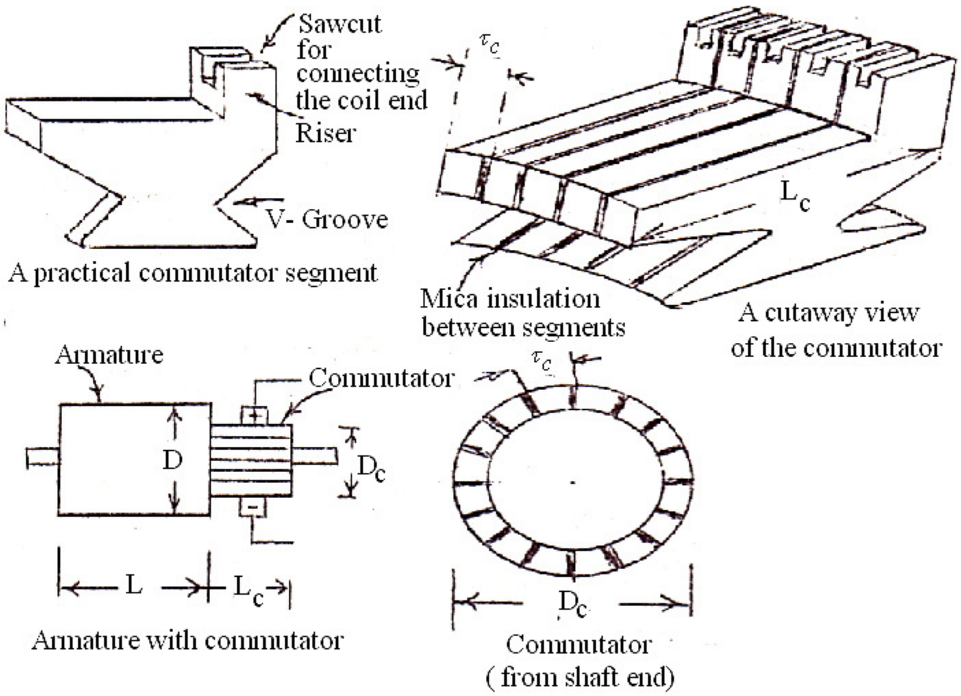
Chapter.3 Design of Commutator and Brushes

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.

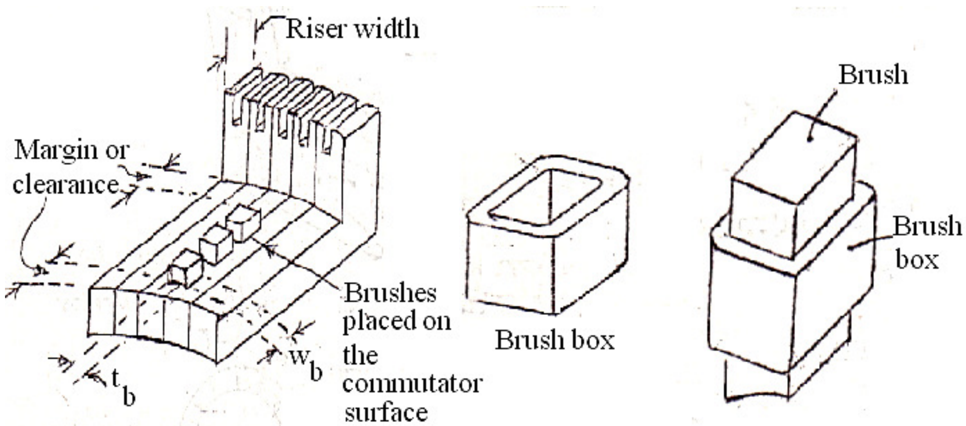
Higher values of commutator peripheral velocity are to be avoided as it leads to lesser commutation time dt, increased reactance voltage $RV = L\frac{di}{dt}$ and sparking commutation. The commutator peripheral velocity $v_c = \pi D_C N / 60$ should not as for as possible be more than about 15 m/s. (Peripheral 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) $= \pi D_C$ / 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 n_b brushes / brush arm or spindle or holder, placed one beside the other on the commutator surface, then the length of the commutator L_C = (width of the brush w_b + 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 D_C L_C, then the commutator length must be increased so that the temperature rise of the commutator does not exceed a permissible value say 55^0C.

