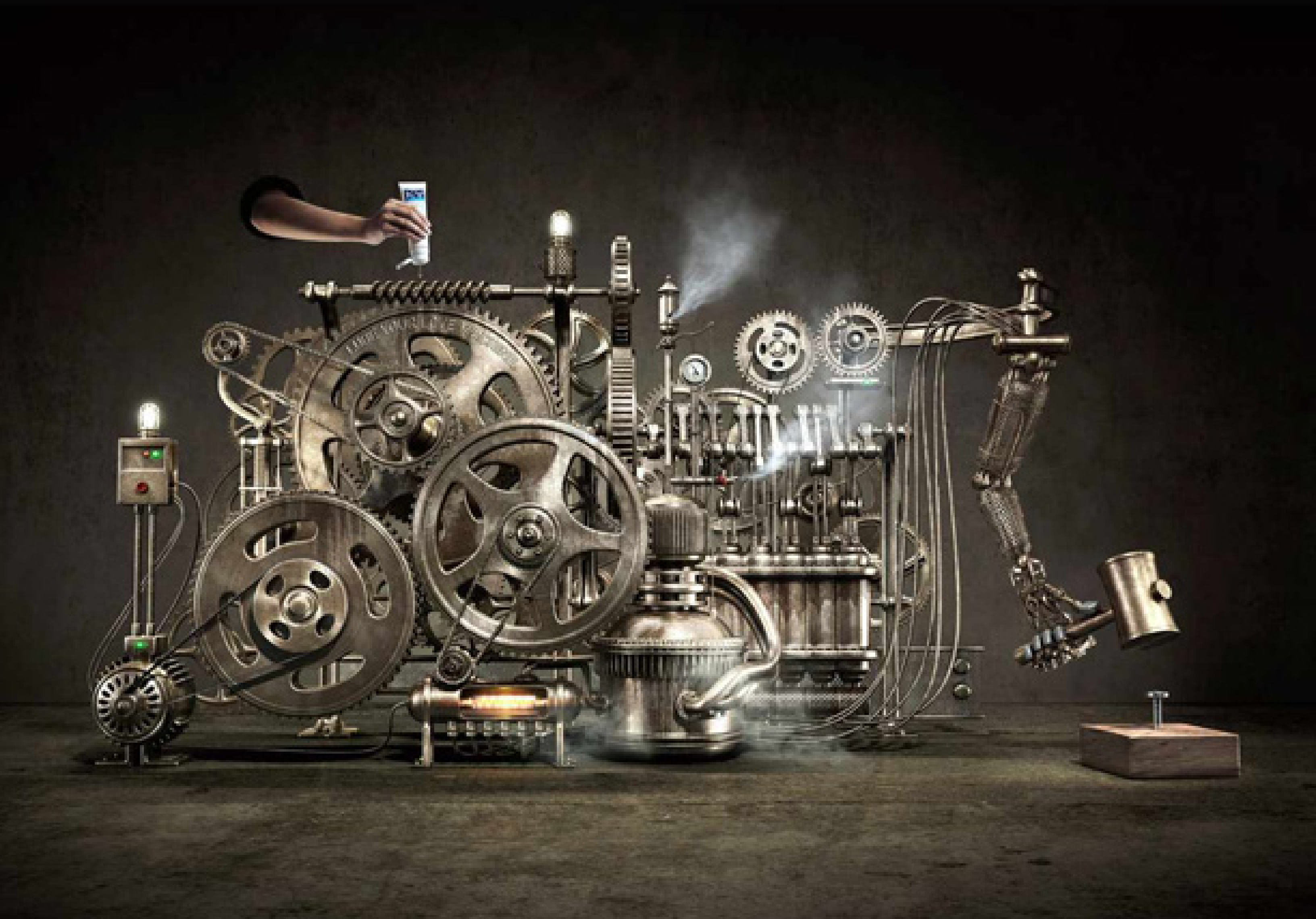
VTU eNotes On DC Machines and Synchronous Machines



Electrical And Electronics Engineering

CLASSIFICATION OF DC MACHINES

METHODS OF EXCITATION: depending on the type of excitation of field winding, there are two basic types of DC machine.

