3.7 Computer program: Design of Armature main dimensions

Problem:

A 250 kw, 460V, 600r.p.m, 6 pole dc is built with an armature diameter of 72cm and core length 27 cm. The lap armature winding has 660 conductors. Using this data obtain preliminary dimensions for the armature, core, number of armature conductors and commutator segments for a 350kw, 500V, 725 r.p.m, 6 pole dc. Assume a square pole with pole arc = .7 pole pitch.

Solution:

Given,

Po = 250kw

N = 600 r.p.m so Ns = N/60 = 10r.p.s

Assume Po = Pa

D = 72 cm = .72m

L = 27 cm = .27m

Pa = CoD2LNs

so Co = Pa/(D2LNs) = 250/(.722*.27*10) = 178.6

Number of conductors per parallel path Zpath = 660/6 = 110

why 6?? cause its a lap wound so parallel path = number of poles.

Hence mean emf induced/conductor ez = 460/110 = 4.18V

Also ez = Bav*L*Va = Bav*L*pi*D*Ns

or Bav = ez/(L*pi*D*Ns) = 4.18/(.27*pi*.72*10) = .68Wb/m2

Now for other dc machine… We have

N = 725r.p.m so Ns = N/60 = 12.08

Pa = 350 kw we already have Co = 178.6

So D2L = Pa/(CoNs) = 350/(178.6*12.08) = .16222m3

L = .7*pi*D/6 = .36652D

giving D3 = .4426

so D = .76m hence length L = .28m

Now ez = Bav*L*Va = .68*.28*pi*.76*12.08 = 5.53V

Number of conductors per parallel path = 500/5.53 = 90

Number of conductors using lap winding = 90*6 = 540

Using single turn coil….

Number of coils = 540/2 = 270

Number of commutator segments = number of coils = 270

Check for minimim pitch of commutator segments….

Commutator diameter = .7D = .7*.76 = .53m

Therefore pitch of commutator segment = pi*.53 = 6.17*10-3m

AS this is more than the minimum allowable pitch of 4mm

Thus 270 commutator segments are well within the limit.

Program:

```
function design_dc_machine_series_connected

%Given

Po = 250;

N = 600;

Ns = N/60;

%Assume

Pa = Po;
```

```
D = .72;
L = .27;
%number of conductors
Z = 660;
pole = 6;
Vin = 460;%V
%Pa = CoD2LNs
Co = Pa/(D*D*L*Ns);
%Number of conductors per parallel path
%as lap winding so number of parallel path = number of poles
Ppath = pole;
Zpath = Z/Ppath;
fprintf('\nProgram to Design a series connected DC machine');
fprintf('\n————————————————————');
fprintf('\nNumber of conductors per parallel path = ');
disp(Zpath);
fprintf('\nHence mean emf induced per conductor = ');
ez = Vin/Zpath;
disp(ez);
%now Bav
Bav = ez/(L*pi*D*Ns);
fprintf('\nAverage Flux density Bav = ');
disp(Bav);
```

```
% for other Dc machine

N1 = 725;

N1s = N1/60;

P1a = 350;

%D2L = Pa/CoNs

%L = .7piD/Pole

% square pole with pole arc = .7 pole pitch.

D3 = (P1a*pole)/(Co*N1s*.7*pi);

D = D3^(1/3);

%hence

L = .7*pi*D/pole;

fprintf('\nDiameter D of the other machine = ');

disp(D);

fprintf('\nLength L of the other machine = ');

disp(L);

%now ez

ez = Bav*L*N1s*D*pi;

%number of conductors per parallel path

%number of conductor Z1

Vin1 = 500;

Zpath = Vin1/ez;

fprintf('\nNumber of conductors per parallel path = ');

disp(round(Zpath));
```

```
fprintf('\nNumber of conductors using lap winding = ');

Zlap = round(Zpath)*pole;

disp(Zlap);

fprintf('\nChecking for minimum pitch of commutator segments…');

CommutatorDia = .7*D;

Commutatorpitch = pi*CommutatorDia;

if(Commutatorpitch>.004)

fprintf('\nYes this is alloeable as Commutator pitch greater than 4mm');

else

fprintf('\nNo thisn is not allowable as Commutator pitch is less than 4mm');

end
```

Output:

Number of conductors per parallel path = 110

Hence mean emf induced per conductor = 4.1818

Average Flux density Bav = 0.6847

Diameter D of the other machine = 0.7620

Length L of the other machine = 0.2793

Number of conductors per parallel path = 90

Number of conductors using lap winding = 540

Checking for minimum pitch of commutator segments…

Yes this is alloeable as Commutator pitch greater than 4mm

3.5 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.

