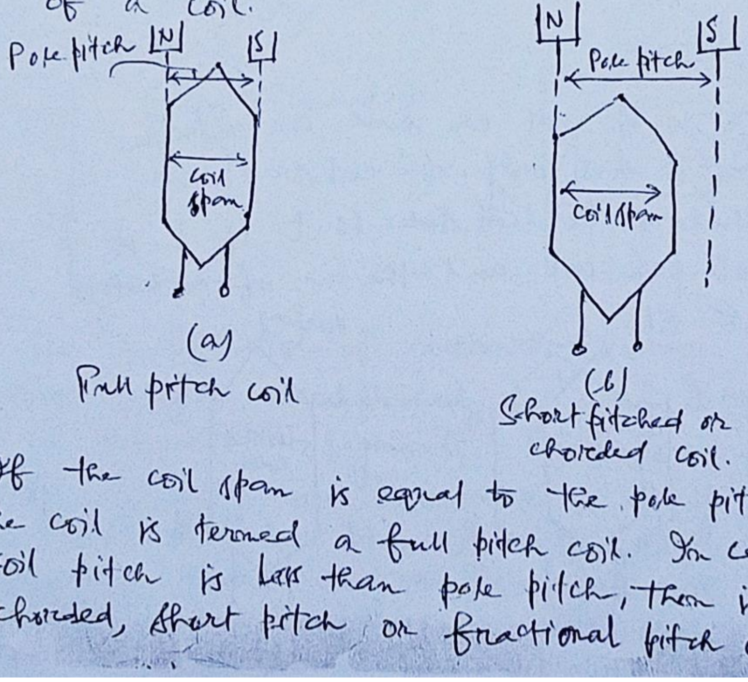
<u>Single layer and double layer winding :-</u>

If the winding is so designed that one coil side occupies the total slot area, then it is called a single-layer-winding. In case, the slot contains even no. (may be 2, 4, 6 etc) of coil sides in two layers, the winding is referred to as a two layer-winding. Single layer winding is used only in small a.c. machines, where as double layer winding is more common above about 5-kw. machines.



(a) one coil side per slot (b) two coil sides per slot
(c) 4- coil sides per slot.

<u>Coil span or Coil pitch :-</u> The distance between the two coil sides of a coil is called coil-span or coil-pitch. It is usually measured in terms of armature slots or armature conductors between the two sides of a coil.



(a)
Full pitch coil

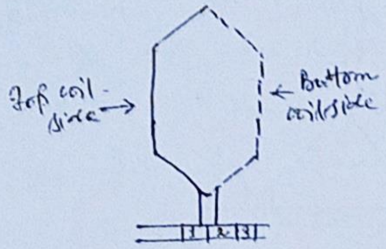
(b)
Short pitched or chorded coil.

If the coil span is equal to the pole pitch, then the coil is termed a full pitch coil. In case, the coil pitch is less than pole pitch, then it is called chorded, short pitch or fractional pitch coil.

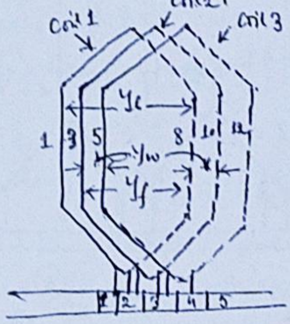
If there are S-slots and P-poles, then
pole pitch = $\frac{S}{P}$ slots per pole.
If coil pitch = $\frac{S}{P}$, it results in full-pitch winding.
In case, coil pitch $< \frac{S}{P}$, it results in chorded, short-pitched or fractional pitch winding. The coil-pitch is rarely greater than pole pitch.

Closed windings:– Closed armature windings are always double layer windings. Each coil in double layer winding has its one coil side in top layer and its other coil side in the bottom layer. Top coil side is shown with a solid line and the bottom coil side by a dotted line.

The simple closed windings are of two types–
(i) Simplex lap winding and (ii) Simplex wave winding.



(a)

