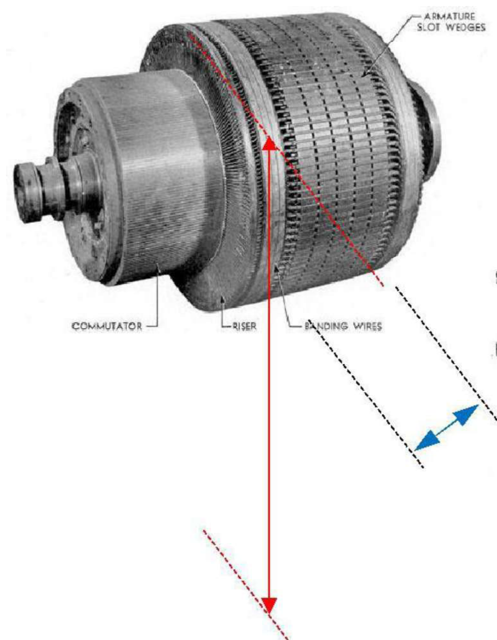
UNIT II DC MACHINES

Output Equations – Main Dimensions - Magnetic circuit calculations – Carter's Coefficient – Net length of Iron –Real & Apparent flux densities – Selection of number of poles – Design of Armature – Design of commutator and brushes – performance prediction using design values.

2.1.Introduction:

The size of the DC machine depends on the main or leading dimensions of the machine viz., diameter of the armature D and armature core length L. As the output increases, the main dimensions of the machine D and L also increases.



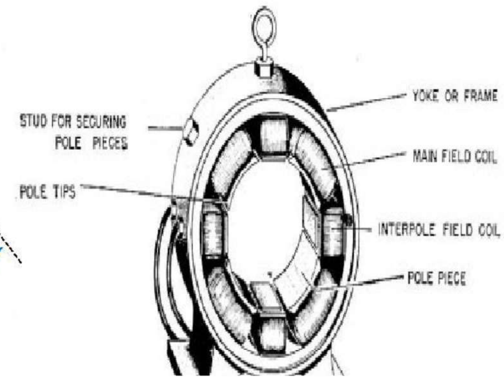
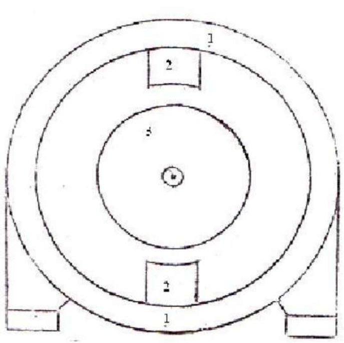
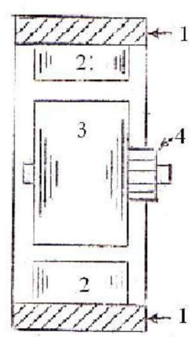


Fig Armature of a dc machine Fig. Yoke and pole arrangement of a dc machine



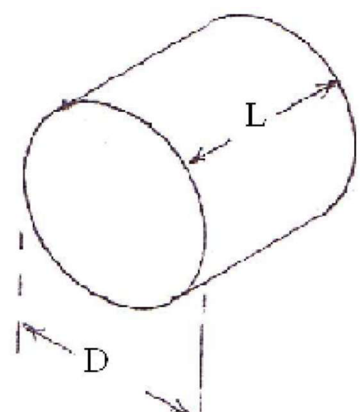
1. Yoke 2. Pole 3. Armature

DC Machine



1.Yoke 2. Pole
3. Armature
4. Commutator

Section of DC machine



Armature

2.2.Output Equations and Main Dimensions of DC Machine

Note: Output equation relates the output and main dimensions of the machine. Actually it relates the power developed in the armature and main dimensions.

E : EMF induced or back EMF

Ia : armature current

φ : Average value of flux / pole

Z : Total number of armature conductors

N : Speed in rpm

P : Number of poles

A : number of armature paths or circuits

D : Diameter of the armature

L : Length of the armature core

Power developed in the armature in kW = $E\ I_a \times 10^{-3}$

$= (\varphi\ Z\ N\ P/60\ A) \times Ia \times 10^{-3}$

$= (P\varphi) \times (I\ a\ Z/A) \times N \times 10\text{-}3/60$ .... (1)

The term P φ represents the total flux and is called the magnetic loading. Magnetic loading/unit area of the armature surface is called the specific magnetic loading or average value of the flux density in the air gap Bav. That is,

$Bav = P\varphi / \pi\ DL\ Wb/m^2$ or tesla denoted by T

Therefore $P\varphi = Bav\ \pi\ DL$ .... (2)

The term (Ia Z/A) represents the total ampere-conductors on the armature and is called the electric loading. Electric loading/unit length of armature periphery is called the specific electric loading q. That is,

Therefore $Ia\ Z/A = q\ \pi\ D$ .... (3)

Substitution of equations 2 and 3 in 1, leads to

$kW = B_{av}\ \pi\ DL \times q\ \pi\ D \times (N \times 10^{-3}/ 60)$

$= 1.64 \times 10^{-4}\ B\ q\ D^2\ L\ N$

$= C_0\ D^2\ L\ N$

Where C_0 is called the output coefficeint of the DC machine and is equal to 1.64 x 10-4 Bq.

Therefore $D^2\ L = (Kw/1.64 \times 10^{-4}\ B\ q\ N)\ m^3$

The above equation is called the output equation. The D^2L product represents the size of the machine or volume of iron used. In order that the maximum output is obtained /kg of iron used, D^2L product must be as less as possible. For this, the values of q and B_{av} must be high.

Effect of higher value of q

Note: Since armature current Ia and number of parallel paths A are constants and armature diameter D must be as less as possible or D must be a fixed minimum value, the number of armature conductors increases as q = Ia Z / A π D increases.

a. As q increases, number of conductors increases, resistance increases, I^2R loss increases and therefore the temperature of the machine increases. Temperature is a limiting factor of any equipment or machine.

b. As q increases, number of conductors increases, conductors/slot increases, quantity of insulation in the slot increases, heat dissipation reduces, temperature increases, losses increases and efficiency of the machine reduces.

c. As q increases, number of conductors increases, armature ampere-turns per pole ATa / pole = (Ia Z / 2 A P) increases, flux produced by the armature increases, and therefore the effect of armature reaction increases. In order to overcome the effect of armature reaction, field MMF has to be increased. This calls for additional copper and increases the cost and size of the machine.

d. As q increases, number of conductors and turns increases, reactance voltage proportional to $(\text{turns})^2$ increases. This leads to sparking commutation.

Effect of higher value of Bav

a. AsBav increases, core loss increases, efficiency reduces.

b. AsBav increases, degree of saturation increases, mmf required for the magnetic circuit increases. This calls for additional copper and increases the cost of the machine.

It is clear that there is no advantage gained by selecting higher values of q and Bav. If the values selected are less, then D2L will be large or the size of the machine will unnecessarily be high. Hence optimum value of q and Bav must be selected.

In general q lies between 15000 and 50000 ampere-conductors/m.

Lesser values are used in low capacity, low speed and high voltage machines. In general Bav lies between 0.45 and 0.75 T.

SEPARATION OF D^2L PRODUCT

Knowing the values of kW and N and assuming the values of q and Bav, a value for

$D^2 L = kW/1.64 \times 10^{-4} \times Bavq\ N$ can be calculated.

Let it be 0.1 m^3.

Since the above expression has two unknowns namely D and L, another expression relating D and L must be known to find out the values of D and L.

