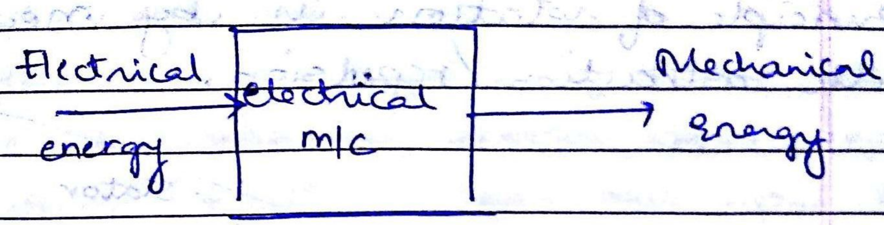
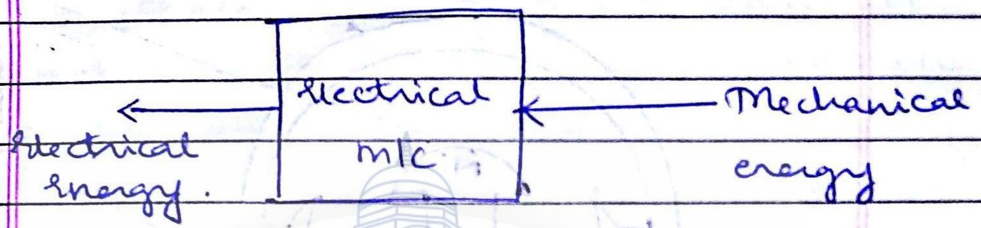
PAGE NO.:
DATE:

Electrical m/c are basically electro-mechanical energy conversion devices. ie





• When electrical i/p is applied to the m/c we get mechanical output. Such a m/c is then called electrical motor

• When mechanical i/p is applied to the m/c to get electrical o/p, it is known as electrical generator.

Note that it is the same m/c the same physical object which performs both the functions ie acting as a motor or generator [depending on which is the i/p & which is the o/p]

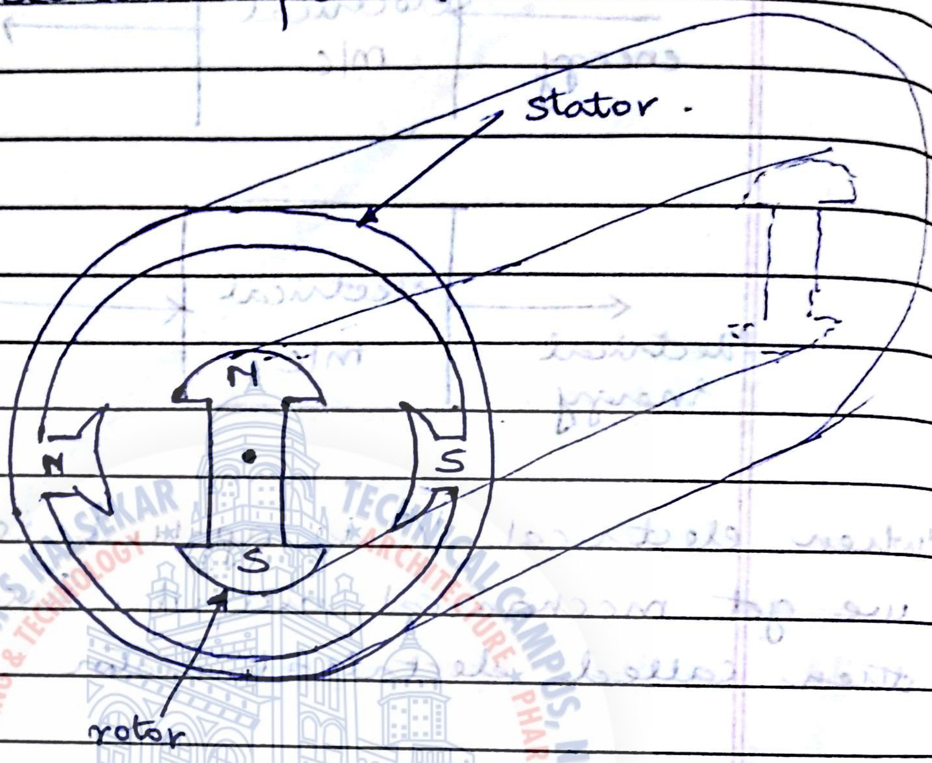
Almost all machines are of the rotating type, the reason being that mechanical i/p or output involves kinetic energy & continuous motion can be obtained by means of the rotating motion.

Prof. Tahoora Qureshi

DATE:

How to introduce rotation in machines?

The principle of rotation is by means of magnetic attraction / repulsion.



(1) The above fig shows the inside of electrical m/c.

(2) There is a magnet kept at the center having north pole & south pole. This body is free to rotate & hence its called as the rotor.

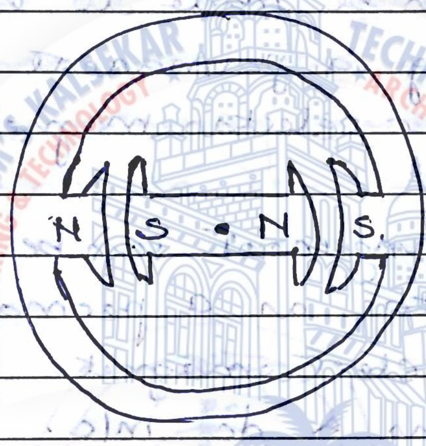
(3) The outer body which is stationary in nature is the stator.

(4) There will be some constructions when the rotor will be outside & the ~~rotor~~ stator inside. However such constructions are rare.

PAGE NO.:
DATE:

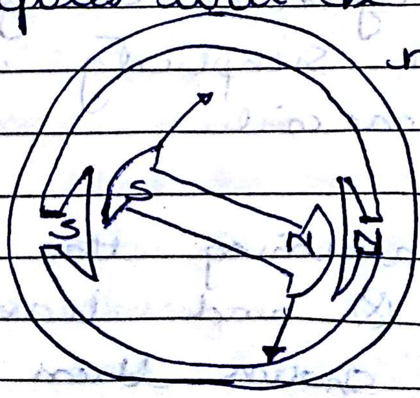
(5) In order to make the rotor rotate we place another North pole & south pole magnets as shown.

(6) Now, the two north poles of stator, rotor & two south poles of stator, rotor repel each other whereas as the opposite poles of stator, rotor attract each other. The net result being the rotor aligns itself in the following manner.



Since the rotor moves to align itself in the above fashion, it somewhat overshoots & then return to align properly.

Now let us consider a different case, ie when two same poles are near each other, the rotor poles will be repelled in the manner shown below.



Now, the question arises how the same 'S' poles and 'N' poles come close to each other?

So instead of using permanent (stator) magnets we go for electro magnets whose polarity can be changed by changing direction of current.

Now the rotor can be made to have a polarity by either using a permanent magnet or by using another electro magnet.

However, the arrangement can be reversed ie by having stator as a permanent magnet & rotor as an electromagnet. Such an arrangement forms a dc m/c.

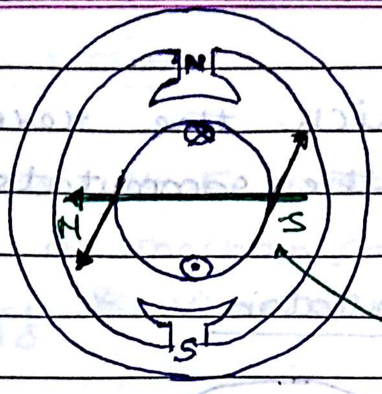
* Cross section of DC m/c :

We are assuming two fixed poles which can either be permanant magnet or electromagnetic as shown below. Inside we have a cylinder carrying an electromagnet & for simplicity we are assuming it has one coil.

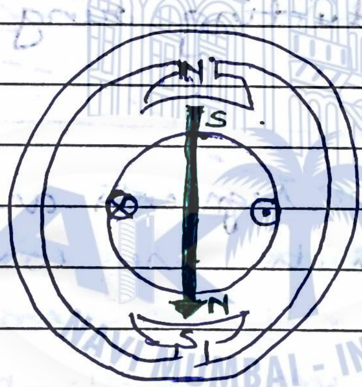
Now if we are assuming the current in coils to enter ⊗ and leave ⊙ in the direction shown then the

⊗ → enter
⊙ → coming out

PAGE NO.:
DATE:



flux line will be produced with a 'N' & 'S' poles as shown above.
So the two 'N' & 'S' poles will cause a repulsion force due to which the rotor starts rotating and at one position it will come to the alligned position. ie.



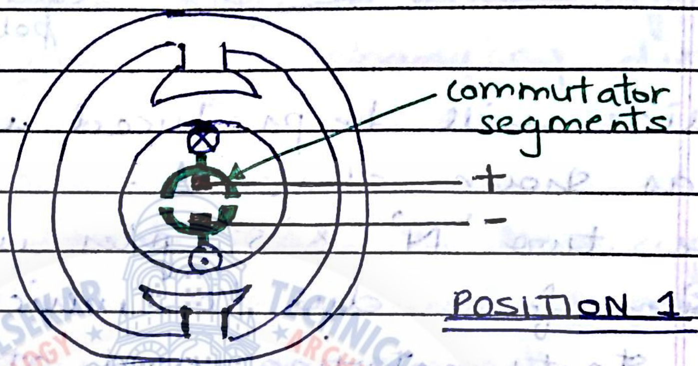
of cource the movement will not stop as shown above; due to mechanical inertia it would try to overshoot.

How, to make a continuous rotating motion, we need to reverse poles of either stator or rotor. In dc m/c the rotor polarity is changed. ie by making ⊗ → ⊙ and ⊙ → ⊗ [reversing I direction]

PAGE NO.:
DATE:

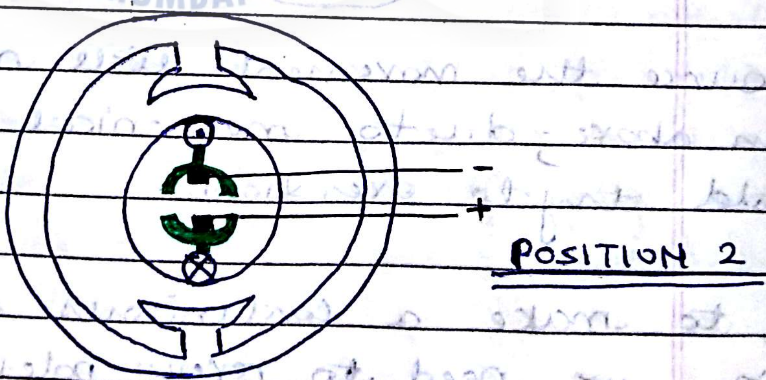
The device by which the reversing current is obtained is the commutator.

*** Placing of Commutator:**



There are two commutator segments each connecting to each conductor. The commutator is therefore a conducting ring split into two segments.

The current to the segments are supplied by the brushes which are connected to the dc supply.



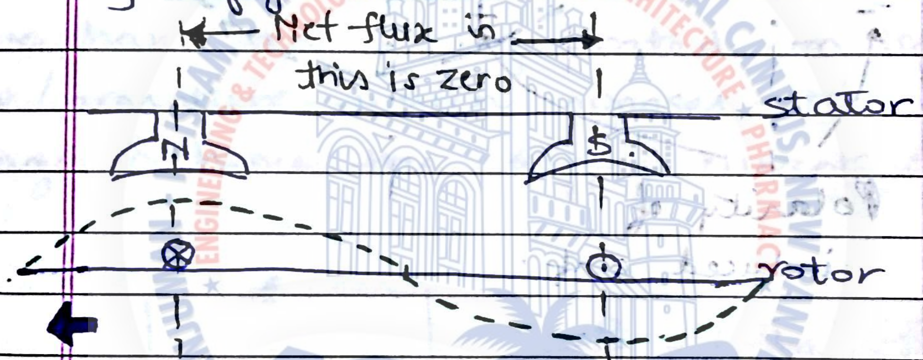
PAGE NO.:
DATE:

Concept of Induction:

The next question that arises is, how does the conversion of mechanical energy to electrical energy & vice-versa take place?