1. Separately excited machine: In this type of machines the field flux is produced by connecting the field winding to an external source.
2. Self excited machine: The field flux is produced by connecting the field winding with the armature in this type. A self excited machine requires residual magnetism for operation.

Depending on the type of field winding connection DC machines can be further classified as:

1. Shunt machine: The field winding consisting of large number of turns of thin wire is usually excited in parallel with armature circuit and hence the nameshunt field winding. This winding will be having more resistance and hence carries less current.
2. Series machine: The field winding has a few turns of thick wire and is connected in series with armature.
3. Compound machine: Compound wound machine comprises of both series and shunt windings and can be either short shunt or long shunt, cumulative, differential or flat compounded.

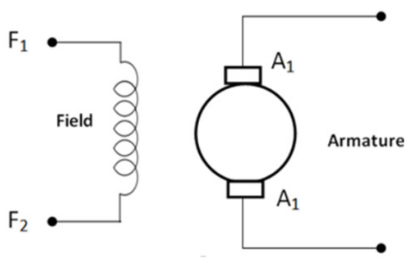


Figure 1.1 Separately Excited Machine

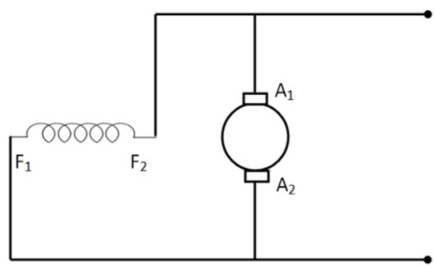


Figure 1.2 Self Excited Machine

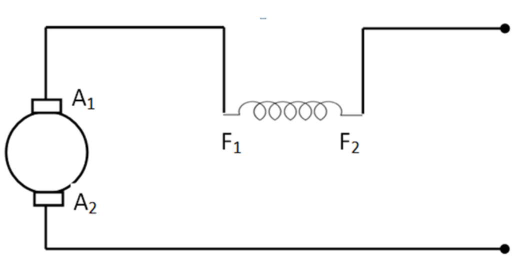


Figure 1.3 Series Wound Machine

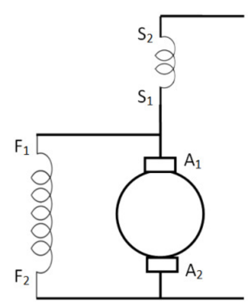


Figure 1.4 Short Shunt Compound Machine

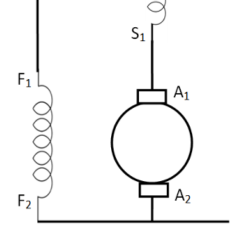


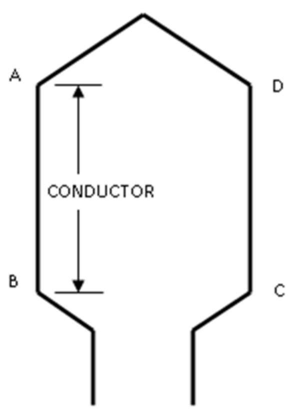
Figure 1.5 Long Shunt Compound Machine

In separate excited DC machine, the field winding is connected to a separate DC source. This type of machine is most flexible as full and independent control of both armature and field circuit is possible. Figure 1.1 shows separately excited DC generator. Permanent magnet machines also fall in this category.

A self excited DC generator could be excited by its armature voltage as shown in figure 1.2 (i.e., shunt excitation) or by its armature current as shown in figure 1.3 (series excitation). Compound wound generator comprises of both series and shunt windings and can be either short shunt (figure 1.4) or long shunt (figure 1.5), cumulative or differential or flat compounded.

ARMATURE WINDINGS

Armature winding is an arrangement of conductors distributed in slots provided on the periphery of the armature. Depending on the way in which the coils are interconnected at the commutator end of the armature, the windings can be classified as lap and wave windings. Further they can be classified as simplex and multiplex. The important terms used in armature windings are given below:



Representation of a Single Turn coil

Figure 1.6

COIL PITCH/COIL SPAN: represents the span of the coil. It can be represented in terms of electrical degrees, slots or conductor. For full pitched winding, the span is 180^0 electrical or number of slots per pole. A full pitched coil leads to maximum voltage per coil.