Usually a value for the ratio armature core length L to pole pitch is assumed to separate D2L product. The pole pitch τ refers to the circumferential distance corresponding one pole at diameter D. In practice L /τ lies between 0.55 and 1.1.

Therefore L = (0.55 to 1.1) τ

= (0.55 to 1.1) π D / P

If L/τ = 1.0 and P = 4, then L = 1.0 × π D / P

= 1.0 × π D / 4 = 0.785D.

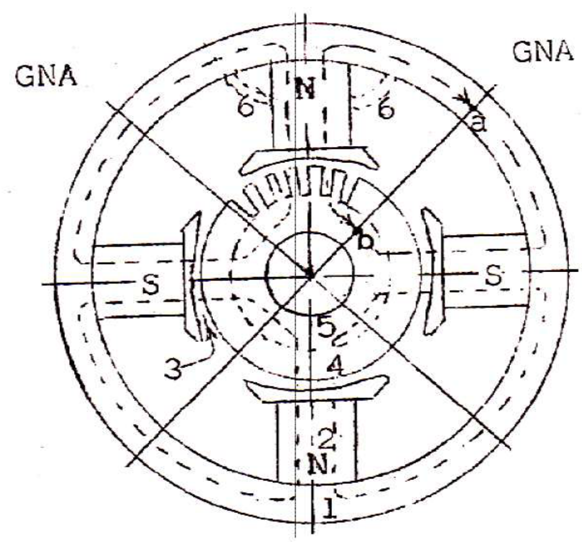
Therefore D2 × 0.785 D = 0.1 or D = 0.5m. Thus L = 0.785 × 0.5 = 0.395 m.

Note: The D2 L product can also be separated by assuming a value for the peripheral velocity of the armature.

2.3.Magnetic circuit calculations

The different parts of the dc machine magnetic circuit / pole are yoke, pole, air gap, armature teeth and armature core. Therefore, the ampere magnetic circuit is the sum of the ampere That is,

AT / pole = ATy + ATp+ ATg



1. Yoke, 2. Pole, 3. Air gap, 4. Armature teeth, 5. Armature core, 6. Leakage flux

ab: Mean length of the flux path corresponding to one pole

Magnetic circuit of a 4 pole DC machine

Note: Leakage factor or Leakage coefficient LC.

All the flux produced by the pole will not pass through the desired path i.e., air gap. Some of the flux produced by the pole will be leaking away from the air gap. The flux that passes through the air gap and cut by the armature conductors is the useful flux and that flux that leaks away from the desired path is the leakage flux

Thus $\phi_P = \phi + \phi_l$

As leakage flux is generally around (15 to 25) % of ϕ,

$$\phi_p = \phi + (0.15 \text{ to } 0.25)\ \phi$$
$$= LC \times \phi$$

where LC is the Leakage factor or Leakage coefficient and lies between (1.15 to 1.25).

Magnitude of flux in different parts of the magnetic circuit

a) Flux in the yoke

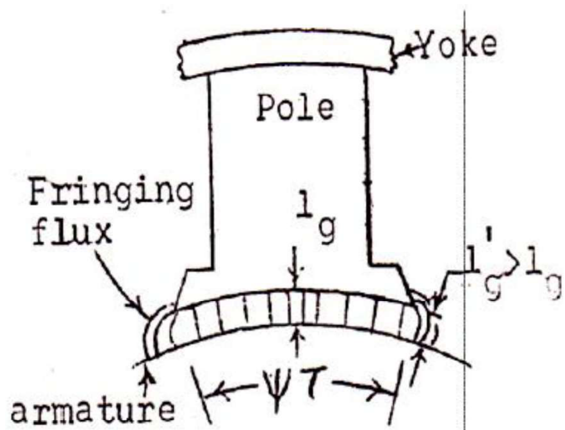
b) Flux in the pole

c) Flux in the air gap

d) Flux in the armature teeth

e) Flux in the armature core

Reluctance of the air gap



Flux distribution under a pole

Where

lg = Length of air gap

t = Width (pole arc) over which the flux is passing in the air gap

L = Axial length of the armature core

y t L = Air gap area / pole over which the flux is passing in the air gap

PROBLEMS:

EX.1. Calculate the ampere turns required for the air gap of a DC machine given the following data. Gross core length = 40cm, air gap length = 0.5 cm, number of ducts = 5, width of each duct = 1.0cm, slot pitch = 6.5cm, average value of flux density in the air gap = 0.63T. Field form factor = 0.7, Carter's coefficient = 0.82 for opening/gap length = 1.0 and Carter's coefficient = 0.82 for opening/gap length = 1.0, and Carter's coefficient = 0.72 for opening/gap length = 2.0.

EX.2. Find the ampere-turns/pole required for a dc machine from the following data. Radical length of the air gap = 6.4mm, tooth width = 18.5 mm, slot width = 13.5mm, width of core packets = 50.8mm, width of ventilating ducts = 9.5mm, Carter's coefficient for slots and ducts = 0.27 and 0.21, maximum gap density = 0.8T. Neglect the ampere turns for the iron parts.

EX.3. Find the ampere turns required for the air gap of a 6pole, lap connected dc machine with the following data. No load voltage = 250V, air gap length = 0.8cm, pole pitch = 50cm, pole arc = 33cm, Carter's coefficient for slots and ducts = 1.2, armature conductors = 2000, speed = 300RPM, armature core length = 30cm.

EX.4. Calculate the ampere turns for the air gap of a machine using the following data. Core length = 32cm, number of ventilating ducts = 4, width of duct = 1.0cm, pole arc of ventilating ducts = 4, width of duct = 1.0cm, pole arc = 19cm. Slot pitch = 5.64 cm, semi-closed slots with slot opening = 0.5cm, air gap length = 0.5cm, flux/pole = 0.05Wb.

EX.5. A DC machine has an armature diameter of 25cm, core length of 12cm, 31 parallel slots 1.0cm wide and 3.0cm deep. Insulation on the lamination is 8.0%. The air gap is 0.4cm long and there is one radial duct 1cm wide in the core. Carter's coefficient for the slots and the duct is 0.68. Determine the ampere turns required for the gap and teeth if the flux density in the gap is 0.7T. The magnetization curve for the iron is:

Flux density in tesla	1.4	1.6	1.8	2.0	2.1	2.2	2.3
ampere- turns/cm	18	30	65	194	344	630	1200

EX.6. Find the ampere turns/pole required to drive the flux through the teeth using Simpson's rule with the following data: flux/pole = 0.07Wb, core-length = 35cm, number of ducts = 4, width of each duct = 1.0cm, slot pitch at the gap surface = 2.5cm, slot pitch at the root of the tooth = 2.3cm, dimensions of the slot = 1.2cm x 5cm, slots/pole-pitch = 12

EX.7. Find the ampere turns required to drive the flux through the teeth with the following data using graphical method. Minimum tooth width = 1.1cm, maximum tooth width = 1.5cm, slot depth = 4.0cm, maximum value of flux density at the minimum tooth section = 2.0T. Material used for the armature is Stalloy.

EX.8. Calculate the apparent flux density at a section of the tooth of the armature of a DC machine with the following data at that section. Slot pitch = 2.4cm, slot width = 1.2 cm, armature core length including 5 ducts each 1.0cm wide = 38cm, stacking factor = 0.92, true flux density in the teeth at the section is 2.2T for which the ampere turns/m is 70000.