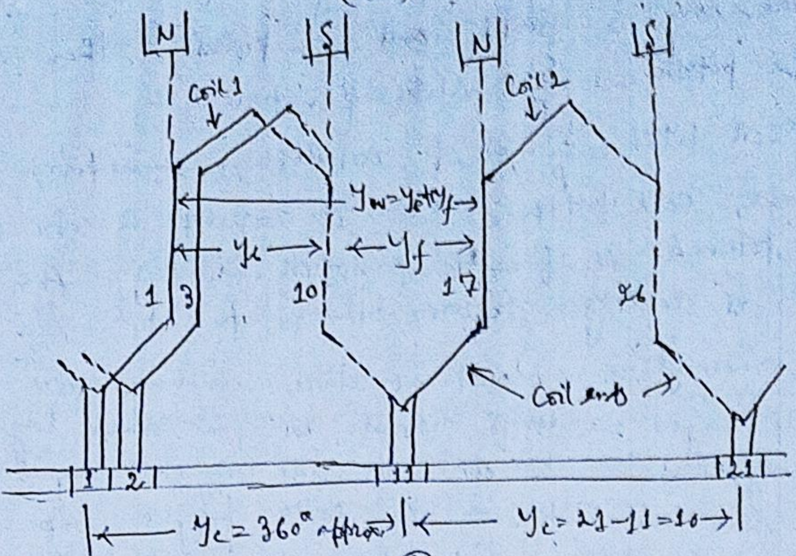


(c)

Lap coil connections – (a) Single multi-turn lap coil
(b) three multi-turn lap coils.

In simplex lap winding (or lap winding), the two coil-ends of a coil are connected to the two adjacent commutator segments as shown in fig. (a). Note that two coil ends, one from top coil side and the other from bottom coil side are connected to adjacent commutator segments.

From fig. (c), it is seen that bottom coil side of coil 1 and top coil side of coil 2 are connected to segment 2; bottom coil side of coil 2 and top coil side of coil 3 are connected to segment 3 and so on. In other words, for simplex lap winding, each commutator segment has two coil ends connected to it, one coil end is from the bottom coil side of one coil and the other from the top coil side of next coil.



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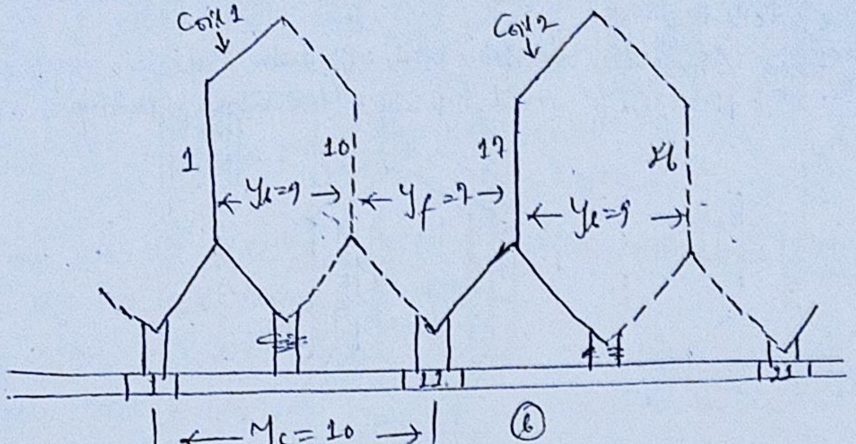
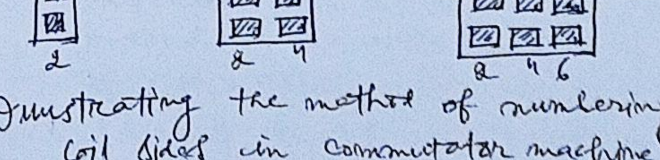


ⓑ

· Simplex wave winding — ⓐ single turn coils
ⓑ multi turn coils.

In simplex wave winding, the two coil ends of a coil are bent in opposite directions and connected to commutator segments which are approximately two pole pitches (i.e., 360° electrical) apart. In wave winding also, each commutator segment has two coil ends connected to it, one from top coil side and the other from bottom coil side.



Illustrating the method of numbering coil sides in commutator machine.

Back pitch (y_b) :- The distance between the top and bottom coil sides of one coil, measured at the back of the armature (or measured at the other side of the commutator) is called back pitch.

In fig. for lap coil, for coil 1, the top coil side is numbered 1 and the bottom coil side is numbered 8. Therefore, back pitch for coil 1 is $8-1=7$. Similarly, for other coils $y_b = 10-3 = 7 = 12-5$.

In figure for wave winding, $y_b = 10-1 = 9$ for coil 1. Similarly, for coil 2, $y_b = 26-17 = 9$. So, y_b is always odd.

Front pitch (y_f) :- The distance between the two coil sides connected to the same commutator segment, is called front pitch.

In fig. for lap winding, front pitch $y_f = 8-3 = 5$. For segment 3, $y_f = 10-5 = 5$.

In. fig. for wave winding, $y_f = 17-10 = 7$.

So, front pitch, y_f is always odd.

Winding pitch (y_w) :- The distance between the two consequtive and similar top or bottom coil sides, as the winding progress, is called the winding pitch. It is expressed in terms of coil sides.