BACK PITCH/COIL SPAN(Y_b): is the distance measured in between the two coil sides of the same coil at the back end of the armature, the commutator end being the front end of armature. It can be represented in terms of number of slots or coil sides. Back pitch also represents the span of coil.

series at the front end of the armature.

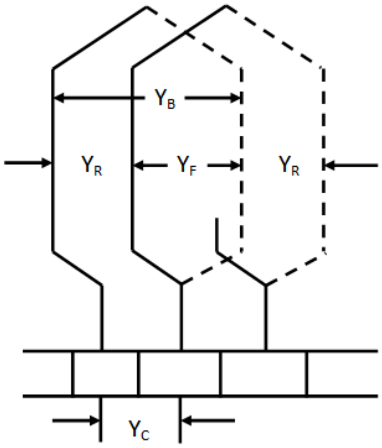


Figure 1.7

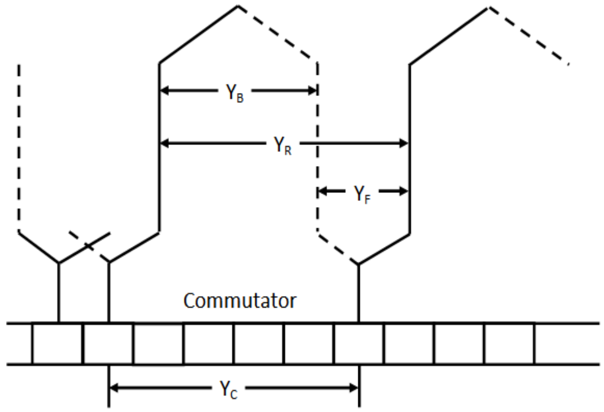


Figure 1.8

COMMUTATOR PITCH (Y_C): is measured in terms of commutator segments between the two coil ends of a coil.

SINGLE LAYER WINDING: In this winding one coil is placed in each slot.

DOUBLE LAYER WINDING: In this winding two or multiples of coil sides are arranged in two layers in each slot.

Front pitch, back pitch and commutator pitch are shown in figures 1.7 and 1.8 for lap and wave windings respectively.

SALIENT FEATURES OF LAP AND WAVE WINDING

1. Armature winding is a closed winding. Depending on the type of winding, the closed path gets divided into number of parallel paths and is available between the positive and negative brushes.
2. Wave winding is used for high voltage low current machines.
3. Equalizing rings are not required in wave winding where as there are used in lap winding.
4. Lap winding is suitable for low voltage high current machines because of more number of parallel paths.

In case of lap winding, the number of parallel path (A) = number of poles (P)

In case of wave winding, the number of parallel path (A) = 2 irrespective of number of poles.

Each path will have $\frac{Z}{A}$ conductors connected in series.

Let Φ= flux per pole in weber

Z = number of armature conductors = Number of slots X conductors per slot.

P = Number of poles; A= Number of parallel paths in armature.

A= P for lap wound armature; A=2 for wave wound armature

N = speed of armature in rpm; E = induced emf in each parallel path.

Average emf generated/conductor in one revolution $= \frac{d\Phi}{dt}$

Flux cut by a conductor in one revolution =$d\Phi$ = $P\Phi$ weber.

Since Number of revolutions/second = $\frac{N}{60}$; Time taken for one revolution = $dt = \frac{60}{N}$ seconds.

EMF generated/conductor = $\frac{d\Phi}{dt} = \frac{\Phi P}{\frac{60}{N}} = \frac{\Phi PN}{60}$ volts.

Since each path has $\frac{Z}{A}$ conductors in series,

EMF generated in each path is E = $\frac{\Phi PN}{60}\ X\ \frac{Z}{A}$ volts $= \frac{\Phi ZPN}{60A}$ volts.............. 1

Also, for a shunt generator, from figure 1.2, E=$V + I_a r_a + BCD$..............2

For a series generator, from figure 1.3, E=$V + I_a(r_a + r_{se}) + BCD$......3

For a short shunt compound generator, from figure 1.4, E= $V + I_a r_a + I_{se} r_{se} + BCD$.....4

For a long shunt compound generator, from figure 1.5, E= $V + I_a r_a + I_a r_{se} + BCD$......5

Where V=Terminal voltage

I_a=Armature current; r_a=Armature resistance

r_{se}=Series field resistance; BCD=brush contact drop

1. The armature of a 4 pole wave wound DC shunt generator has 144 slots and 3 conductors per slot. If armature is rotated with a speed of 1200 rpm in a field of 0.025 wb/pole, calculate the EMF generated.