EX.9. Calculate the apparent flux-density at a particular section of a tooth from the following data. Tooth width = 12mm, slot width = 10mm, gross core length = 0.32mm, number of ventilating ducts = 4, width of the duct each = 10mm, real flux density = 2.2T, permeability of teeth corresponding to real flux density = 31.4x10-6H/m. Stacking factor = 0.9.

EX.10. The armature core of a DC machine has a gross length of 33cm including 3 ducts each 10mm wide, and the iron space factor is 0.9.If the slot pitch at a particular section is 25 mm and the slot width 14mm, estimate the true flux density and the MMF/m for the teeth at this section corresponding to an apparent flux/density of 23T. The magnetization curve data for the armature stamping is,

B in tesla	1.6	1.8	1.9	2.0	2.1	2.2	2.3
At/m	3700	10000	17000	27000	41000	70000	109000

2.4.Carter's Coefficient

Carter's gap expansion coefficient

$$S_{SSA} = \frac{l_g}{\lambda_s L \mu_0} \quad \text{-------} \quad (1)$$

$$S_{AWS} = \frac{l_g}{(b_t + b_s\,\delta_s)\,L\,\mu_0} \quad \text{-------}\ (2)$$

$$\frac{S_{AWS}}{S_{SSA}} = \frac{l_g / (b_t + b_s\,\delta_s)\,L\,\mu_0}{l_g / \lambda_s\,L\,\mu_0} \qquad S_{AWS} = \frac{\lambda_s \times S_{SSA}}{(b_t + b_s\,\delta_s)}$$

$$= \frac{\lambda_s \times S_{SSA}}{b_t + b_s\,\delta_s + b_s - b_s}$$

$$S_{AWS} = \frac{\lambda_s \times S_{SSA}}{\lambda_s - b_s\,(1 - \delta_s)} = K_{gs} \times S_{SSA}$$

Where Kgs is called the Carter's gap expansion coefficient for slots and is greater than 1.0.

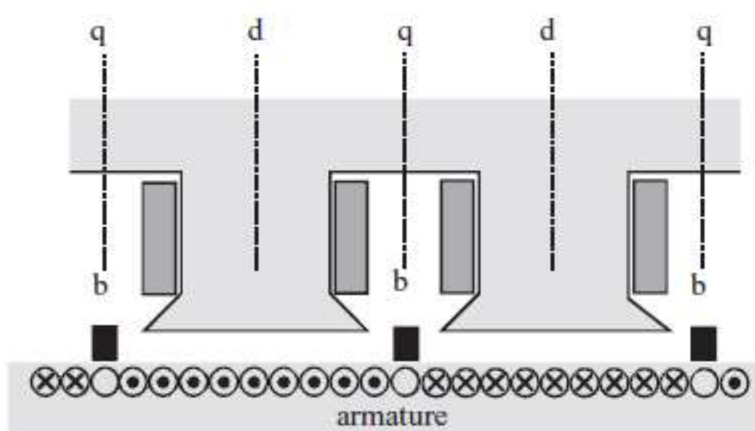
2.5.Net length of Iron

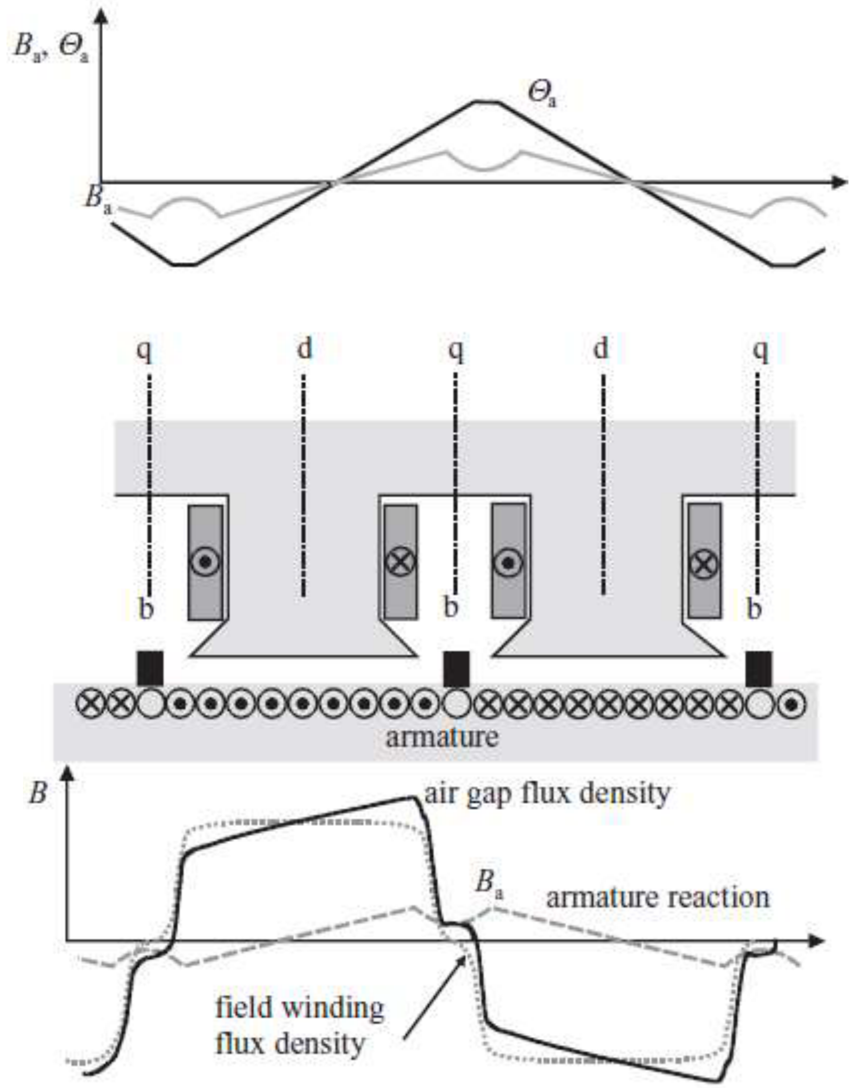
Li = Net iron length of the armature core $= K_i\,(L - n_v b_v)$

2.6.Real & Apparent flux densities

Although a detailed description of the design of a DC machine is beyond the scope of this material, some design principles are still worth mentioning. The methods presented previously are applicable to the design of a DC machine with certain adjustments. One of the most important special features of a DC machine is the armature reaction and, in particular, its compensation.

According to the IEC, the armature reaction is the current linkage set up by the currents in the armature winding or, in a wider sense, the resulting change in the air-gap flux. Since the brushes are on the quadrature axis, the armature current produces the armature reaction also in the quadrature direction; that is, transversal to the field-winding-generated flux. Figure depicts the armature reaction in the air gap of a non compensated DC machine.





Resulting air-gap flux density as a sum of the field winding flux density and the armature reaction. As a result of the armature reaction, the flux densities at the quadrature axes are not zero. This is harmful for the commutation of the machine

2.7.Selection of number of poles

As the armature current increases, cross sectional area of the conductor and hence the eddy current loss in the conductor increases. In order to reduce the eddy current loss in the conductor, cross-sectional area of the conductor must be made less or the current / path must be restricted.

For a normal design, current / parallel path should not be more than about 200A. However, often, under enhanced cooling conditions, a current / path of more than 200A is also being used. By selecting a suitable number of paths for the machine, current / path can be restricted and the number of poles for the machine can be decided. While selecting the number of poles, the following conditions must also be considered as far as possible.

In order to decide what number of poles (more or less) is to be used, let the different factors affecting the choice of number of poles be discussed based on the use of more number of poles.