For that we need to look into another phenomenon which is the induction of voltage by faraday's law.

To understand the concept consider the following figure. (rolled out version)



The 'N' & 'S' pole on the stator are producing magnetic flux & the magnetic flux is max under the pole & min between the 'N' & 'S' pole. [shown by the sine wave].

The net flux passing through the coil is zero between 'N' & 'S' pole.
The above diagram has rotor/armature rotating ie moving in ⟵ direction.

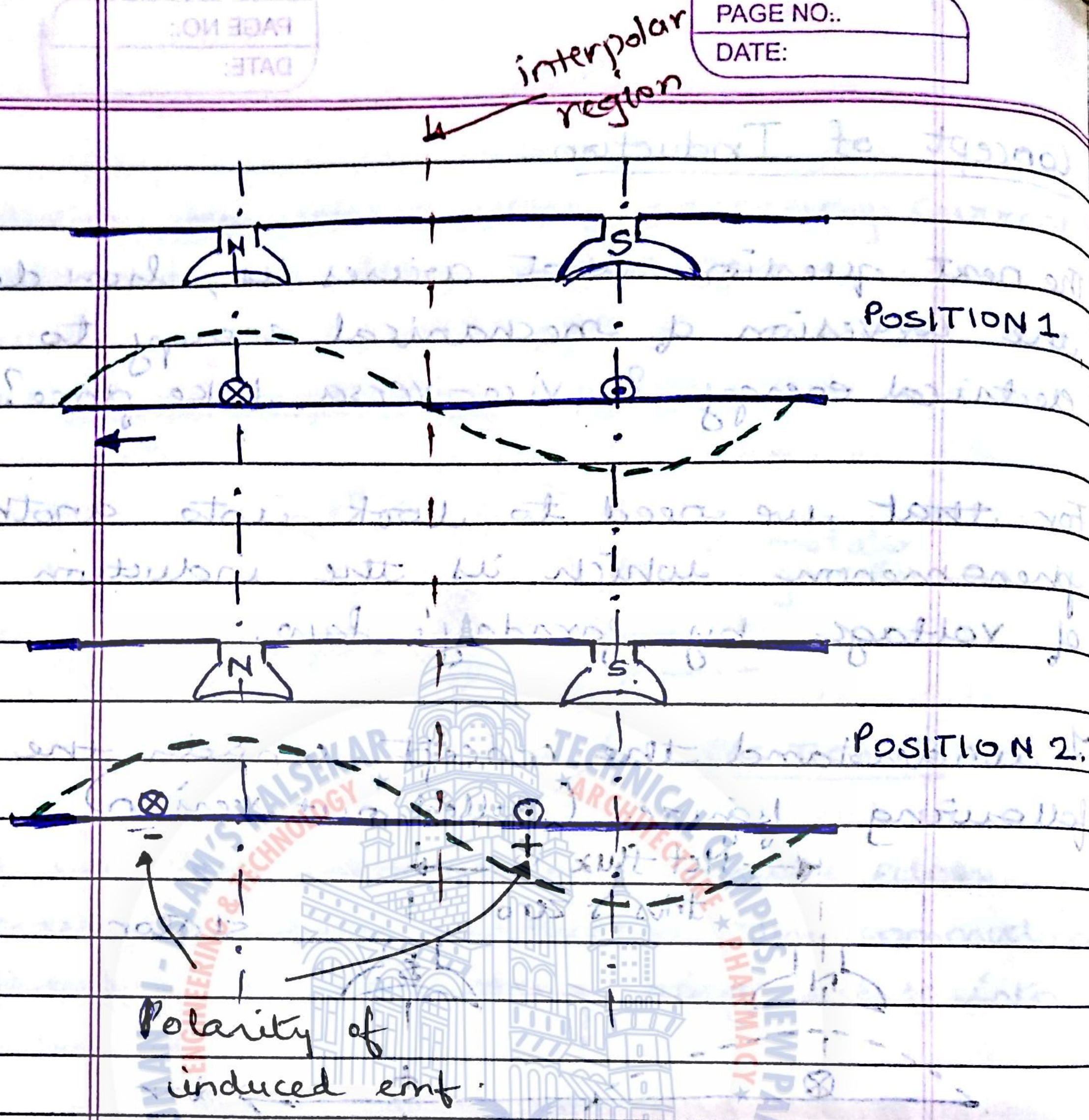


fig: Polarity of Induced emf.

In the alligned position '1' the total flux passing/linking with coil is maximum. "Zero."

At position 2 the total flux passing through the coil is "positive"

Thus there is a rate of change of flux linking the coil which results in an emf being induced in the coil by faraday's law of electromagnetism.

The polarity of voltage induced will be such that it will try to oppose the current in the conductor ie it will try to oppose the motion of the rotor.

In other words the emf polarity will be such that it opposes the cause producing it.

So we have an emf generated on the rotor / armature which opposes the supply voltage & hence the supply current.

$P_e = e \cdot i_a$

MOTOR

In order to force some amount of current into the armature conductors, some amount of energy has to be spent given by

$$P_e = e \cdot i_a$$

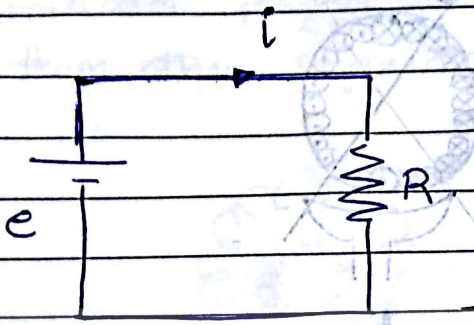
P_e → electrical energy.

Because of this 'Pe' there will be a torque generated inside the m/c which will make the rotor rotate. If there is presence of load torque, it will try to slow down the rotor & hence some mechanical work will be done. In the process the electrical energy supplied by the source will be converted to mechanical energy and this is the motoring mode of operation. In the generating mode, the reverse will happen, a prime mover will be used to rotate the m/c. Voltage will still be induced because there will be a rate of change of flux linkage. As long as we are not connecting any external resistance or load there will not be any flow of current through the coil. & therefore no repulsive force / attraction force and there will be no mechanical work done. However as soon as an external load is connected, a current will start flowing, the direction of current will be in such a direction that it will try to slow down or stop the m/c. That is the current direction will be such that it will produce a torque which will oppose the motion. In order to rotate the rotor against the torque, some amount of mechanical energy has to be spent, this mechanical energy will then be converted into electrical energy

Prof. Tahoora Qureshi

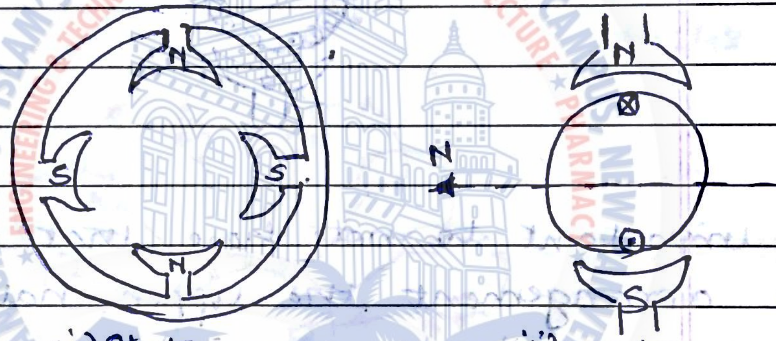
PAGE NO.:
DATE:

as the form of current flowing in the external resistance.



GENERATOR

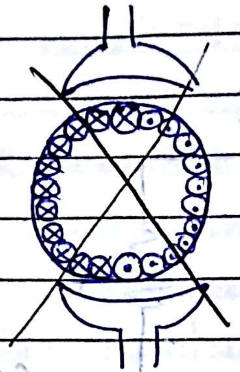
*The practical 'DC' m/c

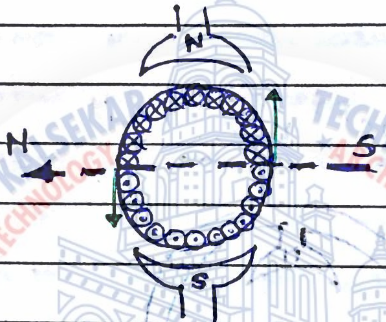


(i) Stator (ii) rotor

The no of poles is not restricted to '2' poles on the stator.

If there is only one conductor as shown in fig (ii), then, the force of attraction/repulsion will be max in the position shown but as the armature rotates & comes near the alligned position, the forces will reduce so the torque produced by this m/c will not be constant but will be time varying which is not desirable. To avoid that, the armature is equipped with distributed winding consisting of several coils.

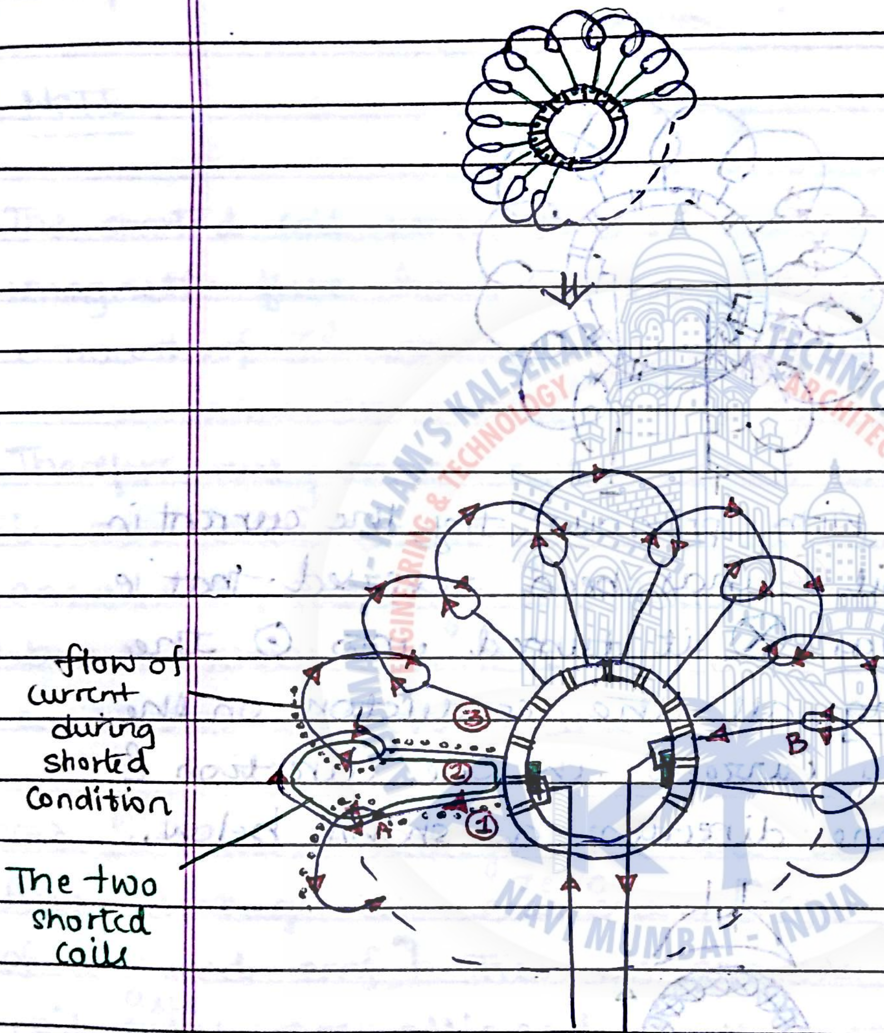




It is important to note here that with the above arrangement the upper half incoming currents should be carried by the upper half conductors & the lower half conductors should be carrying the outgoing currents. This should remain even though the rotor is rotating. There will be instance when some conductors will be carrying more/less currents as per the flux linkages.