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

$$\theta^{o}C = \frac{120 \ \times \ \text{watt loss / cm}^2 \ \text{of dissipating surface} \ \pi \, D_C \ L_C}{1 \ + \ 0.1 \ v_C}$$

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 $\times I_a$

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 $\times$ angular velocity

$$= \text{frictional force in Newton x distance in metre} \times \frac{2\pi N}{60}$$

$$= 9.81\ \mu P_b A_{ball} \times \frac{D_C}{2} \times \frac{2\pi N}{60} = 9.81 \mu P_b A_{ball}\, v_C$$

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

P_b = Brush pressure in kg / m^2 and lies between 1000 and 1500

A_{ball} = Area of the brushes of all the brush arms in m^2

= $A_b \times$ number of brush arms

= $A_b \times$ number of poles in case of lap winding

= $A_b \times$ 2 or P in case of wave winding

A_b = 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 $\frac{2 I_a}{A}$ and the cross-sectional area of the brush or brush arm or holder or spindle $A_b = \frac{2 I_a}{A \delta_b}$ cm^2. The current density δ_b depends on the brush material and can be assumed between 5.5 and 6.5 A / cm^2 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) t_b is the thickness of the brush
ii) w_b is the width of the brush and
iii) $n_b$is the number of sub divided brushes

then$A_b = t_b w_b n_b$

As the number of adjacent coils of the same or different slots that are simultaneously under going 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 under going 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 under going 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

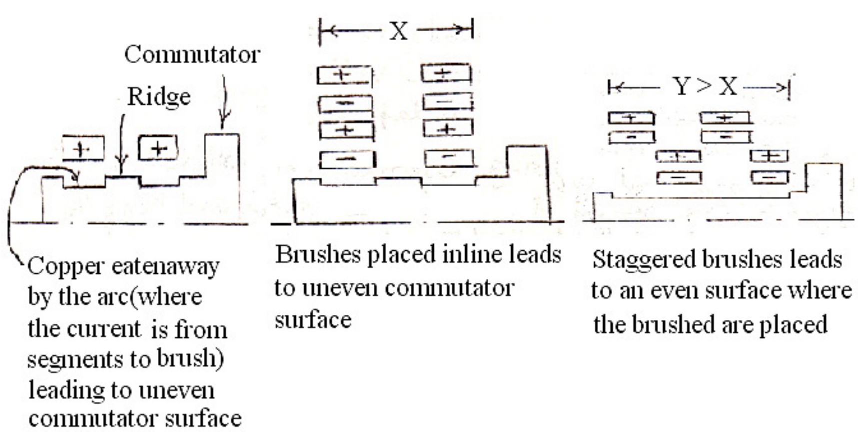
Thus with the brush width assumed, $n_b = \frac{A_b}{t_b\, w_b}$. With the current / sub divided brush assumed

$n_b = \frac{2\, I_a}{A \times 70}$ and $w_b = \frac{A_b}{t_b\, n_b}$

Note :

A) Staggering of Brushes :

Because of the current flowing from commutator segments to the brush, copper is eaten away leading to formation of ridges between the subdivided brushes of the same brush arm. Since it is not possible to avoid eating away copper by the arc, eating away of copper must be made to take place over the entire axial length of the commutator to ensure uniform commutator surface. This is achieved by displacing all the positive brushes in one direction and all the negative brushes in the other direction or by staggering of brushes in pairs as shown below.



B) 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

C) Step by step design procedure of commutator and brushes

1) Diameter of the commutator $D_C = (0.6 \text{ to } 0.8)\, D$ and must be such that the peripheral velocity of the commutator $v_C = \pi D_C N / 60$ is not more than 15 m/s as far as possible.