- Frequency
- Weight of the iron used for the yoke
- Weight of iron used for the armature core (from the core loss point of view)
- Weight of overhang copper
- Armature reaction
- Overall diameter
- Length of the commutator
- Flash over
- Labour charges

Frequency

As the number of poles increases, frequency of the induced EMF — increases core loss in the armature increases and therefore efficiency of the machine decreases.

Weight of the iron used for the yoke

Since the flux carried by the yoke is approximately φ/2 and the total flux φT = pφ is a constant for a given machine, flux density in the yoke

It is clear that is ∝ 1/P

As is also almost constant for a given iron. Thus, as the number of poles increases,

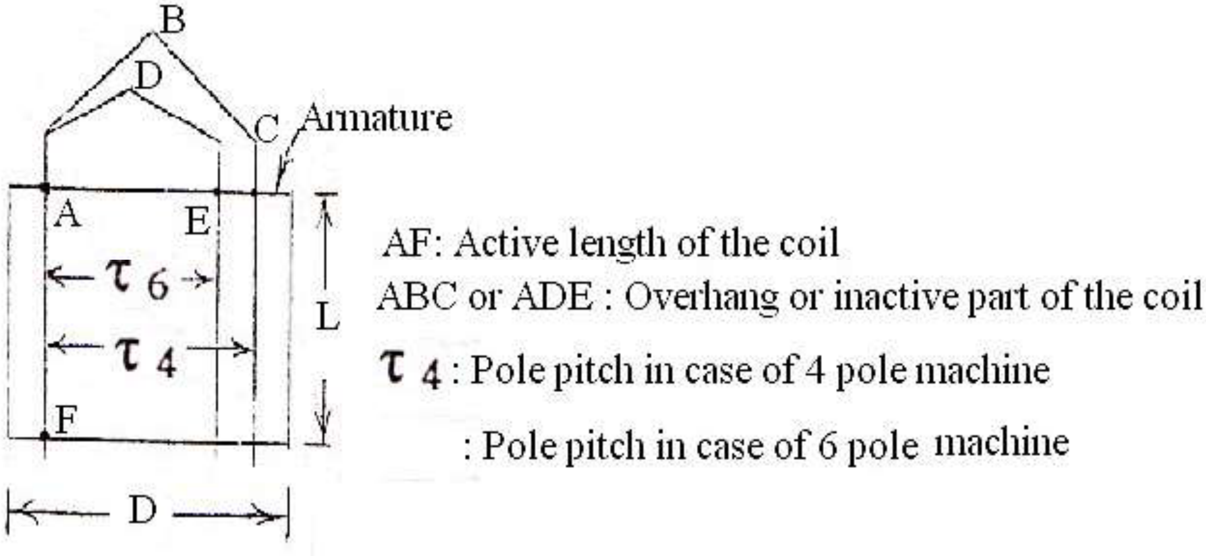
And hence the weight of iron used for the yoke reduces.

Weight of iron used for the armature core (from the core loss point of view)

Since the flux carried by the armature core is φ /2, eddy current loss in the armature core

=> is independent of the number of poles.

Weight of overhang copper: For a given active length of the coil, overhang ∝ pole pitch goes on reducing as the number of poles increases. As the overhang length reduces, the weight of the inactive copper used at the overhang also reduces.



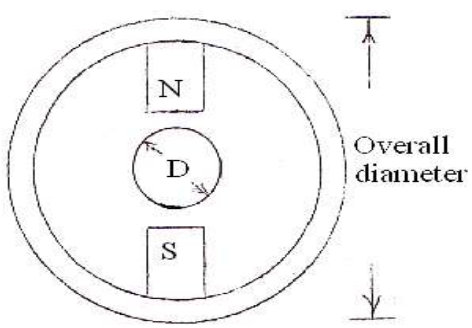
Armature reaction

Since the flux produced by the armature and armature ampere turns

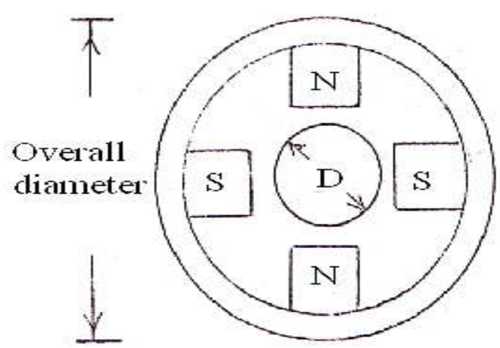
Overall diameter

When the number of poles is less, ATa / pole and hence the flux, produced by the armature is more. This reduces the useful flux in the air gap. In order to maintain a constant value of air gap flux, flux produced by the field or the field ampere-turns must be increased. This calls for more field coil turns and size of the coil defined by the depth of the coil df and height of the coil hf increases. In order that the temperature rise of the coil is not more, depth of the field coil is generally restricted. Therefore height of the field coil increases as the size of the field coil or the number of turns of the coil increases. As the pole height, is proportional to the field coil height, height of the pole and hence the overall diameter of the machine increases with the increase in height of the field coil.

Obviously as the number of poles increases, height of the pole and hence the overall diameter of the machine decreases.



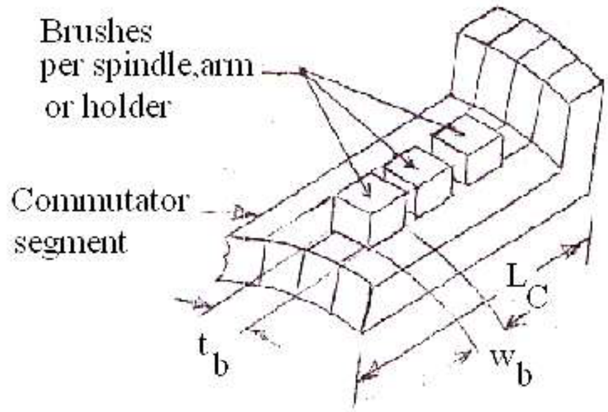
Diameter in case of 2 pole machine



Diameter in case of 4 pole machine

Length of the commutator

Since each brush arm collects the current from every two parallel paths



A portion of the commutator

2.8.Design of Armature

The armature winding can broadly be classified as concentrated and distributed winding.

In case of a concentrated winding, all the conductors / pole is housed in one slot. Since the conductors / slot is more, quantity of insulation in the slot is more, heat dissipation is less, temperature rise is more and the efficiency of operation will be less. Also emf induced in the armature conductors will not be sinusoidal. Therefore

a. design calculations become complicated (because of the complicated expression of non-sinusoidal wave).

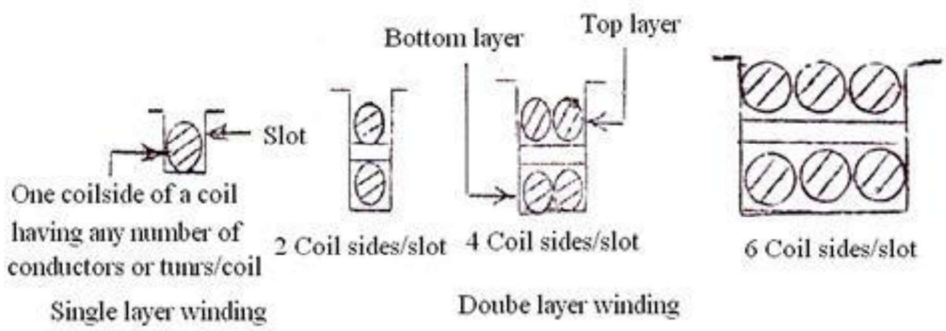
b. Core loss increases (because of the fundamental and harmonic components of the non-sinusoidal wave) and efficiency reduces.

c. Communication interference may occur (because of the higher frequency components of the non-sinusoidal wave).