Thus commutator should be placed such that when it comes in contact with the conductor, the current should reverse thereby maintaining unidirectional torque in m/c.

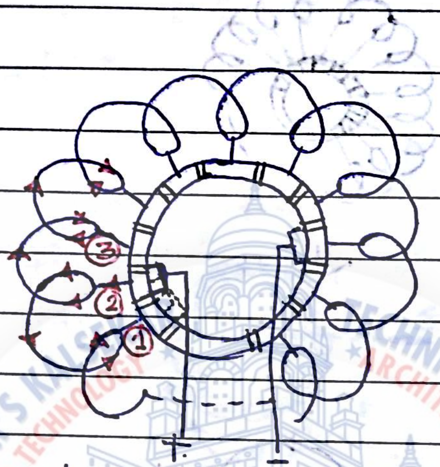
For multiple coils we can have multiple segments on the commutator. Each coil is connected to each commutator segments. Each segment is insulated from other segment.



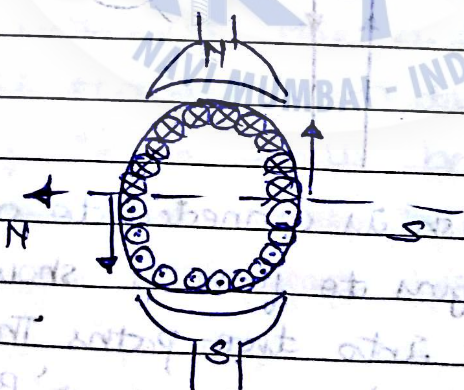
Lec 21
44:48

When the '+ve' brush is connected to one commutator segment current begins to flow as shown. at pt 'A' current gets divided into two paths. The current returns to the '-ve' brush at pt 'B'.

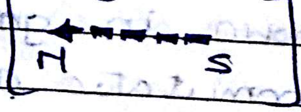
When the commutator moves & the brushes take up position as shown in green, the adjacent segments of commutator are shorted therefore the coils connecting the two segments are shorted. The current is resumed from the remaining part of the coil [ie the split up coil] The next phenomena that happens is illustrated below;



When compared with previous fig, the current in the shorted coil ② has been reversed. that ie if the coil was ⊗ it turned into ⊙ the net effect being, all the conductors on the upper half carry current in one direction & lower half in one direction as shown below.



In other words the distribution of magnetic flux produced by the armature does not change ie



PAGE NO..
DATE:

The armature may be physically rotating but the flux produced by the armature maintains same position as before. The result being we have a production of constant unidirectional torque.

NOTE :

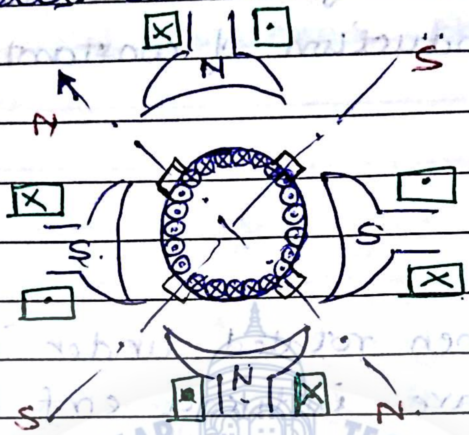
The shorted coil when rotated under influence of magnetic flux have induced emf & thus a large amount of 'I' which will damage the coil.

Therefore only those coils whoes induced voltage is zero will undergo commutation. This is ensured by placing the brush accordingly. The brush shall connect to that ~~brush~~ coil / conductor in which the induced voltage is zero

The induced voltage of a coil is zero when the flux linkage is ~~maximum~~ zero [refer fig of polarity of induced emf] This is possible when the coil ~~sides~~ axis are alligned with the poles. or the coil sides are in the interpolar region. That is why the brushes in the dc m/c is placed in the interpolar region

PAGE NO.:
DATE:

If we have more than two poles on the stator, the armature should also produce equal no of poles otherwise steady torque will not be produced.



So pole pairs (N-S) are created on armature equivalent to pole pairs on stator & these pole pairs are either connected in series or parallel.

Lap winding : Parallel connection of armature poles

Wave winding : Series connection of armature poles

Usually the stator poles are not permanent magnets, but feild coils are employed to create electromagnets which in turn give ability to control the strength of the magnets

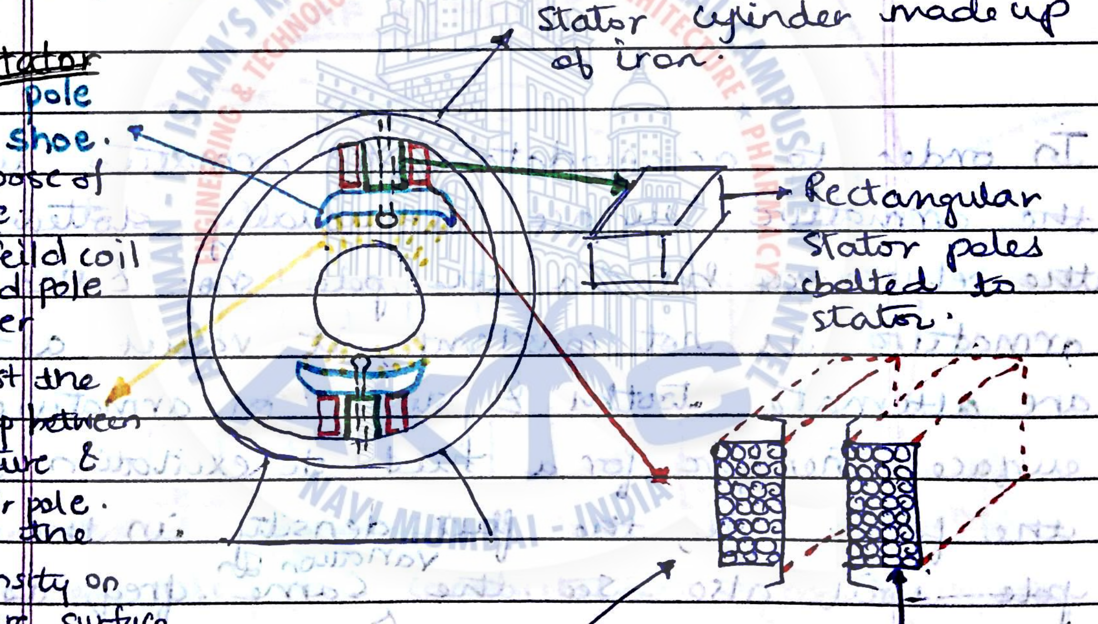
There is a large variety of ways in which field coils are connected as shown above;

If the feild coils are connected in series to armature they form the series m/c. If they are connected in parallel to armature, we get the parallel (shunt) m/c. If they are connected to seperate source, they are called as seperately excited dc m/c

Feild coils can also have parts - one part connected in parallel & other connected in series with the armature. This is the compound feild dc m/c.

*** Construction of DC m/c.**

(i) The stator

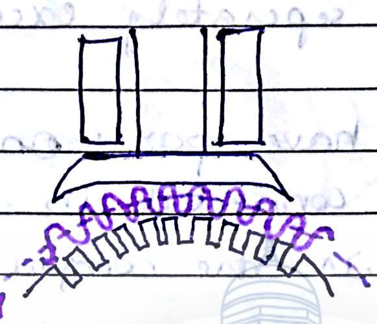


The purpose of pole shoe:
(i) Hold feild coil & feild pole together
(ii) Adjust the airgap between armature & stator pole so that the flux density on armature surface can be given desired waveshape. Usually this flux density is trapezoidal in nature.

The choice of shunt/series connection depend on No of turns & current carrying capacity.

What's shown here is shunt/seperately excited feild which consisted thin windings of large no of turns.

Now, although the main pole body or the stator cylinder is not laminated, the pole shoes are usually laminated. The reason is below;



In order to accomodate the armature winding the armature surface is usually slotted. Therefore the reluctance between the pole shoe & the armature is not constant, it varies as there are alternate tooths & slots on armature surface. Therefore for a fixed dc excitation on the feild coil, the flux density in the feild pole will also see the variation with same freq as the occurance of tooth & slots in the rotor.

The pole shoes experiences a flux density waveform which has a high freq alternating component depending on the no of slots on the armature surface & its rotational speed.

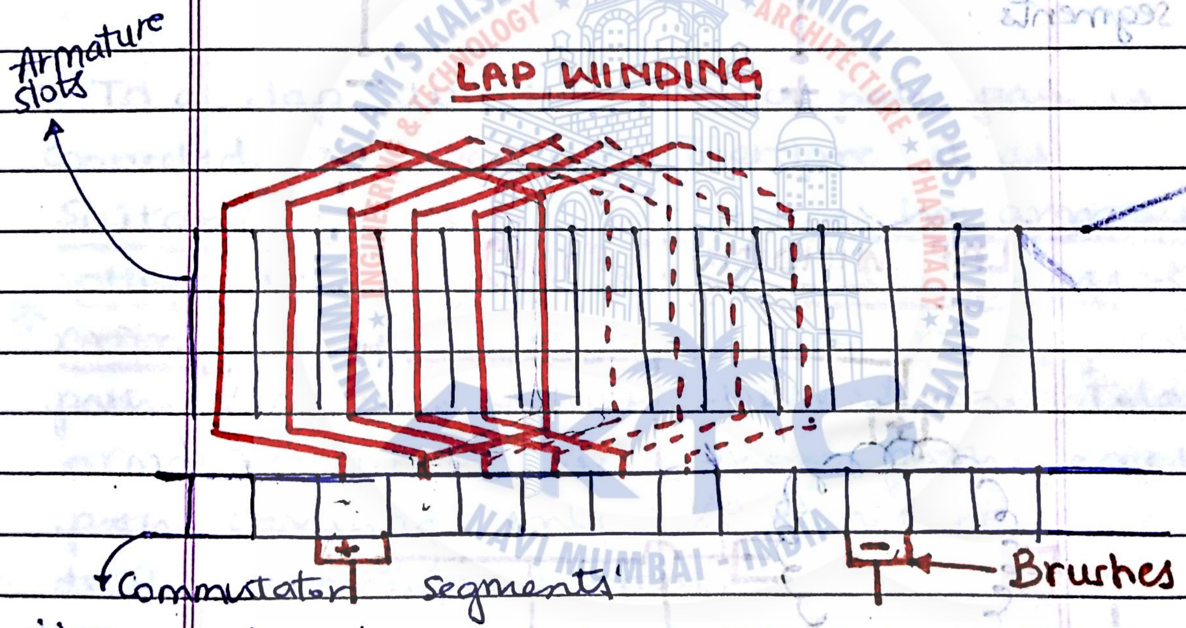
PAGE NO..
DATE:

So there is alternating flux in the pole shoes. In order to prevent a large amount of eddy current loss in the pole shoes, they are laminated.

(ii) The rotor / Armature

One distinct feature of the armature of DC m/c is that its windings is shorted at the ends together.

• Lap & Wave winding.



(i) In a dc m/c, the commutator segments equals the no of coils.