In fig. for lap winding the consequtive and similar top coil sides are numbered 1, 3, 5 or similar bottom coil sides are numbered 8, 10, 12 etc. So winding pitch $y_w = 3-1 = 5-3 = 10-8 = 12-10 = 2$. For simplex lap winding, $y_w = y_b - y_f$.

In fig for wave winding, winding pitch $y_w = 17-1 = 26-10 = 16$. For simplex wave winding, $y_w = y_b + y_f$.
y_w is always even.

Commutator pitch (y_c) :- The distance between the two commutator segments, to which the two sides of one coil are joined, is called the commutator pitch. It is always expressed in terms of commutator segments.

(110)

For simplex lap winding, the two ends of coil 1 are joined to segments 2 and 1. So, $y_c = 2 - 1 = 1$.

For simplex wave winding, the two ends of coil 1 are joined to segments 11 and 1. So $y_c = 11 - 1 = 10$.

as being a *simplex* (single) or *multiplex* ...

In the simplex lap winding there are as many parallel paths or circuits through the winding as there are field poles on the machine.

Double and triple windings are used on armature designed for supply of large currents at low voltage. The sole purpose of such a winding is to increase the number of parallel paths enabling the armature to carry a large total current, at the same time reducing the conductor current to improve commutation conditions. A double or duplex winding consists of two similar simplex windings placed in alternate slots on the armature and connected to alternate commutator segments. Each winding carries half the armature current. Likewise, a triple or triplex winding has three similar windings occupying every third slot and connected to every third commutator segment. Hence in duplex lap winding the number of parallel circuits is twice the number of poles and in triplex lap winding, three times the number of poles. For this reason the lap winding is sometimes called the *multiple or parallel winding* and is suited for machines that operate at relatively low voltages but with high current outputs.

Important Point Regarding Lap Winding. 1. The coil or back pitch Y_b must be approximately equal to the pole pitch *i.e.* $Y_b \approx \frac{Z}{P}$ where Z is the number of conductors on armature and P is the number of poles.

2. The back pitch Y_b should be either lesser or greater than front pitch Y_f by $2m$ where m is the multiplicity of the winding.

$$i.e.\ Y_b = Y_f \pm 2m$$

where, $m = 1$ for simplex winding
$m = 2$ for duplex winding
$m = 3$ for triplex winding and so on.

When Y_b is greater than Y_f the winding progresses from left to right and so known as *progressive winding*. When Y_b is lesser than Y_f the winding progresses from right to left and, therefore, such a winding is known as *retrogressive winding*.

3. The back pitch and front pitch must be odd.

4. The average pitch is given by

$$Y_{av} = \frac{Y_b + Y_f}{2}$$

and should be equal to pole pitch *i.e.* $\frac{Z}{P}$

5. The resultant pitch Y_R is always even, being the difference of two odd numbers and is equal to $2m$ where m is the multiplicity of the winding.

i.e. Resultant pitch, $Y_R = 2$ for simplex lap winding
$Y_R = 4$ for duplex lap winding
and $Y_R = 6$ for triplex lap winding.

6. The commutator pitch, $Y_c = m$ *i.e.*, Y_c is equal to 1, 2, 3, 4 etc., respectively for simplex, duplex, triplex, quadruplex etc. lap windings.

7. Number of parallel paths in lap winding = mP *i.e.* number of parallel paths is equal to P, 2P, 3P, 4P etc. respectively, for simplex, duplex, triplex, quadruplex, etc. lap windings.

Example 4.1. Draw the developed winding diagram of progressive lap winding for 4 poles, 24 slots with one coil side per slot, single layer showing there in position of the poles, direction of motion, direction of induced emfs and position of brushes.

Solution: Developed winding diagram is obtained by imagining the armature surface removed and so laid out flat that the slots and conductors can be viewed without the necessity of turning round the armature in order to trace out the armature winding. Such a developed winding diagram is shown in fig. 4.22.

Number of poles, $P = 4$

Number of coil sides, $Z = 24$

$$\text{Average pitch, } Y_{av} = \frac{Y_b + Y_f}{2} = \frac{Z}{P} = \frac{24}{4} = 6$$