Hence no concentrated winding is used in practice for a DC machine armature.

In a distributed winding (used to overcome the disadvantages of the concentrated winding), conductors / pole is distributed in more number of slots. The distributed winding can be classified as single layer winding and double layer winding.

In a single layer winding, there will be only one coil side in the slot having any number of conductors, odd or even integer depending on the number of turns of the coil. In a double layer winding, there will be 2 or multiple of 2 coil sides in the slot arranged in two layers. Obviously conductors / slot in a double layer winding must be an even integer.



Since for a given number of conductors, poles and slots, a single layer winding calls for less number of coils of more number of turns, reactance voltage proportional to (turn)2 is high. This decreases the quality of commutation or leads to sparking commutation. Hence a single layer winding is not generally used in DC machines. However it is much used in alternators and induction motors where there is no commutation involved.

Since a double layer winding calls for more number of coils of less number of turns/coil, reactance voltage proportional to $(turn)^2$ is less and the quality of commutation is good. Hence double layer windings are much used in DC machines.

Unless otherwise specified all DC machines are assumed to be having a double layer winding.

A double layer winding can further be classified as simplex or multiplex and lap or wave winding.

In order to decide what number of slots (more or less) is to be used, the following merits and demerits are considered.

1. As the number of slots increases, cost of punching the slot increases, number of coils increases and hence the cost of the machine increases.

2. As the number of slots increases, slot pitch

λs = (slot width bs + tooth width bt)

= πD/ number of slots decreases and hence the tooth width reduces. This makes the tooth mechanically weak, increases the flux density in the tooth and the core loss in the tooth. Therefore efficiency of the machine decreases.

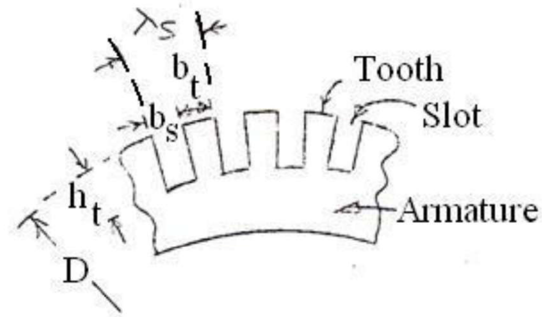


Fig. Armature Dimension view

If the slots are less in number, then the cost of punching & number of coils decreases, slot pitch increases, tooth becomes mechanically strong and efficiency increases, quantity of insulation in the slot increases, heat dissipation reduces, temperature increases and hence the efficiency decreases.

It is clear that not much advantage is gained by the use of either too a less or more number of slots.

As a preliminary value, the number of slots can be selected by considering the slot pitch. The slot pitch can assumed to be between (2.5 and 3.5) cm. (This range is applicable to only to medium capacity machines and it can be more or less for other capacity machines).

The selection of the number of slots must also be based on the type of winding used, quality of commutation, flux pulsation etc.

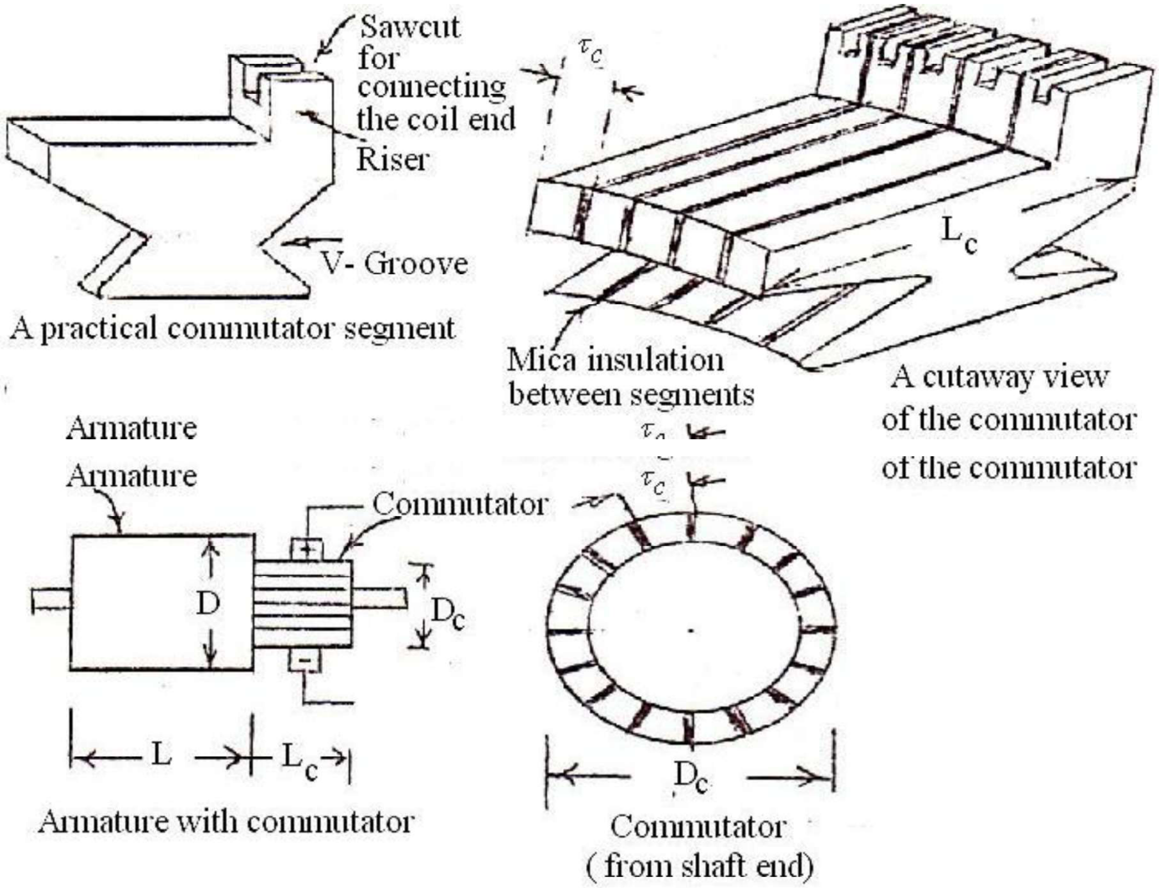
When the number of slot per pole is a whole number, the number slots embraced by each pole will be the same for all positions of armature. However, the number teeth per pole will not be same.

This causes a variation in reluctance of the air gap and the flux in the air gap will pulsate. Pulsations of the flux in the air gap produce iron losses in the pole shoe and give rise to magnetic noises. On the other hand, when the slots per pole is equal to a whole number plus half the reluctance of the flux path per pole pair remains constant for all positions of the armature, and there will be no pulsations or oscillations of the flux in the air gap.

To avoid pulsations and oscillations of the flux in the air gap, the number of slots per pole should be a whole number plus half. When this is not possible or advisable for other reasons, the number of slots per pole arc should an integer.

2.9.Design of commutator and brushes

The Commutator is an assembly of Commutator segments or bars tapered in section. The segments made of hard drawn copper are insulated from each other by mica or micanite, the usual thickness of which is about 0.8 mm. The number of commutator segments is equal to the number of active armature coils.



The diameter of the commutator will generally be about (60 to 80)% of the armature diameter. Lesser values are used for high capacity machines and higher values for low capacity machines.