(ii) Each coil is made up two coils sides which are placed in two different slots.

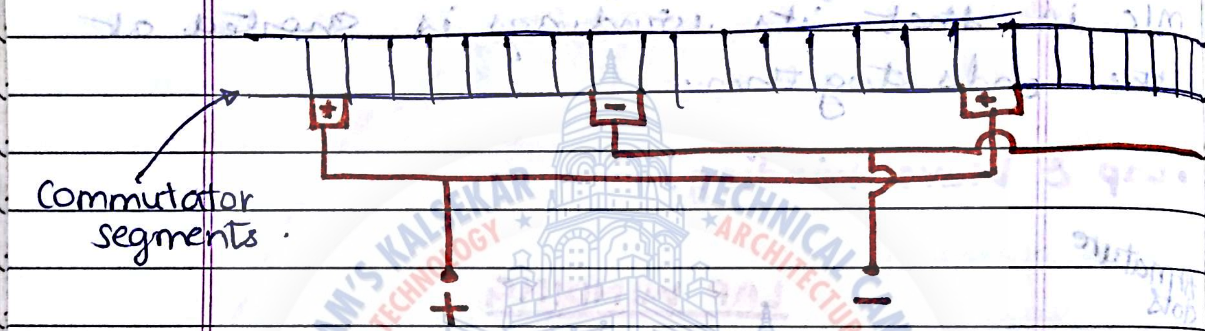
(iii) DC m/c is wound for double layer winding ie. each slot contains two coil sides (one on top, other on bottom)

(iv) No of slots = No of coils

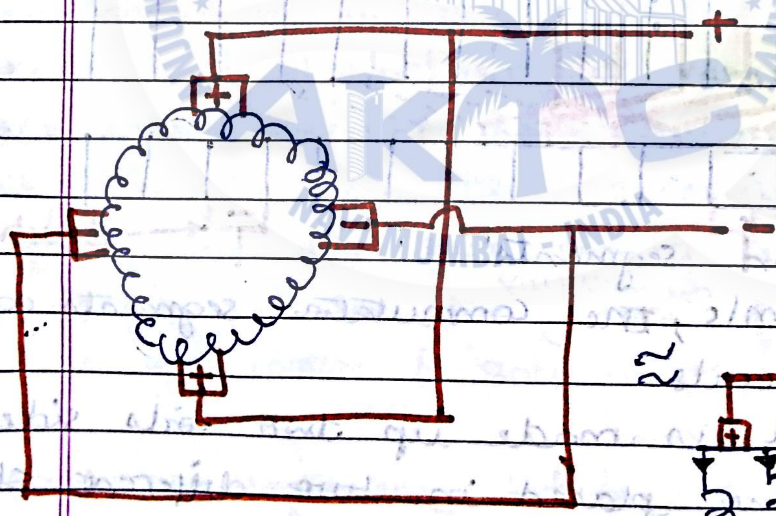
∴ No of commutator segments = No of slots.

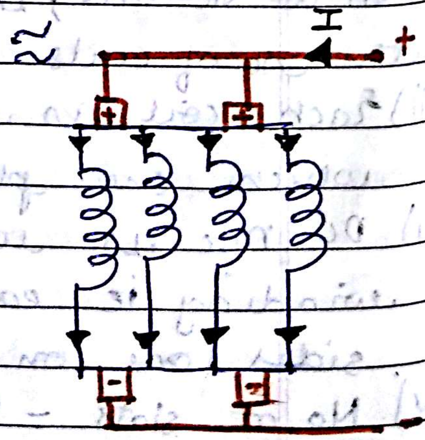
PAGE NO.:
DATE:

(v) In a lap winding, between two commutator segment there is only only coil.
(vi) So the no of brushes equals the no of poles, if there are 4 poles then the brushes will be connected in parallel as below;



LAP WINDING (4 POLE)





The lap winding can be divided into 4 parts shunted across each other with the brush placement as shown. Thus if the total current is 'I', it gets divided in 4 paths in a Lap windings.

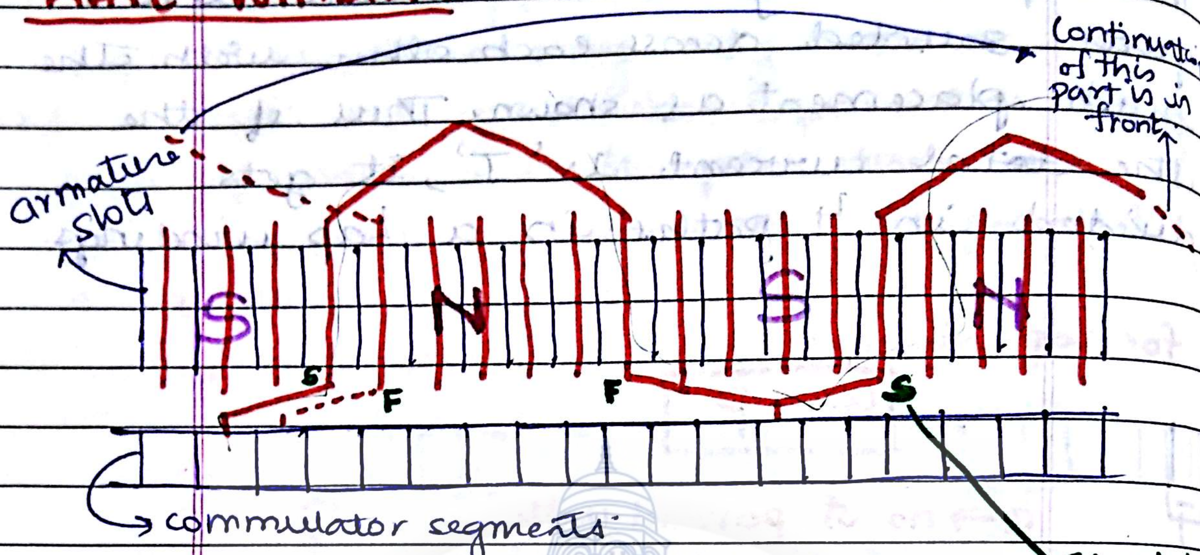
for Lap winding:

$$a = P$$

a → no of parallel path
P → no of poles

∴ In a lap winding each pole pair is connected in parallel. Therefore it is suitable for those m/c whose ~~ha~~ armature voltage rating is low but the current rating is high because the no of parallel paths are more which divides the total armature current in more paths, each path carrying only 1/P times the total armature current.

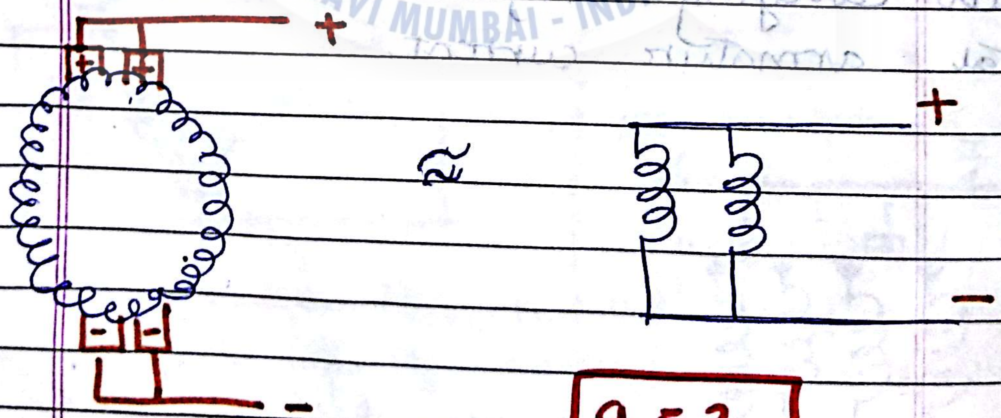
• WAVE WINDING :



(i)

(i) Between two adjacent commutator segments there are P/2 no of coils connected

(ii) This shows that in essence, this wave winding all the field coils & armature coils are 'N' pole & 'S' pole; all the pole pairs are connected in series.



a = 2

a → No of parallel paths

Prof. Tahoora Qureshi

Continuation of this part is in front

Start & Finish pts

segments

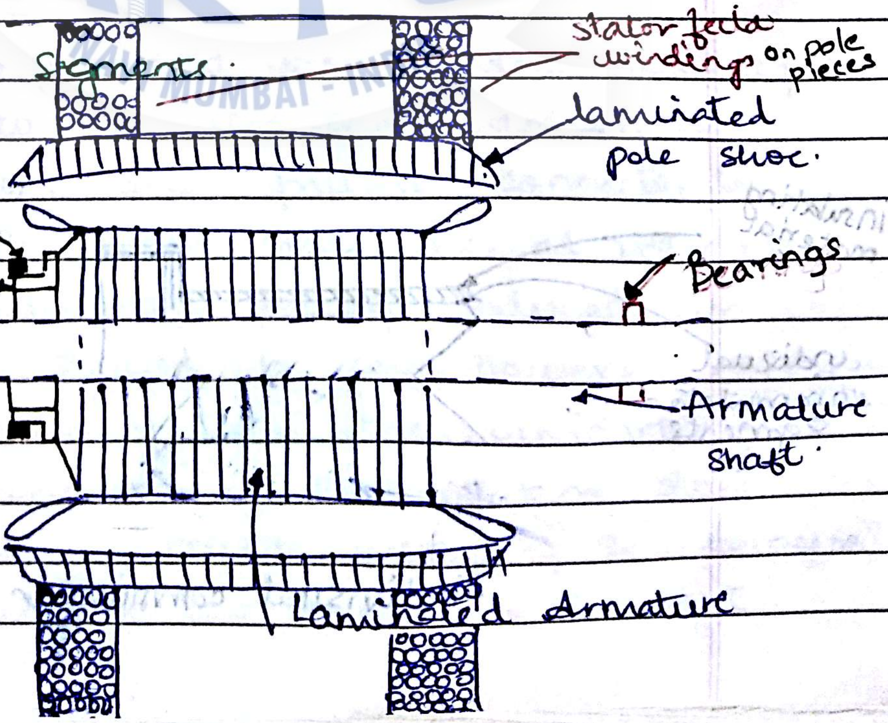
(iii) Opposite ~~commutator segments~~ brushes are 1/P coils apart ~~commutator segments apart.~~

(iv) Between two opposite polarity brushes there are $= \frac{P}{2} \times \frac{1}{P} = \frac{1}{2}$ x the total no of coils are present between any two opposite polarity brushes.

(v) So, one half is connected to one set of brush (++), the other half of the coil is connected to the other set of brush (--)

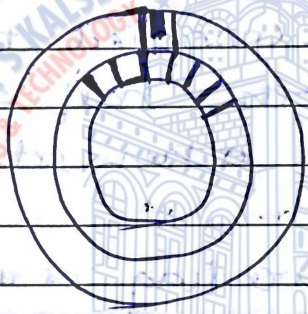
(vi) Therefore this winding is used for dc m/c
* with lower current rating but high voltage rating

* Commutator Segments

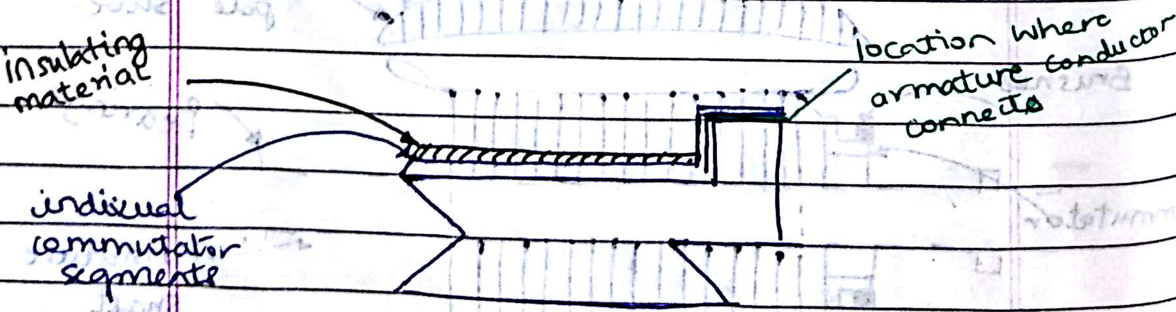


PAGE NO.:
DATE:

- Armature is placed on the armature shaft as shown. It is essentially laminated because the voltage induced is alternating in nature, the individual coils are also carrying alternating currents so that the armature is laminated
- Commutator is made up of copper segments isolated by insulating mica. The no. of commutator segments is equal to the no. of coils in dc m/c.