2) The commutator segment pitch $\tau_C = \pi D_C$ / Number of segments should not be less than 4 mm from the mechanical strength point of view.

3) The number of commutator segments is equal to number of active armature coils.

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

5) Cross-sectional area of the brush / spindle or arm or holder $A_b = \dfrac{2\, I_a}{A\, \delta_b}$ cm^2. The current density in the brushes δ_b lies between 5.5 and 6.5 A / cm^2 for carbon brushes.

6) Maximum thickness of the brush $t_{b\,max} = 4\, \tau_C$ for machines greater than 50 kW
$= 5\, \tau_C$ for machines less than 50 kW

7) With standard brush width W_b assumed, the number of brushes / spindle $n_b = \dfrac{A_b}{t_b\, W_b}$

8) Total commutator losses = Brush contact loss + Brush frictional loss
= voltage drop / brush set $\times I_a + 9.81\, \mu P_b A_{ball}\, v_C$

where

voltage drop / set = 2.0 V for carbon brushes
μ = coefficient of friction and lies between 0.22 to 0.27 for carbon brushes
P_b = Brush pressure and lies between 1000 and 1500 kg / m^2

9) Temperature rise of the commutator

θ^0C = Cooling coefficient x watt loss / dissipating surface

$$= \frac{120}{1 + 0.1\, v_C} \times \text{ watt loss / cm}^2 \text{ of dissipating surface } \pi\, D_C\, L_C$$

10) Temperature rise should be less than about 55^0C.

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DESIGN OF COMMUTATOR AND BRUSHES

Example.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 D_C = (0.6 to 0.8) D = 0.7 x 110 = 77cm

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

Armature current $I_a = \dfrac{kW \ x \ 10^3}{V} = \dfrac{500 \ x \ 10^3}{500} = 1000A$

Note : An armature current of 1000 A obviously calls for a lap winding.

Cross-sectional area of the brush per spindle or brush arm or holder $A_b = \dfrac{2 \, I_a}{A \, \delta_b}$ since the current density lies between 5.5 and 6.5 A/cm^2 for carbon brushes, let it be 6 A/mm^2

$A_b = \dfrac{2 \ x \ 1000}{8 \ x \ 6} = 41.66 \ cm^2$

maximum thickness of the brush = 4 τ_C

Commutator segment pitch $\tau_C = \pi \, D_C$ / Number of segments or coils

Number of coils = Z / 2 x number of turns per coil = 896 / 2 x 1 = 448

Therefore $\tau_C = \dfrac{\pi \ x \ 77}{448} = 0.54$ cm

Maximum thickness of the brush = 4 x 0.54 = 2.16 cm

Let the thickness of the brush t_b= 2.0 cm

If a brush width of 2.2 cm (a standard value) is assumed then W_b = 2.2 cm

Therefore, number of brushes / spindle

$n_b = \dfrac{A_b}{t_b \, W_b} = \dfrac{41.66}{2 \ x \ 2.2} = 9.46$ and is not possible

Let the number of brushes / spindle be = 10

Therefore $L_C = (2.2 + 0.5)\ 10 + 2 + 2 + 2 = 33$ cm

Brush contact loss = voltage drop / brush set x I_a = 2 x 1000 = 2000 W

Brush frictional loss = 9.81 $\mu P_b A_{ball}\, v_C$

Let the coefficient of friction μ = 0.25 as it lies between 0.22 to 0.27 for carbon brushes.