$$\text{or } Y_b + Y_f = 12 \qquad ...(i)$$

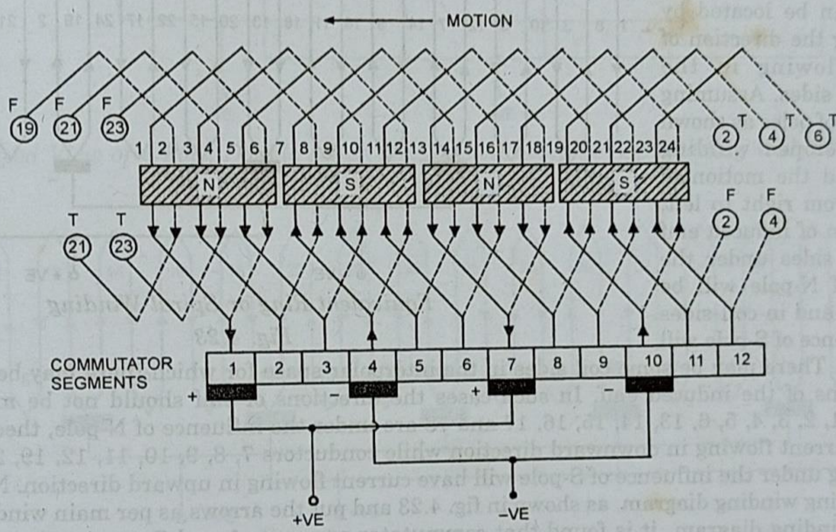
and for progressive simplex lap winding $Y_b = Y_f + 2$ ...(ii)

Solving equations (*i*) and (*ii*) we get $Y_b = 7$ and $Y_f = 5$

Drawing of Winding: In order to draw the winding diagram, first of all draw the coil sides and number them. Now to make connections start from any coil side, say with first coil side.

In order to get the coil side to which the 1st coil side is to be connected at the back, add back pitch to it. So first coil side will be connected to the 1 + 7 = 8th coil side at the back by means of end connections.

In order to get the coil side to which 8th coil side is to be connected on the front or commutator side of the winding, deduct front pitch from it, and, therefore, 8th coil side will be connected to the 8 – 5 = 3rd coil at the front or commutator end.



Developed View of 4-Pole, Single Layer, Progressive Simplex Lap Winding With 24 Coil Sides

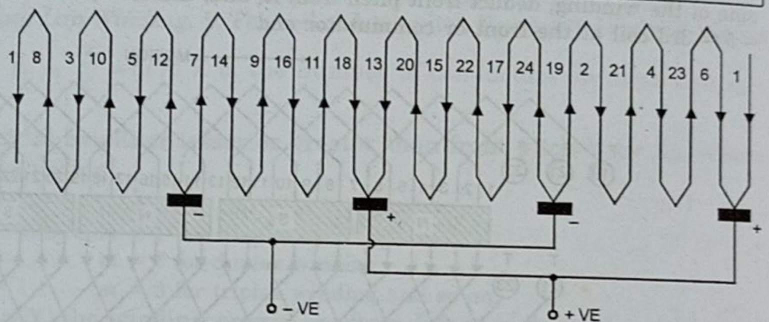
Fig. 4.22

Now repeat the process, according to which 3rd coil side will be connected to 10th coil side at the back and 10th coil side will be connected to 5th coil side at the next commutator segment.

Thus a table can be made indicating the way in which various coil sides will be connected. The coil sides are connected according to table of the end connections given below.

At Back End		At Front End		
Coil Side No.	Connected to Coil Side No.	Coil Side No.	Connected to Coil Side No.	Through Segment No.
1	8	8	3	2
3	10	10	5	3
5	12	12	7	4
7	14	14	9	5
9	16	16	11	6
11	18	18	13	7
13	20	20	15	8
15	22	22	17	9
17	24	24	19	10
19	2	2	21	11
21	4	4	23	12
23	6	6	1	1

Position of Brushes. Brush positions can be located by determining the direction of currents flowing in the various coil sides. Assuming the position of poles as shown in the developed winding diagram and the motion of coil sides from right to left, the direction of induced emf in the coil sides under the influence of N-pole will be downwards and in coil sides under influence of S-pole will be upwards. There may be some coil sides in the interpolar space for which there may be doubt about the directions of the induced emf. In such cases the directions of emf should not be marked. Since conductors 1, 2, 3, 4, 5, 6, 13, 14, 15, 16, 17 and 18 are under the influence of N-pole, these conductors will have current flowing in downward direction while conductors 7, 8, 9, 10, 11, 12, 19, 20, 21, 22, 23 and 24 being under the influence of S-pole will have current flowing in upward direction. Now draw the equivalent ring winding diagram, as shown in fig. 4.23 and put the arrows as per main winding diagram. From the winding diagram it is found that commutator segments 1 and 7 are meeting point of emfs and currents are flowing outwards from the conductors, so + ve brushes be fixed at these segments. Similarly commutator segments 4 and 10 are separating points of emfs and currents are flowing inwards so –ve brushes be fixed at these segments.



Equivalent Ring or Spiral Winding

Fig. 4.23

The brushes of same polarity are connected together and, therefore, the armature winding is divided in four paths in parallel.