- commutator segments.



- individual commutator segment

The indi...
a wedge...
razer sec...
commutat...
to form...
are spri...
good co...
provide...
commuta...

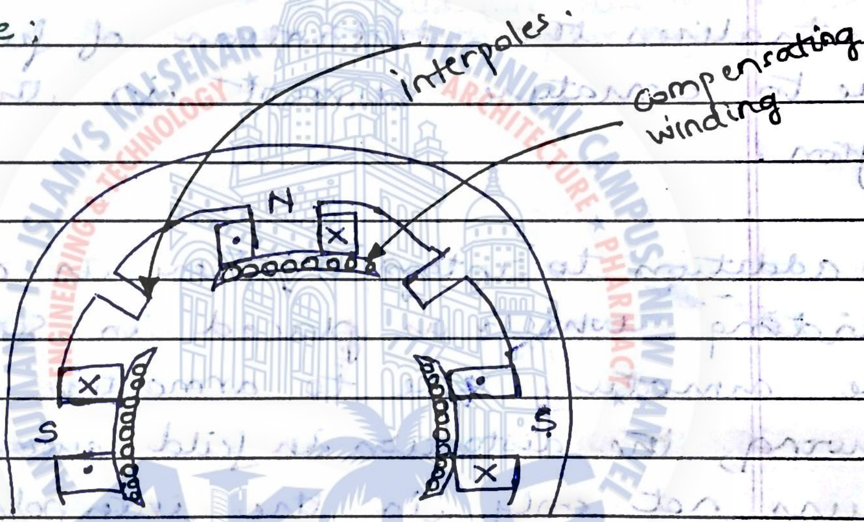
* Interpo...

- Interpoles...
as show...
- We kno...
windings...
location...
these c...
of curre...
the co...
not ha...
the flu...

PAGE NO..
DATE:

The indivisual commutator segment is a wedge shaped copper piece with a razer section. Many such indivisual commutator segments are clamped together to form a cylinder. The carbon brushes are spring loaded so that they provide good contact & the graphite brushes provide good lubrication so that the commutation shall be smooth.

* Interpole:



- Interpoles are provided between the stator poles as shown to aid the commutation
- We know that the brushes connects to windings whoes coil sides are at interpolar location. Ideally the voltage induced in these coils should be zero. However because of current flowing in the armature, the coil undergoing commutation does not have an induced voltage of zero because the flux due to the armature current

PAGE NO.:
DATE:

called as armature reaction distorts the field flux in the interpolar region. So there would be a net voltage induced in the coil undergoing commutation which may give rise to dangerous sparks and overcurrents. In order to neutralize the flux in the interpolar region, an interpole with requisite no of turns & connected in series with the armature is introduced so that it neutralizes the distortion of field flux due to armature current in the interpolar region.

In addition to interpoles, there is another winding which is placed in series with the armature. Due to armature current flowing, the distortion in field ~~current~~ flux occurs not only in the interpolar region but also under the pole there will be some distortion. In order to compensate for that we put compensating windinging on the pole face which compensates for the main field flux due to the current flowing in the armature. This coils is also connected in series with the armature. This is called the compensating winding.

* Main

(1) Sta
(2) Fie
(3) Inte
(4) Arm
(5) Con
(6) Bru
(7) Com

PAGE NO.:
DATE:

* Main constructional parts of DC Motor:

(1) Stator Core → provides return path for field flux

(2) Field Poles → pole, pole shoe, winding } produced field flux

(3) Interpoles → compensates distortion in field flux due to armature current in interpolar region

(4) Armature winding → carries current, voltage is induced & torque is produced

(5) Commutators → provides direction of current change

(6) Brushes → provides moving contact to commutators with armature winding

(7) Compensating winding → compensates for the distortion in the field flux due to Armature current in the polar region

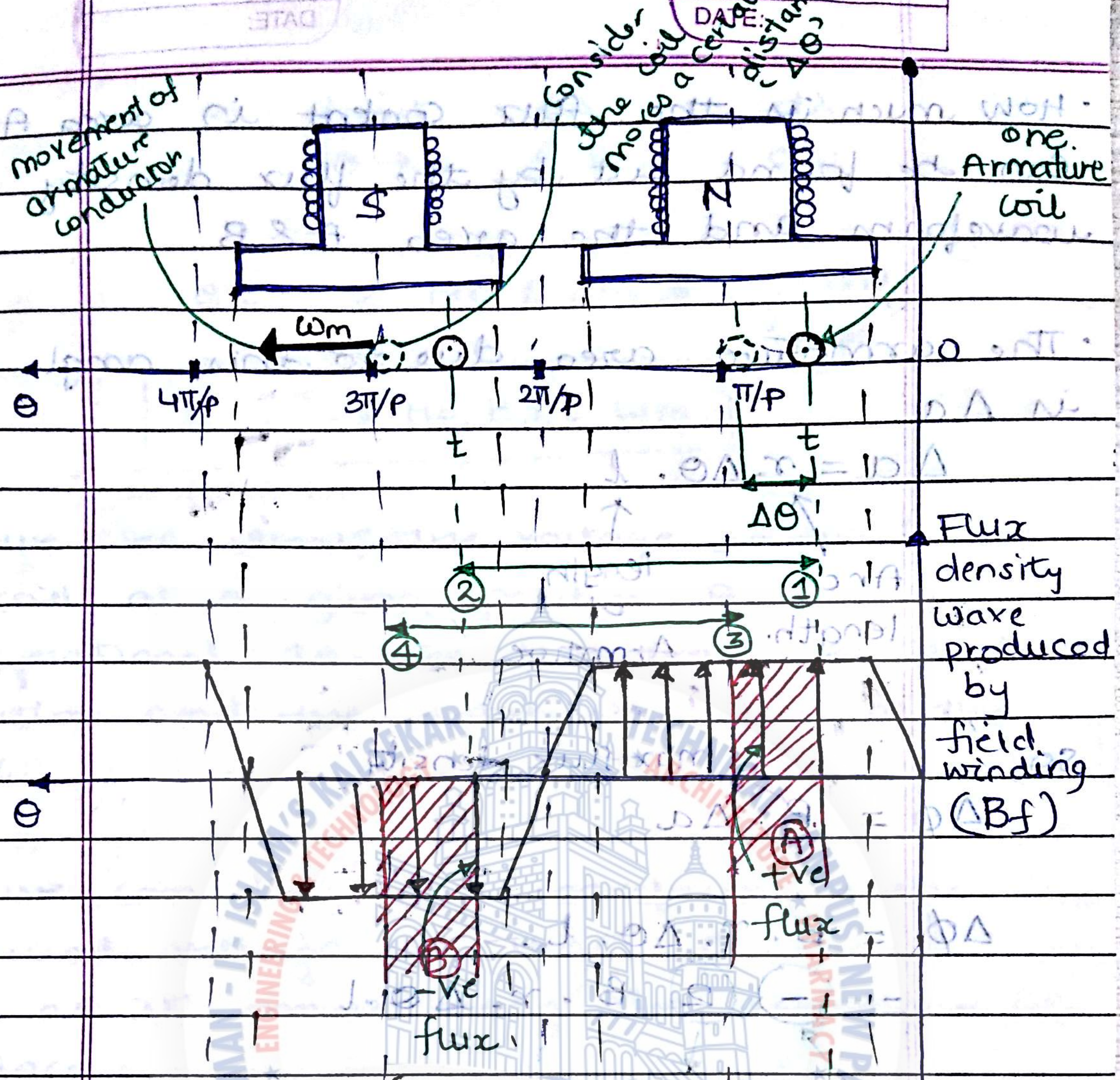
* Emf & Torque Equation of DC m/c:

- With the construction of DC m/c it is clear that the armature conductor or rotor rotates inside the stator and emf is induced inside the armature coils and across the brushes.

- When ~~external~~ current is allowed to flow through the conductors by;
  - (i) either connecting external 'R' & rotating the m/c or [in which case it acts as a generator]
  - (ii) supplying the armature by external voltage source [in which case it acts as a motor]

  a torque is produced.

- Hence we need to find the expression for generated emf & generated torque.



(FIG 1)

- $\Delta\theta = \omega_m \Delta t$

- We now need to see the change in flux linkage $\Delta\lambda$ which can be found by integrating the flux density waveform between ① & ② and at time $(t+\Delta t)$ the flux density waveform ③ & ④

- Change in flux $\Delta\phi$:

from fig, it is clear that area A containing +ve flux has gone out of the coil as well as some amount of -ve flux (Area B) has been included.
Area A = Area B.

• How much is the flux content in area A & B can be found out by the flux density waveform and the area A & B.

• The armature area due to this angle $\Delta\theta$ is Δa

$$\Delta a = r \cdot \Delta\theta \cdot l$$

(r: Arc length; l: length of Armature)

so;

$$\Delta\phi = B \cdot \Delta a$$

(B: max flux density)

$$\Delta\phi = B \cdot r \cdot \Delta\theta \cdot l$$

$$= (-)(2)\, B \cdot r \cdot \Delta\theta \cdot l$$

(−: Because +ve flux ↓, −ve flux ↑; 2: two times as shown in fig.)

and;

$$\Delta\lambda = -2\, N_c\, B \cdot r \cdot \Delta\theta \cdot l$$

(N_c: No of turns in the coil)

$$\Delta\lambda = N_c \Delta\phi$$

so the magnitude of emf induced in the coil at instant 't' is given by;