Higher values of commutator peripheral velocity are to be avoided as it leads to lesser commutation time dt, increased reactance voltage — and sparking commutation.

The commutator peripheral velocity vc = π DC N / 60 should not as for as possible be more than about 15 m/s. (Peripheral velocity of 30 m/s is also being used in practice but should be avoided whenever possible.)

The commutator segment pitch τ_C = (outside width of one segment + mica insulation between segments) = π DC / Number of segments should not be less than 4 mm. (This minimum segment pitch is due to 3.2 mm of copper + 0.8 mm of mica insulation between segments.) The outer surface width of commutator segment lies between 4 and 20 mm in practice.

The axial length of the commutator depends on the space required

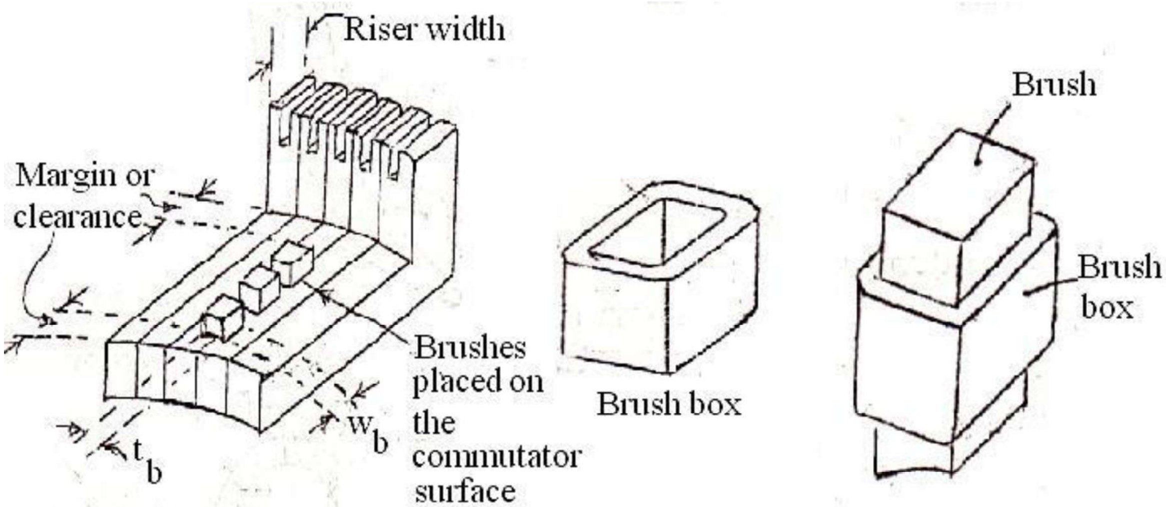
1) by the brushes with brush boxes

2) for the staggering of brushes

3) for the margin between the end of commutator and brush and

4) for the margin between the brush and riser and width of riser.

If there are nb brushes / brush arm or spindle or holder, placed one beside the other on the commutator surface, then the length of the commutator LC = (width of the brush wb + brush box thickness 0.5 cm) number of brushes / spindle + end clearance 2 to 4 cm + clearance for risers 2 to 4 cm + clearance for staggering of brushes 2 to 4 cm.



Cutaway view of the commutator with brushes placed init

If the length of the commutator (as calculated from the above expression) leads to small dissipating surface π DC LC, then the commutator length must be increased so that the

temperature rise of the commutator does not exceed a permissible value say 550C.

The temperature rise of the commutator can be calculated by using the following empirical formula.

The different losses that are responsible for the temperature rise of the commutator are

(a) Brush contact loss and

(b) Brush frictional loss.

Brush contact loss = voltage drop / brush set × Ia

The voltage drop / brush set depend on the brush material – Carbon, graphite, electro graphite or metalized graphite. The voltage drop / brush set can be taken as 2.0 V for carbon brushes.

Brush frictional loss (due to all the brush arms)

= frictional torque in Nm × angular velocity

= frictional force in Newton x distance in meter × 2 π N/60

= 9.81 μPbAball ×DC /2×2π N/60

= 9.81μPbAball v_C

whereμ = coefficient of friction and depends on the brush material. Lies between 0.22 and 0.27 for carbon brushes

Pb = Brush pressure in kg / m2 and lies between 1000 and 1500

Aball = Area of the brushes of all the brush arms in m2

= Ab × number of brush arms

= Ab × number of poles in case of lap winding

= Ab × 2 or P in case of wave winding

Ab = Cross-sectional area of the brush / brush arm

Brush Details

Since the brushes of each brush arm collets the current from two parallel paths, current collected by each brush arm is 2 I/2 Ia and the cross-sectional area of the brush or brush arm or holder or spindle

A_b = —cm^2. The current density δ_p depends on the brush material and can be assumed between 5.5 and 6.5 A / cm2 for carbon.

In order to ensure a continuous supply of power and cost of replacement of damaged or worn out brushes is cheaper, a number of subdivided brushes are used instead of one single brush. Thus if

i) tb is the thickness of the brush ii) wb is the width of the brush and

iii) nbis the number of sub divided brushes

thenAb = tbwbnb

As the number of adjacent coils of the same or different slots that are simultaneously undergoing commutation increases, the brush width and time of commutation also increases at the same rate and therefore the reactance voltage (the basic cause of sparking commutation) becomes independent of brush width.

With only one coil undergoing commutation and width of the brush equal to one segment width, the reactance voltage and hence the sparking increases as the slot width decreases. Hence the brush width is made to cover more than one segment. If the brush is too wide, then those coils which are away from the commutating pole zone or coils not coming under the influence of inter pole flux and undergoing commutation leads to sparking commutation.

Hence brush width greater than the commutating zone width is not advisable under any circumstances. Since the commutating pole zone lies between (9 and 15)% of the pole pitch,

15% of the commutator circumference can be considered as the maximum width of the brush.

It has been found that the brush width should not be more than 5 segments in machines less than 50 kW and 4 segments in machines more than 50 kW.

The number of brushes / spindle can be found out by assuming a standard brush width or a maximum current / sub divided brush.

Standard brush width can be 1.6, 2.2 or 3.2 cm

Current/subdivided brush should not be more than 70A

2.10. Brush materials and their properties:

Material	Peripheral velocity m/s	Current density in A/cm^2	Voltage drop per brush set in volts	Coefficient of friction
Normal carbon	5 to 15	5.5 to 6.5	2.0	0.22 to 0.27
Soft graphite	10 to 25	9.0 to 9.5	1.6	0.12
Metalized graphite (copper carbon mixture)	5 to 15	15 to 16	0.24 to 0.35	0.16
Electro graphite (Graphitized by heating)	5 to 15	8.5 to 9.0	1.7 to 1.8	0.22

Problems:

EX.1. A 500kW, 500V, 375 rpm, 8 pole dc generator has an armature diameter of 110 cm and the number of armature conductor is 896. Calculate the diameter of the commutator, length of the commutator, number of brushes per spindle, commutator losses and temperature rise of the commutator. Assume single turn coils.

Diameter of the commutator DC = (0.6 to 0.8) D = 0.7 x 110 = 77cm

Length of the commutator LC = (width of the brush Wb + brush box thickness 0.5 cm) number of brushes / spindle nb + end clearance 2 to 4 cm + clearance for risers 2 to 4 cm + clearance for staggering of brushes 2 to 4 cm.