SOLUTION: Z = 144 X 3 = 432; $E = \frac{\Phi ZNP}{60A} = 432\ volts.$

2. An 8 pole DC generator has 960 conductors and a flux/pole of 20 m wb. Calculate the EMF generated when running at 500 rpm for (i) A lap connected armature winding and (ii) A wave connected armature winding.

SOLUTION: (i) Lap winding $E = \frac{\Phi ZNP}{60\ A} = 160\ V$

(ii) Wave winding $E = \frac{\Phi ZNP}{120} = 640\ V$

3. An 8 pole DC shunt generator with 778 conductors wave connected and running at 500 rpm supplies a load of 12.5 Ω resistance at terminal voltage of 250 V, the armature resistance is 0.24Ω and the field resistance is 250 Ω. Find the armature current, induced emf and Φ/pole.

SOLUTION:$I_L = \frac{V}{R} = \frac{250}{12.5} = 20\ A$

$I_{sh} = \frac{250}{250} = 1\ A$

$I_a = 20 + 1 = 21\ A$

$E = 250 + (21\ X\ 0.24) = 255.04\ V$

$E = \frac{\Phi ZNP}{60A}$ Φ = 9.83 m wb.

4. A 4 pole long shunt lap wound generator supplies 25 kW at a terminal voltage of 500 V. The armature resistance is 0.03 Ω. Series field resistance is 0.04Ω and shunt field resistance is 200 Ω. The brush drop may be taken as 1.0 V. Determine the emf generated. Calculate also the number of conductors if the speed is 1200 rpm and Φ/pole is 0.02 wb. Neglect armature reaction.

SOLUTION:$I = \frac{25X1000}{500} = 50A;$ $I_{sh} = \frac{500}{200} = 2.5\ A$

$I_a = I + I_{sh} = 50 + 2.5 = 52.5\ A$

Series field drop = 52.5 x 0.04 = 2.1 V

Armature drop$I_a r_a = 52.5\ X\ 0.3 = 1.575\ V$

Brush drop = 2 x 1 = 2V

$E = 500 + 1.575 + 2.1 + 2 = 505.67\ V$

$E = \frac{\Phi ZNP}{60A};\ Z = 1264$

The three important characteristics of DC generator are

1. **Open circuit characteristic or Magnetization curve or No – load saturation Curve**

Open circuit characteristic is the relation between the No-load generated emf in the armature, and the field exciting current at a fixed speed. It is the magnetization curve for the material of electro-magnets. It is same for separately excited or self excited machine.

2. **Internal or total characteristic**

This characteristic curve gives the relation between the emf generated in the armature and the armature current.

3. **External characteristic**

This gives the relation between the terminal voltage and the load current. This characteristic takes into account the voltage drop due to armature circuit resistance and the effect of armature reaction. This characteristic is of importance in judging the suitability of generator for a particular purpose. This characteristic is also referred to as performance characteristics or voltage regulating curve.

1. open circuit characteristics $\left(\frac{E}{I_f}\right)$

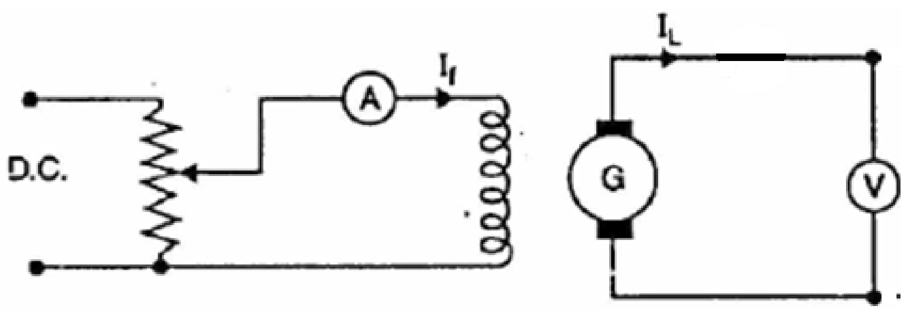


Figure 1.9

The circuit diagram for obtaining the OCC is shown in figure 1.9. Irrespective of the type of the DC machine, namely, shunt, series, compound, the shunt field winding is disconnected and excited from an external source.