PAGE NO..
DATE:

$$e = \lim_{\Delta\theta \to 0} \frac{\Delta\lambda}{\Delta t} = \frac{d\lambda}{dt}$$

$$e = -2\,N_c . B . r . l . \frac{d\theta}{dt}$$

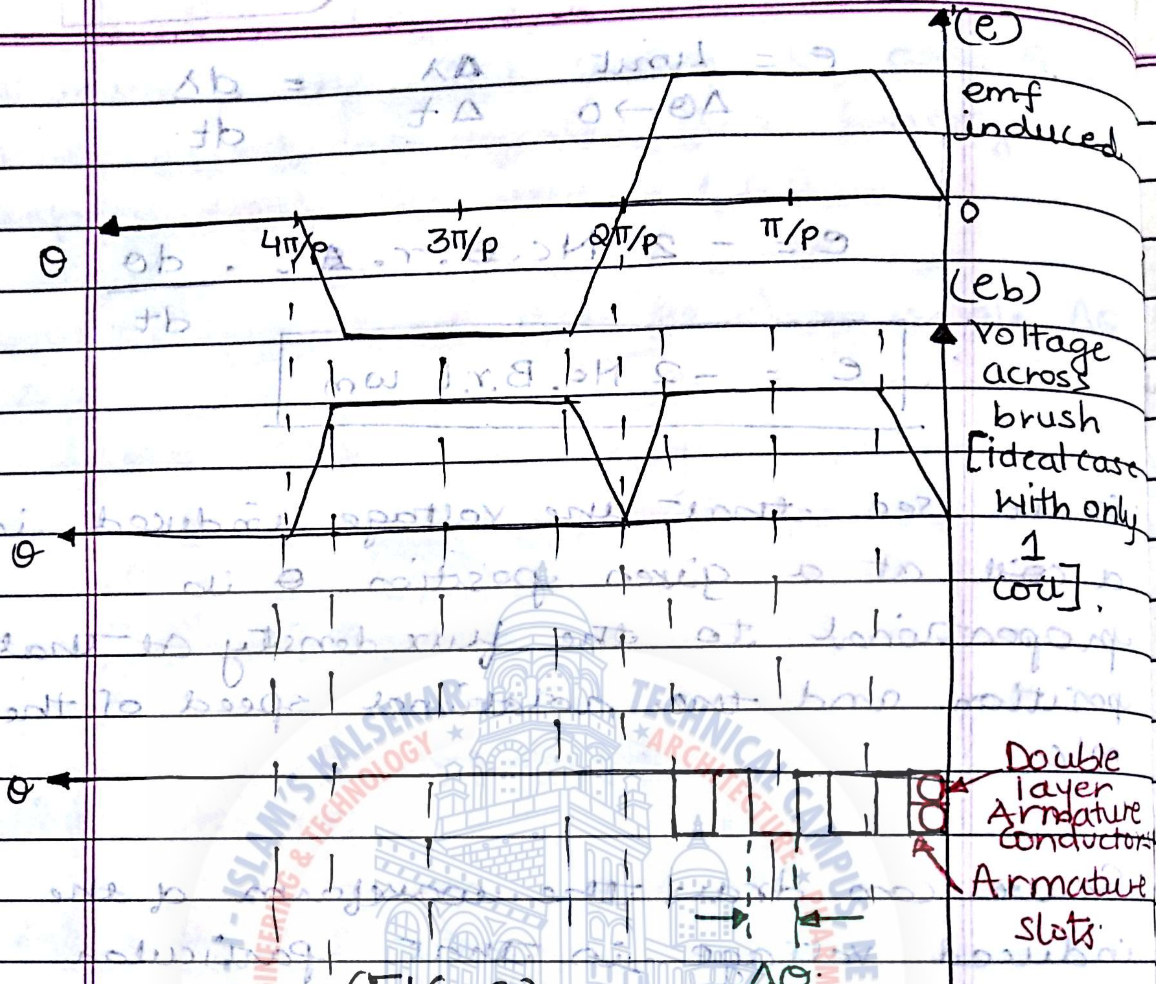
$$\therefore \boxed{e = -2\,N_c . B . r . l\ \omega_m}$$

- So we see that the voltage induced in a coil at a given position θ is proportional to the flux density at that position and the rotational speed of the m/c.

- So we can draw the waveform of the induced voltage in that particular coil as it moves along the armature surface.

- Voltage induced at the brush will be the rectified voltage waveform of the voltage induced in the coil.

PAGE NO.:
DATE:



(FIG-2)

Let;

$Z \rightarrow$ Total no. of armature conductors distributed over the periphery.

Z no of conductors are spread over mechanical angle of 4π

$N_c \rightarrow$ No of turns in a coil

- $$n_c = \frac{Z}{4\pi} \times \Delta\theta$$

- $$e_c = -2\left(\frac{Z}{4\pi}\, d\theta\right) B\, r\, l\, \omega_m.$$

[voltage induced in single coil]

Prof. Tahoora Qureshi

$\theta \to a$
$\phi \to P.$

Now;
between two brushes there are no of coils connected in parallel. In fact all the coils which are in the span $\left(\frac{2\pi}{a}\right)$; the

brushes are set apart by an angle of the number of conductors between two opposite polarity brushes is given by $\left(\frac{2\pi}{a}\right)$

The no of coils connected in series ~~is~~ between two brushes is $\left(\frac{2\pi}{a}\right)$.

Therefore the induced vg between the brushes can be written as;

$$e_b = \int_0^{2\pi/a} e_c \, d\theta$$

→ One brush will be at instant 'o'

→ Other brush will be at interpolar region which is $\frac{2\pi}{P}$ but no of coils connected in series between the brush at 'o' and brush at $(2\pi/p)$ will be $\left(\frac{2\pi}{a}\right)$

$$e_b = \int_0^{2\pi/a} + 2\left(\frac{z}{4\pi}\right) B r l \omega_m \, d\theta$$

Now we change the variable.

Prof. Tahoora Qureshi

$\phi \to P$, $\theta \to a$

$$\phi = \frac{a\,\theta}{P} \quad ; \quad d\phi = \frac{a\,d\theta}{P}$$

$$\therefore e_b = 2\omega_m \frac{Z}{4\pi} \cdot \frac{P}{a} \int_0^{2\pi/P} B\,r\,l\,d\phi$$

This term is identified as the total flux passing through North pole ∴ termed flux/pole or ϕ_p.

$$e_b = 2\omega_m \frac{Z}{4\pi} \cdot \frac{P}{a} [\phi_p]$$

∴ Back emf $(E_b) = e_b = 2\omega_m \frac{Z}{4\pi} \cdot \frac{P}{a} [\phi_p]$

$$E_b = \frac{Z}{2\pi} \cdot \frac{P}{a} \cdot \phi_p \cdot \omega_m$$

$$= K \, \phi_p \, \omega_m$$

Where;

$$K = \frac{Z}{2\pi} \cdot \frac{P}{a}$$

$a = P$ for lap winding

$a = 2$ for wave winding

Now;

$$\omega_m = \frac{2\pi N \text{ (rpm)}}{60}$$

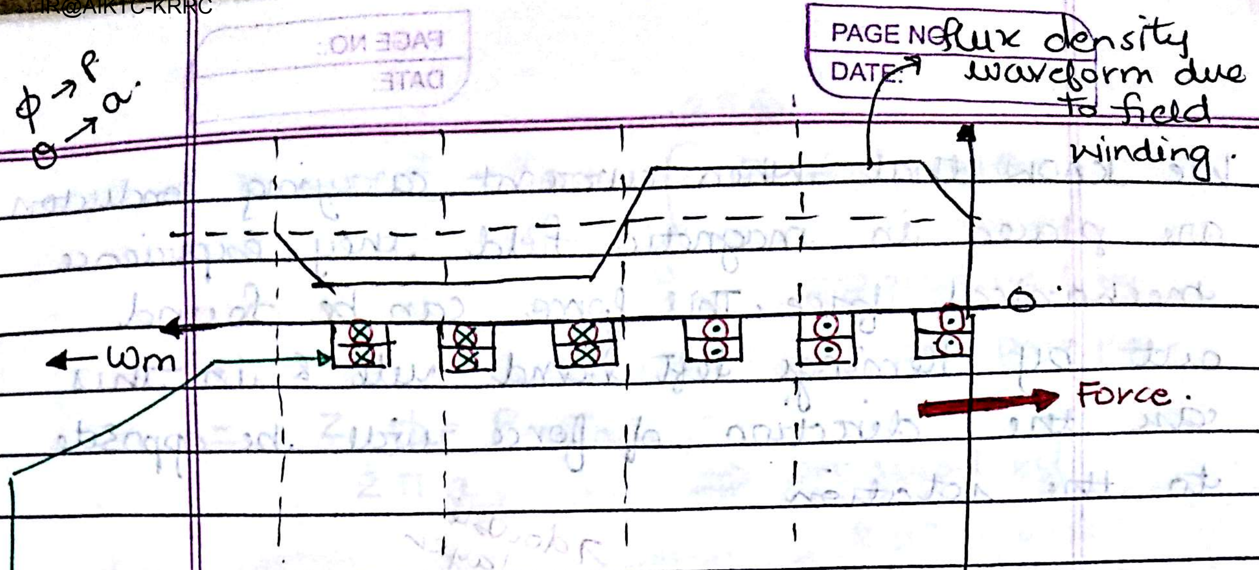
$$\therefore E_b = \frac{\phi_p Z}{2\pi} \cdot \frac{P}{a} \cdot \frac{2\pi N}{60}$$

$$\boxed{E_b = \frac{\phi_p Z N P}{60 A}}$$

$\leftarrow \omega_m$

The ... obey ... rotor ... linked ... linke... The ... that ... oppose ... entire ... shou...

Prof. Tahoora Qureshi



The coils are provided ⊙ and ⊗ polarity by considering fig (FIG-1) in which the rotor moves towards left ie the (+ve) flux linkage tends to reduce & the (-ve) flux linkage tends to increase (shaded portion). The current ∴ flows in such a fashion that this decrease in flux linkage is opposed (lenz law). Therefore current is entering in -ve half of flux density waveform shown above.

We know that when current carrying conductors are placed in magnetic field they experience mechanical force. This force can be found out by flemings left hand rule & in this case the direction of force will be opposite to the rotation

- Magnitude of force acting on one coil (ΔF) $= (2) n_c . B\, L . I_c$ → double layer

- $I_c = \dfrac{I_a}{a}$

$$\therefore \Delta F = 2 n_c B L \frac{I_a}{a}$$

$$\therefore \Delta T = 2 r \Delta F \longrightarrow (\text{lec23}, 38:39)$$

$$= 2r \left(2 n_c B L \frac{I_a}{a} \right)$$

$$= 4 r n_c B L \frac{I_a}{a}$$

$$= 4r \left(\frac{Z \cdot d\theta}{4\pi} \right) B L \frac{I_a}{a}$$

$$\Delta T = \frac{Z}{\pi} B r L \frac{I_a}{a} d\theta$$

→ To get the total torque, we need to add torques produced by each coil between two brush

$$T = \frac{Z}{\pi} \cdot \frac{I_a}{a} \int_0^{2\pi/a} B\, r\, L\, d\theta$$ ⇒ produced by one pole pair.

$$= \frac{Z\, \phi_p\, P\, I_a}{2\pi a}$$ ⇒ produced by 2 pole pairs (4 pole m/c)

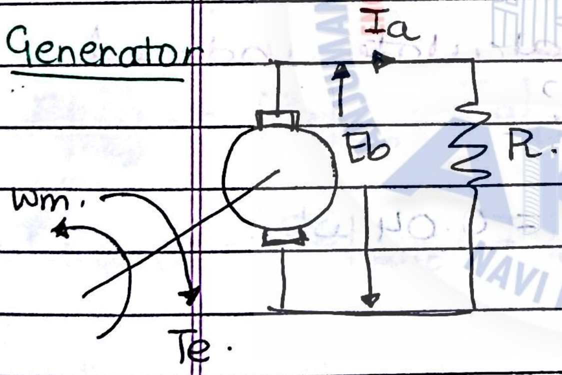
$$= \frac{Z}{2\pi} \cdot \frac{P}{a} \cdot \phi_p \cdot I_a$$

$$\boxed{T = K \phi_p I_a}$$

Where; $K = \frac{Z P}{2\pi a}$

Alternatively :

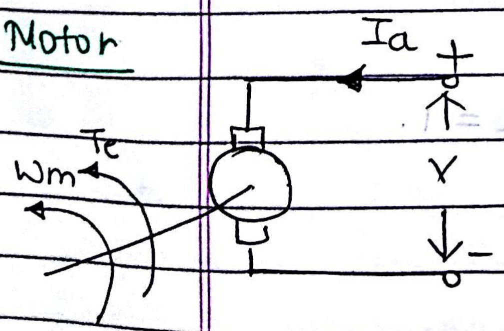
Generator



- consider $R_a = 0$ [No loss]
- $P_e = E_b I_a$
  $= (K \phi_p \omega_m) I_a$
- $P_m = P_e$
- $P_m = T_e \omega_m$
- $T_e \omega_m = K \phi_p \omega_m I_a$

or $\boxed{T_e = K \phi_p I_a}$

Motor



- $V = E_b = K \phi_p \omega_m$
- $I_a V = K \phi_p \omega_m I_a$
- $T_e \omega_m = K \phi_p \omega_m I_a$

$$\boxed{T_e = K \phi_p I_a}$$

- If current is made to flow through the armature conductors either by appling a seperate source (motor) or by connecting it to load (generator). then an electromagnetic torque is generated the magnitude of which is $\propto$ to ϕ_p and I_a.
- For motoring mode, the current is injected so that Pe is i/p to m/c & hence Te is in direction which assists motion ie (ω_m)
- For generating mode, the reverse happens, if a load is connected then the current flowing through the armature winding will try to stop the rotation. ie Te is opposite to ω_m

* An example how to calculate induced voltage in Armature?