EX.2. A 600 kW, 6 pole lap connected D.C. generator with commutating poles running at 1200 rpm develops 230V on open circuit and 250V on full load. Find the diameter of the commutator, average volt / conductor, the number of commutator segments, length of commutator and brush contact loss. Take Armature diameter = 56 cm, number of armature conductors = 300, number of slots = 75, brush contact drop = 2.3 V, number of carbon brushes = 8 each 3.2 cm x 2.5 cm. The voltage between commutator segments should not exceed 15V.

2.11. Performance prediction using design values.

Based on the design data of the stator and rotor of DC Machine, performance of the machine has to be evaluated. The parameters for performance evaluation are

1. Iron losses,
2. No load current,
3. No load power factor,
4. Leakage reactance etc.

Based on the values of these parameters design values of stator and rotor can be justified.

Iron losses: Iron losses are occurring in all the iron parts due to the varying magnetic field of the machine. Iron loss has two components, hysteresis and eddy current losses occurring in the iron parts depend upon the frequency of the applied voltage. The frequency of the induced voltage in rotor is equal to the slip frequency which is very low and hence the iron losses occurring in the rotor is negligibly small. Hence the iron losses occurring in the induction motor is mainly due to the losses in the stator alone. Iron losses occurring in the stator can be computed as given below.

Problems:

a. A 150hp, 500V, 6pole, 450rpm, dc shunt motor has the following data. Armature diameter = 54cm, length of armature core = 24.5cm, average flux density in the air gap = 0.55T, number of ducts = 2, width of each duct = 1.0cm, stacking factor = 0.92. Obtain the number of armature slots and work the details of a suitable armature winding. Also determine the dimensions of the slot. The flux density in the tooth at one third height from the root should not exceed 2.1T.

b. For a preliminary design of a 1500kW, 275V, 300rpm, dc shunt generator determine the number of poles, armature diameter and core length, number of slots and number of conductors per slot. Assume: Average flux density over the pole arc as 0.85T, Output coefficient 276, Efficiency 0.91.Slot loading should not exceed 1500A.

c. Calculate the armature diameter and core length for a 7.5kW, 4pole, 1000rpm, and 220V shunt motor. Assume: Full load efficiency = 0.83, field current is 2.5% of rated current. The maximum efficiency occurs at full load.

d. For a preliminary design of a 50hp, 230V, 1400 rpm dc motor, calculate the armature diameter and core length, number of poles and peripheral speed. Assume specific magnetic loading 0.5T, specific electric loading 25000 ampere- conductors per meter, efficiency 0.9.

e. Determine the diameter and length of the armature core for a 55kW, 110V, 1000rpm, and 4pole dc shunt generator. Assume: Specific magnetic loading 0.5T, Specific electric loading 13000 ampere – turns, Pole arc 70% of pole pitch and length of core about 1.1 times the pole arc, Allow 10A for field current and a voltage drop of 4V for the armature circuit.

f. Determine also the number of armature conductors and slots. A design is required for a 50kW,4pole,600rpm, and 220V dc shunt generator. The average flux density in the air gap and specific electric loading are respectively 0.57T and 30000 ampere- conductors per metre. Calculate suitable dimensions of armature core to lead to a square pole face. Assume that full load armature drop is 3% of the rated voltage and the field current is 1% of rated full load current. Ratio pole arc to pole pitch is 0.67.

g. Determine the main dimensions of the armature core, number of conductors, and commutator segments for a 350kW, 500V, 450 rpm, 6pole shunt generator assuming a square pole face with pole arc 70% of the pole pitch. Assume the mean flux density to be 0.7T and ampere conductors per cm to be 280.

h. Determine the number of poles, armature diameter and core length for the preliminary design of a 500kW, 400V, 600 rpm, dc shunt generator assuming an average flux density in the air gap of 0.7 T and specific electric loading of 38400 ampere- conductors per metre. Assume core length/ pole arc = 1.1. Apply suitable checks

QUESTION BANK

Unit-II D.C. MACHINES

1. **Define gap expansion factor and give the equation for it.**
   The ratio of reluctance of flux path when armature with slot to reluctance of flux path when armature without slot.
   Kgs = Ys / (Ys - Kcs Ws) > 1 slots
   Kgd = L / (L-Kcd nd Wd) >1 ducts
2. **What is the advantage of large number of poles?**
   - weight of iron parts decreases
   - weight of copper part decreases
   - length of commutator reduces
   - overall length of machine reduces
   - Distortion of field form becomes less at full load condition.
3. **Why the interlope is used in a dc machine.**
   - To reduce the armature reaction.
   - To improve commutation.
4. **Why the brush is made up of carbon?**
   - To reduce spark between brush and commutator.
   - To conduct electric current.
   - To avoid wear and tear due to rubbing.
5. **Define leakage coefficient and give the equation for it.**
   The ratio of total flux per pole to the useful flux per pole is called leakage coefficient or leakage factor.
   C1 = Φ p/Φ=1.08 to 1.25
6. **Define iron stacking factor.**

   It is defined as the ratio of net length of armature to the gross length of the armature.
   Ki = 0.9 to 0.96
7. **What is meant by peripheral speed of armature?**
   The distance travel by the armature per unit time is called as peripheral speed.
   Va = ∏ Dn m/sec
   n = speed in r.p.s.
   D = diameter of armature in m
8. **Define armature reaction.**
   The flux produced due to current flow to the armature conductors opposes the main flux. This phenomenon is known as armature reaction.
9. **What are the effects of armature reaction?**
   - Reduction in emf
   - Increase in iron loss
   - Sparking and ring fire
   - Delayed commutation
10. **What does staggering of brushes mean?**
    Brushes are provided in different planes instead of same plane at the surface of commutator to avoid the formation of ridges. This is called staggering.
11. **Mention the different modes of operation of a D.C. Machine.**
    - **Generator mode:** In this mode, the machine is driven by a prime mover with mechanical power converted into electrical power.

- **Motor mode**: The machine drives a mechanical load with the electrical power supplied converted into mechanical power.
- **Brake mode**: The machine works as a generator and the electrical power developed is either pumped back to the supply as in regenerative braking.

12. State use of a yoke in a D.C. machine.

The yoke serves as a path for flux in D.C. machine and it also serve as an enclosure for the machine.

13. What purpose is served by the pole shoe in a D.C. machine?

The pole shoes serve the following purposes:

- They spread out the flux in the air gap.
- Since they are of larger cross section, the reluctance of the magnetic path is reduced.
- They support the field coils.

14. Mention the factors that affect the size of rotating machines.

The factors that affect the size of rotating machines are:

- Speed and
- Output co-efficient

15. What is known as output equation?

The output of a machine can be expressed in terms of its main dimensions, specific magnetic and electric loadings and speed. The equation describing this relationship is known as output equation.

16. Derive the output equation of a D.C. machine.

Power developed by armature in KW,

P_a = Generated emf * armature current * 10^{-3}

$P_a = (\Pi D L B_{av})(\Pi D ac) n * 10^{-3}$

$= (\Pi^2 B_{av} ac * 10^{-3}) D^2 L n$

$= \mathbf{C_0 D^2 L n}$

where $\mathbf{C_0 = \Pi^2 B_{av} ac * 10^{-3}}$

D = armature diameter, m

L = stator core length, m

n = speed, rps

C_0 is the output co-efficient

16. How is specific magnetic loading determined?

The specific magnetic loading is determined by

- Maximum flux density in iron parts of machine
- Magnetizing current and core losses

17. Calculate the output co-efficient of a dc shunt generator from the given data.

$B_g = 0.89$ Wb/m^2 ; ac = 3200 amp.cond/m ; $\Psi = 0.66$.