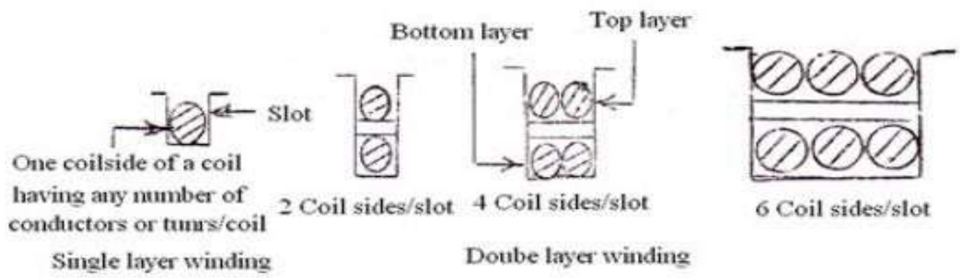

Figure 3.5.1 Single and double layer winding

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.2]

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.

NUMBER OF ARMATURE SLOTS

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

$$\lambda s = (\text{slot width } bs + \text{tooth width } bt)$$

$$= \pi D / \text{number of slots } S$$

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.

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.

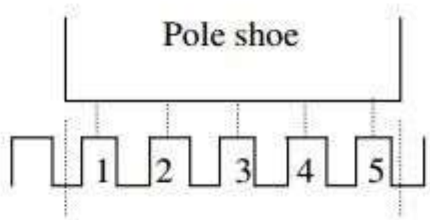

Figure 3.4.2 Flux pulsations with integral number of slots per pole arc.

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.43]

Number of teeth/pole shoe = 5 and flux passes through 5 teeth. The reluctance of the air gap is inversely proportional to the area corresponding to 5 teeth.

Number of teeth/pole shoe = 5 and flux passes through 6 teeth when the armature is moved half tooth pitch to the right.The reluctance of the air gap is inversely proportional to the area corresponding to 6 teeth. The reluctance in this case is less and the flux is more compared to the former case. Therefore, the flux pulsates i.e. Varies in magnitude.

Number of teeth/pole shoe = (5+ 0.5) and flux passes through 6 teeth. The reluctance of the air gap is inversely proportional to the area corresponding to 6 teeth.

Number of teeth/pole shoe = (5+0.5) and flux passes through 6 teeth when the armature is moved half tooth pitch to the right.The reluctance of the air gap is inversely proportional 6 teeth as before. The reluctance and the flux in both the cases remains the same in all positions of the armature. However, the reluctance and the flux under the tips of the pole are not the same for all the positions of armature. Therefore when the armature rotates the flux under the pole oscillates between the pole tips. This produces ripple in the voltage induced in the conductors moving under poles. The flux pulsation under inter pole causes the sparking. A small tooth pitch helps to reduce the effect of armature slots upon the inter poles.

To obtain good commutation, the flux density in the air gap must decrease gradually from maximum value under the center of the pole to zero on the center line between two poles, and the flux densities near the neutral point must be low. A field form that drops off rapidly from maximum value to zero not only leads to commutation difficulties but may also give rise to noises in machines with slotted armatures. In order to achieve good commutation the pole shoe is designed to cover only certain percentage of the pole pitch. The circumferential distance covered by the pole shoe on the armature surface is called the pole arc. The ratio of the pole arc to pole pitch is called per unit embrace or enclosure. That is, per unit enclosure ψ lies between 0.6 and 0.7.

3.3 Choice of specific loadings

Specific magnetic loading:

Following are the factors which influences the performance of the machine.

(i) Iron loss:

A high value of flux density in the air gap leads to higher value of flux in the iron parts of the machine which results in increased iron losses and reduced efficiency.

(ii) Voltage:

When the machine is designed for higher voltage space occupied by the insulation becomes more thus making the teeth smaller and hence higher flux density in teeth and core.