Data; $P=4$; $Z=1000$; $\phi_p = 0.04$ wb.
$N = 500$ rpm.

$$E_b = \frac{\phi_p Z N}{60} \cdot \frac{P}{a}$$

for lap ; $P = a$ $\therefore$ $P/a = 1$.

$$E_b\Big|_{Lap} = \frac{0.04 \times 1000 \times 500}{60}$$

$= 330V$.

PAGE NO..
DATE:

for wave;

$a = 2$

$$\therefore E_b = \frac{0.04 \times 1000 \times 500}{600} \times \frac{4}{2}$$

$$\therefore E_b\big|_{wave} = 660\,V.$$

with lap connection voltage is ↓ and with wave connection voltage is ↑.

· The current carrying capacity of the winding is 'I_c' & does not change for lap or wave connection.

→ Lap; $I_a = a I_c = 4 I_c$.

→ Wave; $I_a = a I_c = 2 I_c$

$P\big|_{lap} = E_b\big|_{lap} \cdot I_a\big|_{lap} = 330 \times 4 I_c = 1320 I_c$.

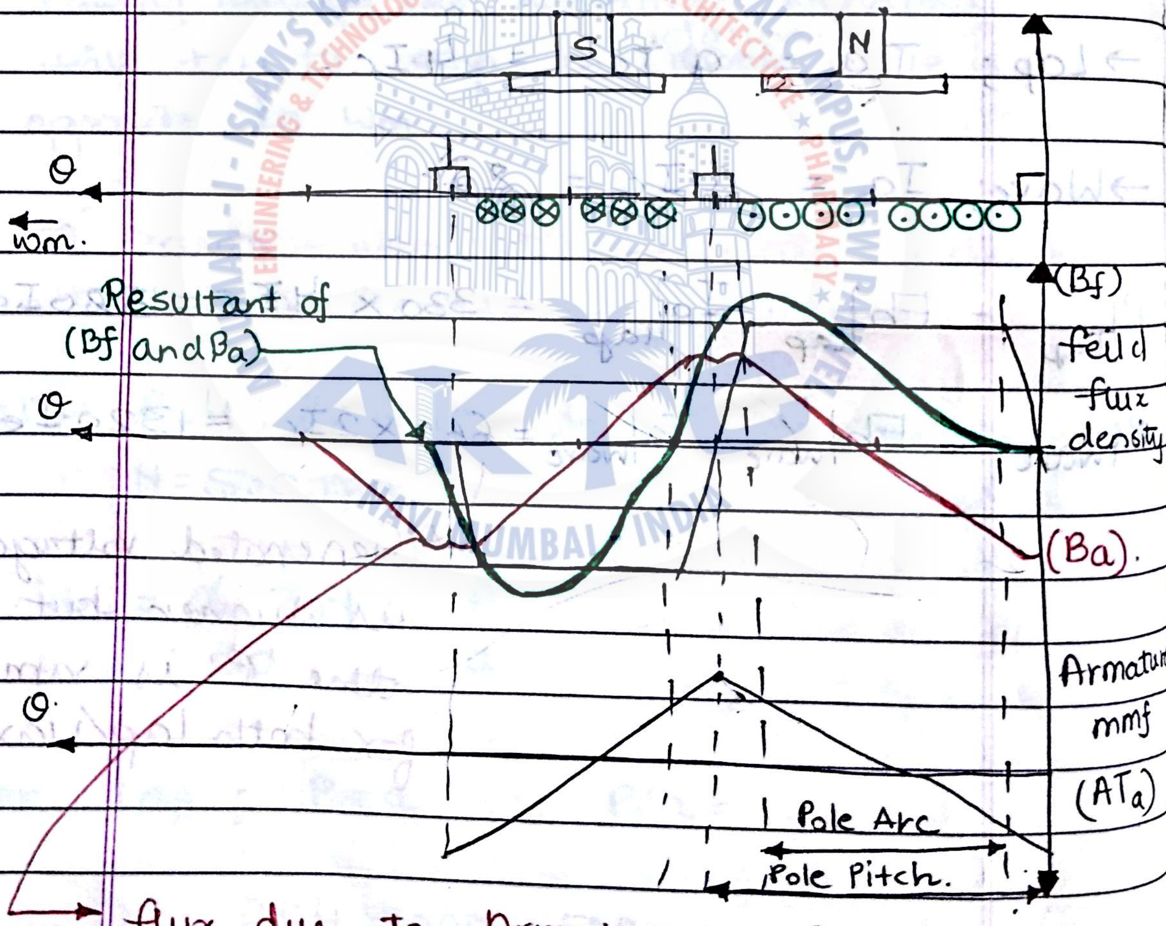
$P\big|_{wave} = E_b\big|_{wave} \cdot I_a\big|_{wave} = 660 \times 2 I_c = 1320 I_c$

↳ Generated voltage is higher but the 'P' is same for both lap/wave

* Armature Reaction

So far we have studied the effect of field pole on generated Voltage & torque, however in a practical dc m/c, both the field winding & the armature winding carries current simultaneously. We know that induced emf & torque is due to the resultant flux density waveform of the interaction of stator flux density wave with the rotor.

When the armature flux modifies the field flux wave, it is called as armature reaction.



flux due to Armature mmf which has zero crossing beneath the pole and high value at the interpolar region but with a slight dip due to large airgap in interpolar region.

Prof. Tahoora Qureshi

PAGE NO.
DATE:

Thus the resultant of Bf and Ba is distorted. This distortion of the field flux due to current flowing into the Armature is called Armature reaction.

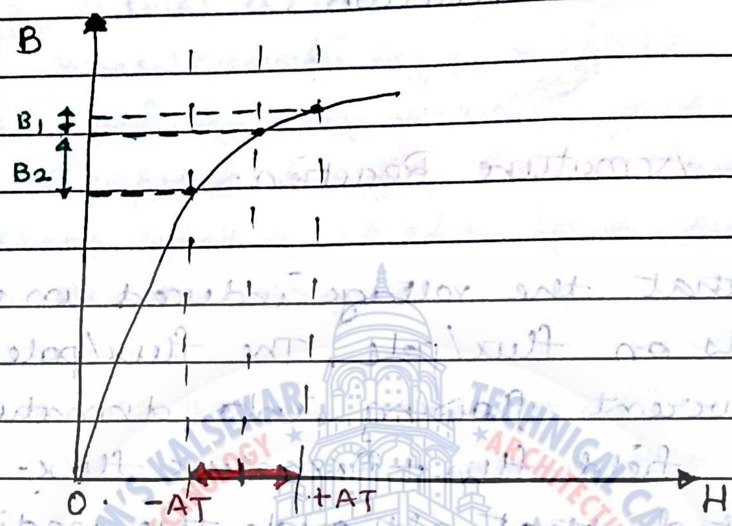
* Effects of Armature Reaction.

We know that the voltage induced in Armature coil depends on flux/pole. The flux/pole due to the current flowing into Armature is due to field flux + Armature flux. It is to be noted that although the individual armature coils are moving with the armature, the pattern of dot & cross currents do not change with time. Therefore, the armature mmf & hence the armature flux density waveform are stationary in space, they do not change.

It is seen that net Armature mmf under one pole is zero. [see diagram]. If the field ckt is linear, ie flux density is proportional to the mmf, then there will be no change in the net flux/pole. hence the induced voltage will not change.

But in general the m/c do not work in the unsaturated region of the magnetisation curve.

If we consider the magnetisation, the saturation of the armature & the iron of the dc m/c then we arrive at a different picture.



If we add a '+ve' & '-ve' Ampere turn of equal magnitude (shown in red) we find the change in flux density (B) are not same. ie ↑ in B due to ↑ in AT is less than decrease. Therefore what will happen is, due to same, there will be a net demagnetization of the field flux. ie the flux/pole (Øp) will reduce & hence the induced voltage will also reduce.

Another problem is that we find that the position of zero crossing of resultant (Bf + Ba) wave is different from the zero crossing of the field flux alone.

The br... zero cr... armatu... position... Hence t... the br... voltage... during... be zer... problem...

Ano... induced... value f... Becaus... the in... will r... Hence, t... will b... voltage... insula... Therefor... effect

PAGE NO..
DATE:

The brushes are usually placed at the zero crossing of field flux, but because of armature reaction the resultant flux density at the position of the brushes is no longer zero hence the coil that will be connecting to the brushes will not have zero induced voltage at the moment of commutation hence, during commutation induced vg won't be zero & there will be circulating currents problem.

Another thing is we know that the voltage induced in every coil has its instantaneous value proportional to the flux density. Because of this ↑ and ↓ in B waveform, the instantaneous induced voltage in a coil will be far larger than their average value. Hence, the adjacent commutator segments will be subjected to a much larger peak voltage which may cause breakdown of insulation between the commutator segment. Therefore it is necessary to counter the effect of armature Reaction in dc m/c.

PAGE NO.:
DATE:

* Method to counter-act the effect of Armature Reaction in DC m/c.

Total no of Armature Conductors → Z
Total no of turns [one turn consists of 2 conductors] → Z/2
Total Armature current → Ia.
Total parallel paths → a.
Current carrying capacity of conductor → $I_c = \frac{I_a}{a}$.

$$\frac{Z I_c}{2P} \text{ - Ampere turns/pole.}$$

$$\frac{Z I_a}{2aP} = AT_a \text{ (peak).}$$

In order to negate the effect of Armature reaction the above ampere turns needs to be compensated. This can be done by putting a winding to the pole face. These windings are connected in series with the armature so that the armature mmf is to some extent cancelled by the mmf produced by the compensating winding. It is a pole face winding which carries a current which is proportional to the armature current

PAGE NO..
DATE:

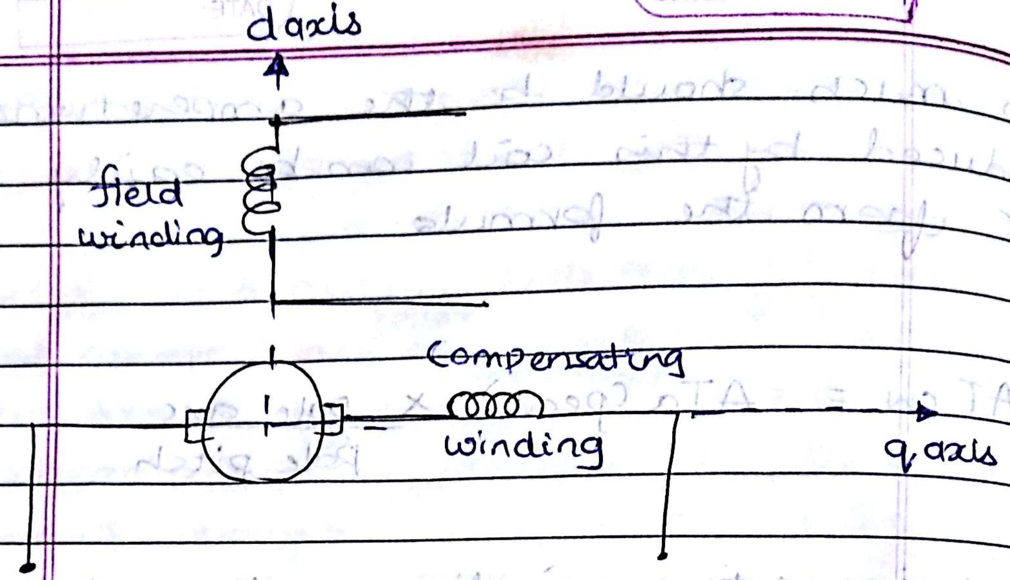
How much should be the ampereturns produced by this coil can be easily found out from the formula:

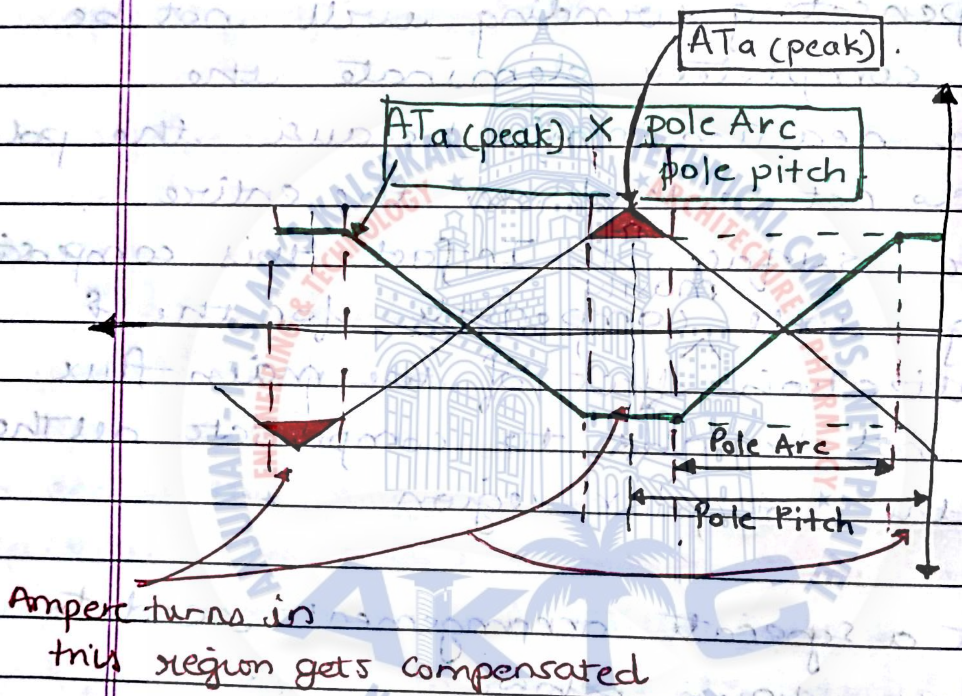
$$AT_{cw} = AT_a (peak) \times \frac{\text{pole arc}}{\text{Pole pitch}}.$$

The compensating winding will not be able to completely eliminate the armature reaction mmf because the pole shoes do not extend over the entire armature surface. Infact, this compensating winding will mostly compensate for the demagnetization effect of the main flux. It will not be able to compensate all the flux in the interpolar region.

For that a seperate arrangement needs to provided as shown below.

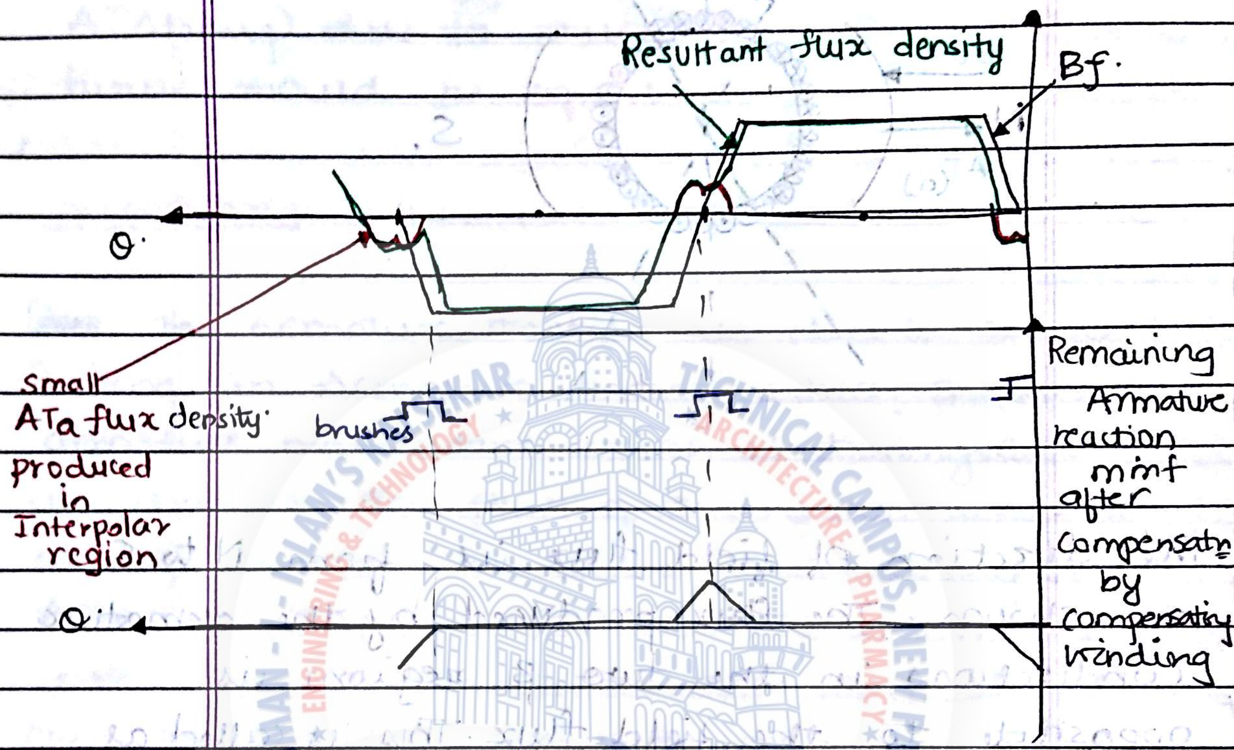
Prof. Tahoora Qureshi



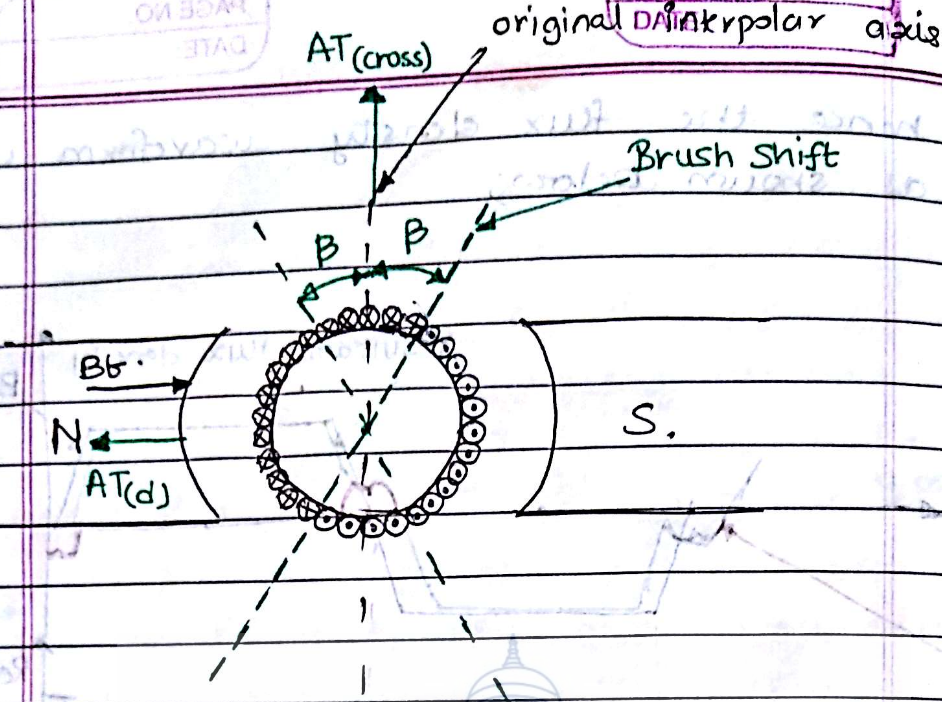


The compensating winding is placed on the q axis & the main flux is on the q axis. The compensating will now cancel the armature mmf flux directly under the pole but it will not compensate completely, the mmf at the interpolar region. The black wave is armature AT and the green wave is the compensating winding AT. However the portion shown by the red is ATa still uncompensated at the interpolar region.

and hence the flux density waveform will look as shown below;



From above, its clear that the resultant flux density wave has a shift in magnetic neutral axis, which means that the position where the brushes are normally kept will not have zero flux. This will give rise to problem is commutation.



The direction of field flux is from N to S as shown. The flux produced by the armature conductors in the two β regions is opposite to the field flux. This is called as the demagnetizing flux due to brush shift.

$$AT(demag) = \frac{Z}{4\pi} \times 2\beta I_c.$$

where;

$$I_c = \frac{I_a}{a}.$$

The rest of the armature conductors will contribute to the cross-magnetizing ie AT that produces flux alligned with q axis whereas the demagnetizing AT ~~that~~ produces flux alligned to "d" axis opposite to field flux.

Therefore if brush shift is applied it is necessary that no of field turns be necessary modified accordingly to counter the effect of AT(demag) due to brush shift. The field turns should be equal to AT(deg).

Summary:

~~Due to~~ Armature reaction is due to current flowing in Armature winding which produces armature mmf wave which is triangular in nature. The peak of triangular wave is at the q axis while the zero crossing of ATa is on d axis i.e directly under the pole. This Armature reaction mmf is stationary even though the armature conductors rotate in space because the conduction pattern of current between two brushes does not change with time. Therefore the armature mmf wave & hence the ~~field~~ (Ba) produced by the armature remains stationary in space.

The effect of Armature mmf is that it produces a Ba wave which has zero crossing under the poles but its peaks are at interpolar region. Since the interpolar region has larger reluctance, the peak usually occurs somewhat before that & hence it tends to strengthen the flux density at one end of pole shoes while decreasing ~~the~~ it on other end.

Prof. Tahoora Qureshi

PAGE NO.:
DATE:

If the m/c is operating in the unsaturated region of the magnetic ckt, then the net increase in Øp (flux/pole) will not change. Hence there will be no change in the induced emf. However most practical m/c are not operated in the unsaturated region of magnetic ckt because of the saturating, the ↓ in Bf will be more than its ↑ & hence there will be net ↓ in Øp & due to Armature reaction, the induced emf will reduce. Due to Armature reaction there will be Ba at interpolar region while Bf is zero at interpolar axis. This will create problem during commutation hence it is necessary to compensate for the armature reaction flux produced by Ia. This is normally done by using compensating winding. It is pole face winding & connected in series with Armature (brushes). However a compensating winding can compensate for ATa which are directly under pole shoe but as the pole shoe does not extend over the entire Armature periphery, the compensating winding can copmpensate only part of Armature reaction flux. ATa under the interpolar axis cannot be directly compensated by compensating winding. For this purpose, interpole is used.