Induced emf E $=\frac{\Phi ZNP}{60\ A}$

If the speed is constant, then E = K Φ where K is a constant.

emf increases as flux increases with increase in excitation current. As the field current increases further the iron starts saturating, the emf will not increase proportionately as the flux is not varying proportionately with the current. This is shown by the knee 'pq' of the characteristic curve shown in figure 1.10. A further increase in field current leads to saturation of iron and the flux remains almost constant and hence the induced emf will also remain constant. This is shown by the region 'qr' in the figure1.10.

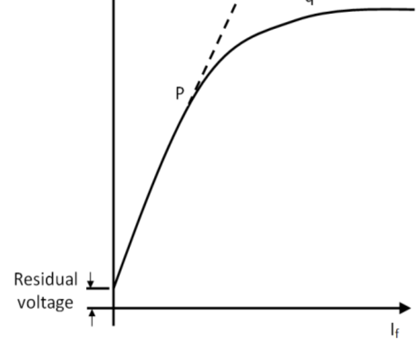


Figure 1.10

CRITICAL RESISTANCE FOR SHUNT GENERATOR

When the armature is rotating with armature open circuited, an emf is induced in the armature because of the residual flux. When the field winding is connected with the armature, a current flows through the field winding (in case of shunt field winding, field current flows even on No-load and in case of series field winding only with load) and produces additional flux. This additional flux along with the residual flux generates higher voltage. This higher voltage circulates more current to generate further higher voltage. This is a cumulative process till the saturation is attained. The voltage to which it builds is decided by the resistance of the field winding as shown in the figure 1.11. If field circuit resistance is increased such that the resistance line does not cut OCC like 'om' in the figure 1.11, then the machine will fail to build up voltage to the rated value. The slope of the air gap line drawn as a tangent to the initial linear portion of the curve represents the maximum resistance that the field circuit can have beyond which the machine fails to build up voltage. This value of field circuit resistance is called critical field resistance. The field circuit is generally designed to have a resistance value less than this so that the machine builds up the voltage to the rated value.

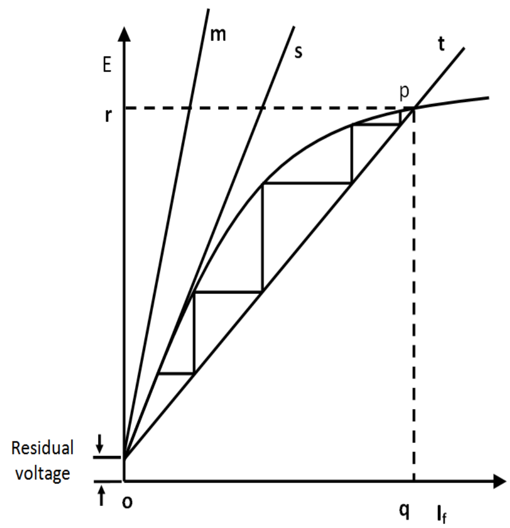


Figure 1.11

Following are the conditions necessary for the voltage build up of a self excited generator.

(i) Residual magnetism must be present.

(ii) For the given direction of rotation, the field coils must be properly connected to the armature so that the flux produced by the field current reinforces the residual flux.

(iii) Its field resistance must be less than the critical field resistance.

CRITICAL SPEED

Critical speed of a generator is that speed for which the field circuit resistance becomes the critical field resistance.