(iii) Transient short circuit current:

A high value of gap density results in decrease in leakage reactance and hence increased value of armature current under short circuit conditions.

(iv) Stability:

The maximum power output of a machine under steady state condition is indirectly proportional to synchronous reactance. If higher value of flux density is used it leads to smaller number of turns per phase in armature winding. This results in reduced value of leakage reactance and hence increased value of power and hence increased steady state stability.

(v) Parallel operation:

The satisfactory parallel operation of synchronous generators depends on the synchronizing power. Higher the synchronizing power higher will be the ability of the machine to operate in synchronism. The synchronizing power is inversely proportional to the synchronous reactance and hence the machines designed with higher value air gap flux density will have better ability to operate in parallel with other machines.

Specific Electric Loading:

Following are the some of the factors which influence the choice of specific electric loadings.

(i) Copper loss:

Higher the value of q larger will be the number of armature of conductors which results in higher copper loss. This will result in higher temperature rise and reduction in efficiency.

(ii) Voltage:

A higher value of q can be used for low voltage machines since the space required for the insulation will be smaller.

(iii) Synchronous reactance:

High value of q leads to higher value of leakage reactance and armature reaction and hence higher value of synchronous reactance. Such machines will have poor voltage regulation, lower value of current under short circuit condition and low value of steady state stability limit and small value of synchronizing power.

(iv) Stray load losses:

With increase of q stray load losses will increase. Values of specific magnetic and specific electric loading can be selected from Design Data Hand Book for salient and non-salient pole machines.

Separation of D and L:

Inner diameter and gross length of the stator can be calculated from D2L product obtained from the output equation. To separate suitable relations are assumed between D and L depending upon the type of the generator. Salient pole machines: In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines, the diameter of the machine will be quite larger than the axial length.

3.1 Construction

The construction of DC machine can be done using some of the essential parts like Yoke, Pole core & pole shoes, Pole coil & field coil, Armature core, Armature winding otherwise conductor, commutator, brushes & bearings. Some of the parts of the DC machine is discussed below.