Output co-efficient , $\mathbf{C_0 = \Pi^2 \Psi B_g ac * 10^{-3}}$

$= \Pi^2 * 0.66 * 0.89 * 3200 * 10^{-3}$

= 185.5 KW / m^3 – rps.

18. What is the range of specific magnetic loading in D.C. Machine?

The usual range of specific magnetic loading in dc machine is 0.4 to 0.8 Wb/m^2.

19. What are the factors to be considered for the selection of number of poles in dc machine?

The factors to be considered for the selection of number of poles in dc machine are:

- Frequency
- Weight of iron parts
- Weight of copper
- Length of commutator

- Lab our charges
- Flash over and distortion of field mmf

20. What are the quantities that are affected by the number of poles?

Weight of iron and copper, length of commutator and dimension of brushes are the quantities affected by the number of poles.

21. List the disadvantages of large number of poles.

The large number of poles results in increases of the following:

- Frequency of flux reversals
- Labour charges
- Possibility of flash over between brush arms

22. Mention guiding factors for the selection of number of poles.

- The frequency should lie between 25 to 50 Hz.
- The value of current per parallel path is limited to 200A, thus the current per brush arm should not be more than 400A.
- The armature mmf should not be too large. The mmf per pole should be in the range 5000 to 12,500 AT.
- Choose the largest value of poles which satisfies the above three conditions.

23. What are the losses at the commutator surface?

The losses at the commutator surface are the brush contact losses and brush friction losses.

24. Write down the expression for brush friction losses.

The brush friction loss is given as $P_{bf} = \mu P_b A_B V_c$

Where μ = co-efficient of friction

P_b = brush contact pressure

A_B = total contact area of all brushes, m^2

V_c = Peripheral speed of commutator, m/s

25. What are the advantages of carbon brushes?

- They lubricate and polish the commutator
- If sparking occurs, they damage the commutator less than with the copper brushes.
- They provide good commutation.

26. What is the height occupied by series field coil in a field pole?

In a field pole of compound machine, approximately 80% of the height is occupied by shunt field coil and 20% by the series field coil.

27. How the Ampere turns of the series field coil is estimated?

In compound machines, the ampere turns to be developed by the series field coil are estimated as 15 to 25% of full load armature mmf. In series machines, the ampere turns to be developed by the series field coil are estimated as 1.15 to 1.25 times of full load armature mmf.

28. Mention the factors to be considered for the design of shunt field coils.

- Mmf per pole and flux density
- Loss dissipated from the surface of field coil
- Resistance of the field coil
- Current density in the field conductors

29. State the use of interpoles.

The interpoles are used in D.C. machines to neutralize the cross magnetizing armature mmf at the interpolar axis and to neutralize the reactance voltage in the coil undergoing commutation.

30. State the relation between the armature and the commutator diameter for various ratings of D.C. machines. The diameter of the commutator is chosen as 60 to 80% of armature diameter. The limiting factor is the peripheral speed. The typical choice of commutator diameter for various voltage ratings are listed here:

Voltage range (Volts)	Commutator diameter (D_c)
350 to 700	0.62 D
200 to 250	0.68 D
100 to 125	0.75 D

Where D is the armature diameter.

31. Why is the value of magnetizing current not a series design consideration in D.C.machines?

The value of magnetizing current is not a series design consideration in D.C.machines as there is sample space on salient poles to accommodate the required number of field turns.

32. What should be the peripheral speed of the commutator?

The commutator peripheral speed is generally kept below 15 m/s. Higher peripheral speeds upto 30m/s are used but should be avoided wherever possible. The higher commutator peripheral speeds generally lead to commutation difficulties.

33. How is the length of commutator designed?

The length of the commutator is designed based upon the space required by the brushes and upon the surface required to dissipate the heat generated by the commutator losses.

Length of commutator, $\mathbf{L_c = n_b (W_b + C_b) + C_1 + C_2}$

Where n_b = number of brushes per spindle

W_b = width of each brush

C_b = clearance between the brushes

C_1 = clearance allowed for staggering the brushes

C_2 = clearance for allowing the end play

34. What is the purpose of slot insulation?

The conductors are placed on the slots in the armature. When the armature rotates, the insulation of the conductors may damage due to vibrations. This may lead to a short circuit with armature core if the slots are not insulated.

35. State any three conditions in deciding the choice of number of slots for a large D.C.machine.

- The slot loading should be less than 1500 ampere conductors.
- The number of slots per pole should be greater than or equal to 9 to avoid sparking.
- The slot pitch should lie between 25 to 35 mm.

36. What are the factors that influence the choice of commutator diameter?

- Peripheral speed
- The peripheral voltage gradient should be limited to 3V/mm
- Number of coils in the armature

37. What type of copper is used for commutator segment?

The commutator segments are made of hard drawn copper or silver copper (0.05% silver)

38. What are the materials used for brushes in D.C.machine?

- Natural graphite
- Hard carbon
- Electro graphite
- Metal graphite

39. What are the points to be considered while fixing up the dimensions of the slot?

- Excessive flux density
- Flux pulsations
- Eddy current loss in conductors
- Reactance voltage
- Mechanical difficulties

40. Mention the factors that govern the choice of number of armature slots in a d.C.machine.

- Slot pitch

- Slot loading
- Commutation
- Suitability for winding
- Flux pulsations

41. What is back pitch?

The distance between top and bottom coil sides of a coil measured around the back of the armature is called the back pitch. The back pitch is measured in terms of coil sides.

42. When are the pulsations and oscillations of air gap flux reduced to minimum?

The pulsations and oscillations of air gap flux reduced to minimum when,

- The number of slots under the pole shoe is equal an integer plus ½.
- The number of slots per pole is equal to an integer plus ½.

43. What factor decides the minimum number of armature coils?

The maximum voltage between adjacent commutator segments decides the minimum number of coils.

44. Explain how depth of armature core for a D.C. machine is determined.

Let $\acute{\O}$ = Flux/pole ; L_i = Net iron length of armature;

$\acute{\O}_c$ = Flux in armature core ; d_c = depth of armature core ;

B_c = Flux density in the armature core ; A_c = Area of cross-section of armature core.

Now $\acute{\O}_c = \acute{\O}/2$ and $A_c = \acute{\O}_c / B_c$

Also $A_c = L_i d_c$ $\quad$ $\mathbf{d_c = \acute{\O} / 2 L_i B_c}$

45. List the characteristics of wave winding.

- The number of parallel paths is two.
- The current through a conductor is $I_a / 2$, where I_a is the armature current.
- The winding will have less number of conductors with larger area of cross-section
- The emf induced in both the parallel paths will be always equal

46. What are the applications of D.C. special motors?

The D.C. special motors are used in closed loop control system as power actuators and to provide linear motions. They are also used as clutches, couplings, eddy current brakes, very high speed drives, etc.,.

47. Why square pole is preferred?

If the cross-section of the pole body is square then the length of the mean turn of field winding is minimum. Hence to reduce the copper requirement a square cross-section is preferred for the poles of D.C.machine.

48. Distinguish between lap and wave windings used in D.C. machine.

The lap and wave windings primarily differ from each other in the following two factors:

- The number of circuits between the positive and negative brushes, i.e., number of parallel paths.
- The manner in which the coil ends are connected to the commutator Segments.

49. What are dummy coils?

The coils which are placed in armature slot for mechanical balance but not connected electrically to the armature winding are called dummy coils.

50. What are the different types of commutation?

The different types of commutation are:

- Resistance commutation
- Retarded commutation
- Accelerated commutation
- Sinusoidal commutation