From the figure 1.12 $\frac{BC}{AC} = \frac{N_C}{N}$

Critical speed $N_c = \frac{BC}{AC} X N$ where N is the full speed

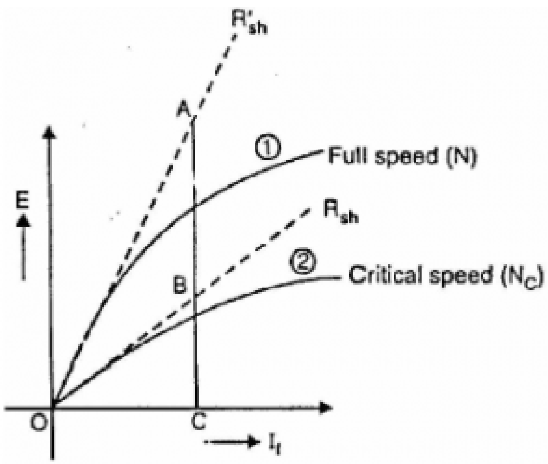


Figure 1.12

Relation between induced emf and terminal voltage will provide an insight into the performance of the machine. The terminal voltage of the machine under loaded condition reduces from the no-load induced emf value because of the armature circuit voltage drop and armature reaction. Further the contact drop of the brushes will have to be taken into account. Usually a brush contact drop of 1volt is considered for a brush. This will be constant throughout the operating range of the machine.

The action of magnetic field set up by armature current on the distribution of flux under main poles of a DC machine is called the armature reaction.

When the armature of a DC machines carries current, the distributed armature winding produces its own mmf. The machine air gap is now acted upon by the resultant mmf distribution caused by the interaction of field ampere turns (AT_f) and armature ampere turns (AT_a). As a result the air gap flux density gets distorted.

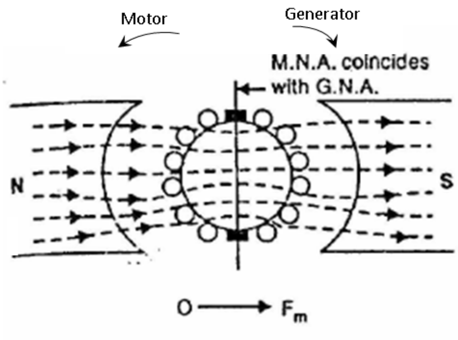


Figure 1.13

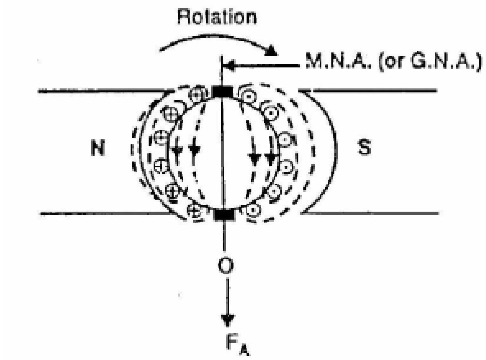


Figure 1.14

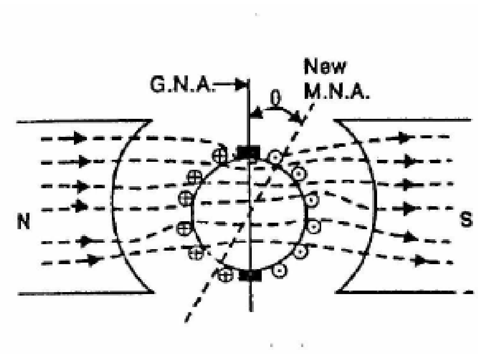


Figure 1.15

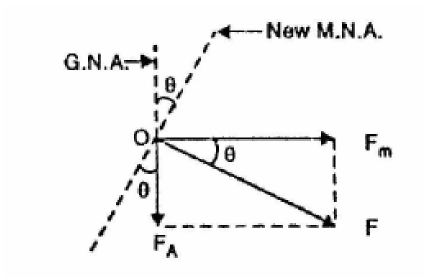


Figure 1.16

Figure 1.13 shows a two pole machine with single equivalent conductor in each slot and the main field mmf (F_m) acting alone. The axis of the main poles is called the direct axis (d-axis) and the interpolar axis is called quadrature axis (q-axis). It can be seen from the Figure 1.14 that ATais along the interpolar axis as shown. AT_a which is at 90^0 to the main field axis is known as cross magnetizing mmf. Figure 1.14 shows the armature mmf (F_A) acting alone.

Figure 1.15 shows the practical condition in which a DC machine operates. Both the main flux i.e., AT_f(Field mmf) and AT_a (armature mmf) are existing. Because of bothmmfacting simultaneously,

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