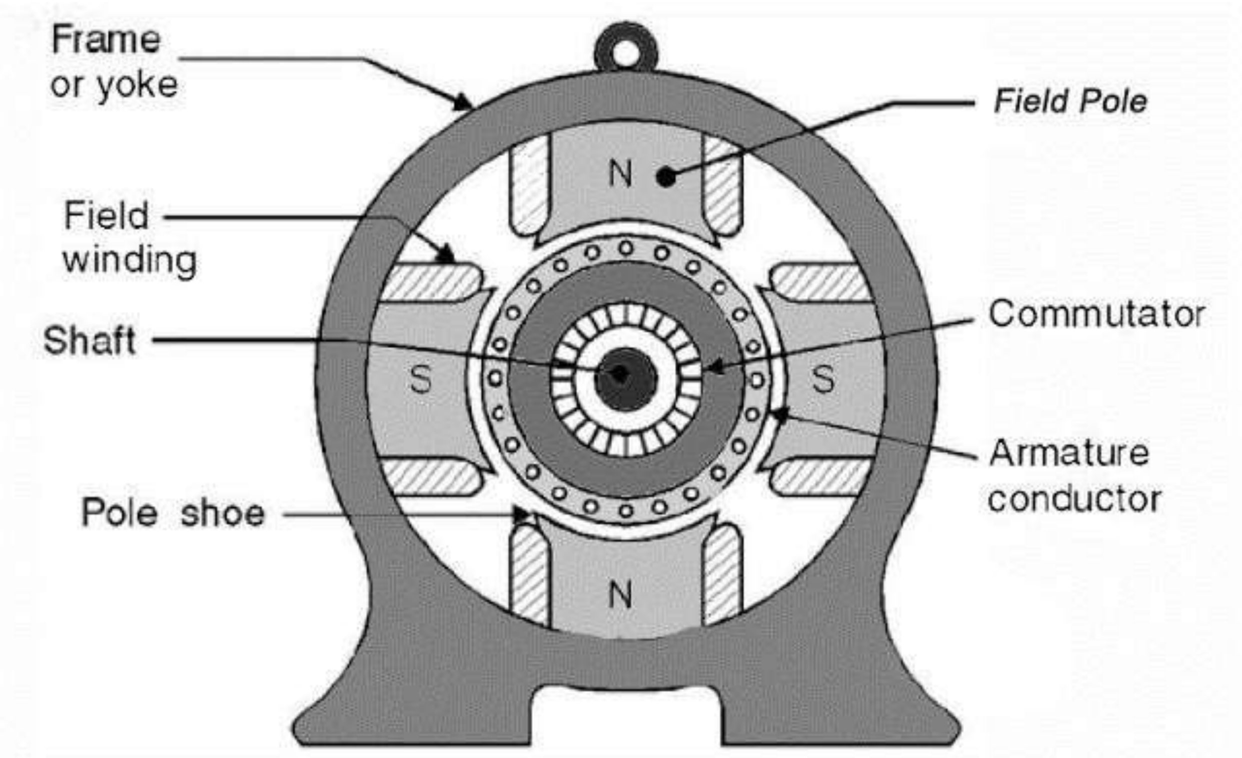

Figure 3.1.1 cross-section of DC Machine

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.22]

Yoke

Another name of a yoke is the frame. The main function of the yoke in the machine is to offer mechanical support intended for poles and protects the entire machine from the moisture, dust, etc. The materials used in the yoke are designed with cast iron, cast steel otherwise rolled steel.

Pole and Pole Core

The pole of the DC machine is an electromagnet and the field winding is winding among pole. Whenever field winding is energized then the pole gives magnetic flux. The materials used for this are cast steel, cast iron otherwise pole core. It can be built with the annealed steel laminations for reducing the power drop because of the eddy currents.

Pole Shoe

Pole shoe in DC machine is an extensive part as well as enlarge the region of the pole. Because of this region, flux can be spread out within the air-gap as well as extra flux can be passed through the air space toward armature. The materials used to build pole shoe is cast iron otherwise cast steed, and also used annealed steel lamination to reduce the loss of power because of eddy currents.

Field Windings

In this, the windings are wounded in the region of pole core & named as field coil. Whenever current is supplied through field winding then it electromagnetics the poles which generate required flux. The material used for field windings is copper.

Armature Core

Armature core includes the huge number of slots within its edge. Armature conductor is located in these slots. It provides the low-reluctance path toward the flux generated with field winding. The materials used in this core are permeability low-reluctance materials like iron otherwise cast. The lamination is used to decrease the loss because of the eddy current.

Armature Winding

The armature winding can be formed by interconnecting the armature conductor. Whenever an armature winding is turned with the help of prime mover then the voltage, as well as magnetic flux, gets induced within it. This winding is allied to an exterior circuit. The materials used for this winding are conducting material like copper.

Commutator

The main function of the commutator in the DC machine is to collect the current from the armature conductor as well as supplies the current to the load using brushes. And also provides uni-directional torque for DC-motor. The commutator can be built with a huge number of segments in the edge form of hard drawn copper. The Segments in the commutator are protected from thin mica layer.

Brushes

Brushes in the DC machine gather the current from commutator and supplies it to exterior load. Brushes wear with time to inspect frequently. The materials used in brushes are graphite otherwise carbon which is in rectangular form.

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.

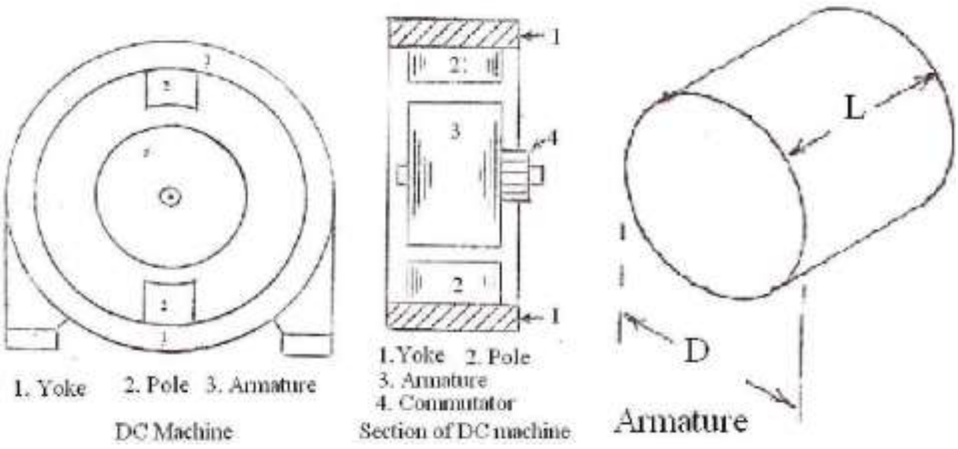

Figure 3.1.2 Main dimensions of DC Machine

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.22]

3.6 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.