Let the brush pressure P_b= 1215 kg/m^2 as it lies between 1000 to 1500 kg/m^2

A_{ball} = Area of the brushes of all the brush arms
= $t_b w_b n_b$ x number of brush arms or number of poles as the number of brush arms number of poles for a lap winding
= 2 x 2.2 x 10 x 8 x 10^{-4} = 0.0352 m^2

Brush frictional loss = 9.81 x 0.25 x 1215 x 0.352 x 15.1 = 1583.8 W

Therefore commutator losses (total) = 2000 + 1583.8 = 3583.8 W

Temperature rise in degree centigrade

$$\theta = \frac{120 \text{ x watt loss / cm}^2 \text{ of the commutator dissipating surface } \pi D_C L_C}{1 + 0.1 v_C}$$

$$= \frac{120 \text{ x } 3583.8 / \pi \text{ x } 77 \text{ x } 33}{1 + 0.1 \text{ x } 15.1} = 21.46$$

Example.2

A 20 Hp, 4 pole, 250V, 1000 rpm wave wound D.C. machine has the following design data. Diameter of the armature = 25 cm, number of slots = 41, number of coil sides / slot = 4, turns / coil = 2. Calculate the number of segments, outside width of one segment and mica, brush thickness, length of the commutator and brush contact loss.

Number of segments = number of active coils for a wave winding

i) Number of coil sides (total) = 41 x 4 = 164
Number of coils = 164 / 2 = 82 as each coil will have 2 coil sides OR

ii) Since the coil is of 2 turns, each coil side will have 2 conductors and therefore the number of conductors per slot = 4 x 2 = 8.
Total number of conductors = 41 x 8 = 328

$$\text{Number of coils} = \frac{\text{total number of conductors}}{2 \text{ x number of turns / coil}} = \frac{328}{2 \text{ x } 2} = 82 \quad \text{OR}$$

iii) Number of coils = number of slots x number of coil sides / layer
= 41 x 2 = 82

For a wave winding $Y_C = \frac{C \pm 1}{p}$ must be an integer. With the number of coils calculated, $Y_C = \frac{82 \pm 1}{2}$ is a fraction. Therefore a wave winding is not possible. However a wave winding can be made possible by considering one of the coils as dummy. Therefore number of active coils = 81 and number of commutator segments = 81.

Outside width of one segment and mica = Commutator segment pitch

$$= \frac{\pi D_C}{\text{number of segments}}$$

$$= \frac{\pi \text{ x } 0.7 \text{ x } 25}{81} \text{ with the assumption that } D_C = 0.7\, D$$

$$= 0.68 \text{ cm}$$

Maximum thickness of the brush = 5 times the commutator segment pitch
= 5 x 0.68 = 3.4 cm

Let the thickness of the brush t_b = 2.5 cm

Armature current $I_a = \frac{\text{Hp x } 746/\eta}{V} = \frac{20 \text{ x } 746/0.9}{250} = 66.3$ A

Cross-sectional area of the brush / spindle $A_b = \frac{2\,I_a}{A\,\delta_b} = \frac{2 \text{ x } 66.3}{2 \text{ x } 6} = 11.65 \text{ cm}^2$

Let the standard brush width W_b = 1.6 cm

Number of brushes / spindle $n_b = \frac{A_b}{t_b\,W_b} = \frac{11.65}{2.5 \text{ x } 1.6}$ = 2.76 and is not possible
= 3 (say)

Length of the commutator L_C = (1.6 + 0.5) 3 + 2 + 2 + 2 = 12.3 cm

Brush contact loss = Voltage drop / brush set x I_a = 2.0 x 66.3 = 132.6W

Example.3

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.

[Note :

1. The D.C. generator is a cumulative compound one, with 230V on open circuit and 250V on full load. Therefore while calculating the load current, 250V is to be considered.

2. The number of commutator segments or coils and hence the number of turns / coil must be so selected that the voltage per segment is not greater than 15V.
3. For a given voltage between segments, the volt / conductor goes on reducing as the number of turns / coil goes on increasing. Thus the volt / conductor is maximum when the turns / coil is minimum or turns / coil is one.
4. Volt / conductor = (voltage between segments) / (conductors /coil) or (2 x number of turns per coil)
5. There are 8 brushes / spindle of width 3.2 cm or 2.5 cm.]

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