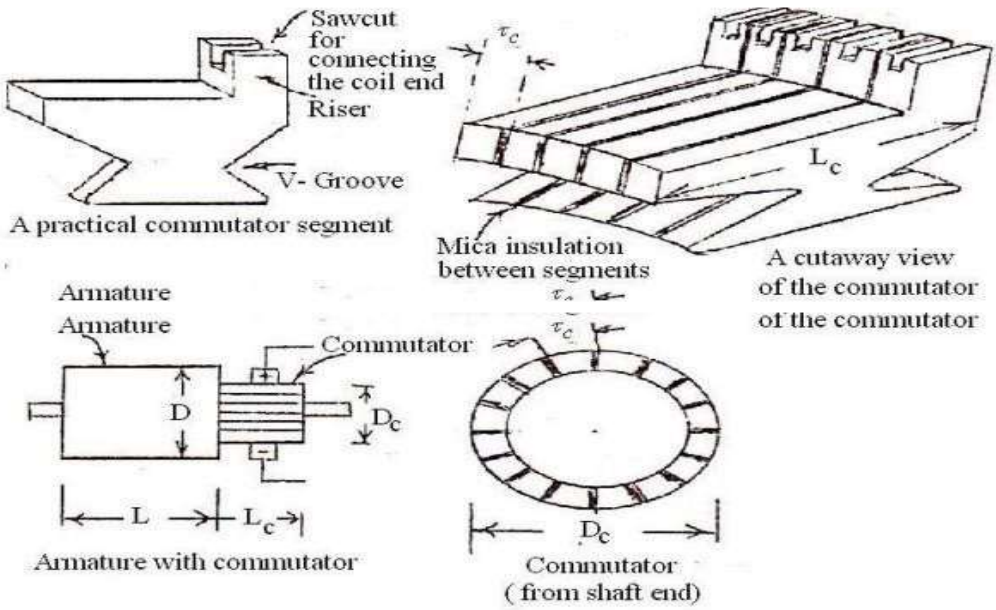

Figure 3.6.1 Commutator and brushes

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.89]

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 τC = (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.

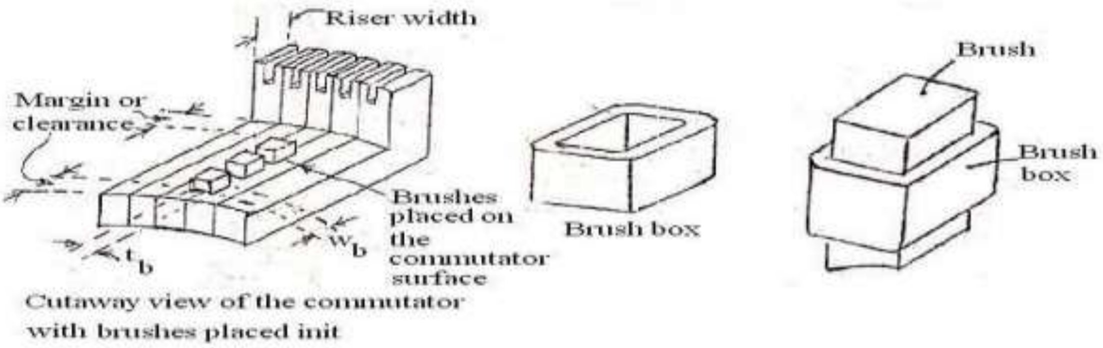

Figure 3.6.2 Brushes plased on commutator surface

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.89]

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 55^{0}C.

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

$$\theta^o C = \frac{120 \quad \text{watt loss / cm}^2 \text{ of dissipating surface} \quad D_c \ L_c}{1 + 0.1 \ v_c}$$

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 vC

Where μ = 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 Ab. The current density δp 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) nb is the number of sub divided brushes

then Ab = tb wb nb

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.

3.2 Output Equations & Main Dimensions

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 = Pφ /π DL Wb/m^2 or tesla,

Therefore Pφ = Bav π 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 π 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 $(turns)^2$ increases. This leads to sparking commutation.

Effect of higher value of Bav

a. As Bav 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.

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 $L = (0.55 \text{ to } 1.1)\ \tau$

$= (0.55 \text{ to } 1.1)\ \pi D / P$

If $L/\tau = 1.0$ and $P = 4$, then $L = 1.0 \times \pi D / P$

$= 1.0 \times \pi D / 4 = 0.785D.$

Therefore $D^2 \times 0.785\ D = 0.1$ or $D = 0.5$m.

Thus $L = 0.785 \times 0.5 = 0.395$ m.

Note: The D^2 L product can also be separated by assuming a value for the peripheral velocity of the armature.

3.4 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 f = PN/120 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

$$B_y = \frac{\phi/2}{\text{cross sectional area of the yoke } A_y} = \frac{\phi_T}{2PA_y} \propto \frac{1}{PA_y}.$$

It is clear that Ay is µ 1/p as By is also almost constant for a given iron. Thus, as the number of poles increases, Ay and hence the weight of iron used for the yoke reduces.

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 ATa/pole is proportional to 1 / P, Φa reduces as the number of poles increases. This in turn reduces the effect of armature reaction.

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.

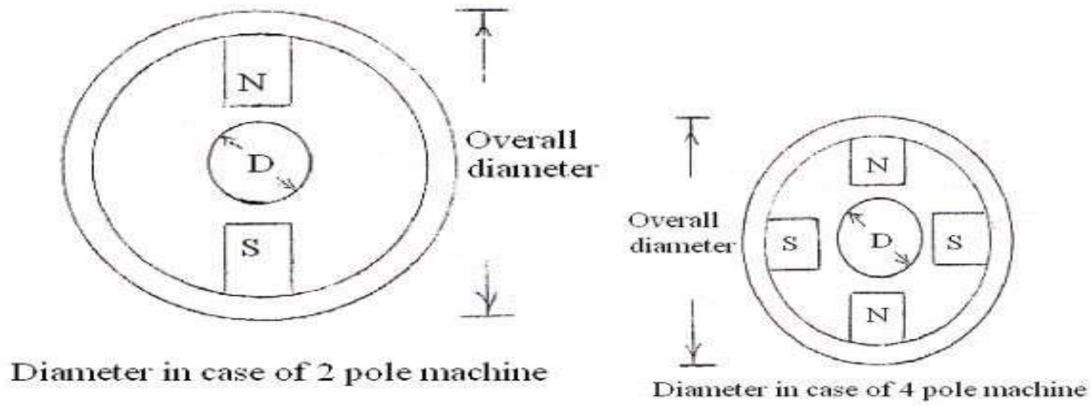

Figure 3.4.1 Decrease in machine dimensions increase the number of poles

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-9.19]

Length of the commutator

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

= 2 Ia / A and the cross sectional area of the brush / arm

$A_b = 2Ia / A\delta_b = 2Ia / P\delta_b$

$\propto 1 / P$

reduces as the number of poles increases. As $A_b = t_b w_b n_b$ and t_b is generally held constant from the commutation point of view, $w_b n_b$

reduces as Ab reduces. Hence the length of the commutator

Lc = ($w_b n_b$ + clearances) reduces as Ab reduces or the number of poles increases.

w_b – width of the brush,

t_b – thickness of the brush,

n_b – number of brushes per spindle

Flash over

As the number of poles increases, voltage between the segments increases. Because of the increased value of Eb and carbon dust collected in the space where the mica is undercut, chances of arcing between commutator segments increases. The arc between the segments in turn may bridge the positive and negative brushes leading to a dead short circuit of the armature or flash over.

$$E_b = \frac{\text{voltage between positive and negative brushes}}{\text{number of segments / pole}}$$

Labour charges

As the number of poles increases cost of labor increases as more number of poles are to be assembled, more field coils are to be wound, placed on to the pole, insulate, interconnect etc. It is clear that, when the number of poles is more, weight of iron used for yoke and armature core, weight of inactive copper, overall diameter, length of commutator and effect of armature reaction reduces. On the other hand, efficiency reduces chances of flash over increases and cost of machine increases. Since the advantages outnumber the disadvantages, more number of poles is preferable.