CHAPTER 6
COMMUTATION

6.1 Introduction

The commutator is a characteristic feature of dc machines. Its purpose is to match the alternating currents and voltages of the armature coils to the direct current and voltage of the brushes as already explained in chapters 1 and 3. However, the commutation process is quite complicated, and gives rise to secondary effects that place limits on the over-all performance of the machine. This chapter explains the commutation process and its main effects.

6.2 The process of commutation

Fig. 6.1 Shows a general arm coil C moving to the right as it rotates with the armature; it is connecter to commutator bars a and b which move with it. (a)When the coil sides are under the poles, the coil is part of a certain armature path and carries a path current I_a:

$I_a = I_A / 2a$

(b)As the coil sides approach the q-axis (or brush axis), there will be an instant t_1 at which the brush contacts bars a and b simultaneously; thus, starts the short circuit of the coil by the brush.

(c)The coil continues to be short-circuited by the brush; it is said to be ‘undergoing commutation’.

(d)As coil sides move away from the q-axis, there will be an instant t_2 at which bar b breaks contact with the brush so that the short circuit ends.

(e)Coil sides move under poles, and the coil is now port of a different path; the coil current is I_a again, but in a direction opposite to the original one.

Clearly, then, the coil is short-circuited for an interval T_C

$T_C = t_2 - t_1$

During this interval, the coil current changes from I_a to $-I_a$; i.e. it reverses or ‘commutates’. As shown in fig. 6.2, the change in current must follow some time-curve from the point $(t_1, I_a)$to the point $(t_2, -1_a)$. Depending on various conditions that will be explained in later sections, we may have linear commutation (curve 1), over-commutation (curve 2), or under-commutation (curve 3).

To calculate the SC interval (or commutation interval), let u_c denote the speed of the bars; thus

$$U_c = 2\pi\, r_c\, n$$

Where r_c is the radius at the commutator surface. From fig. 6.3, it is seen that the leading edge of bar a move from x_1 at t_1 to x_2 at t_2; Thus

$$u_c = \frac{x_2 - x_1}{t_2 - t_1} = \frac{w - y_i}{T_c}$$

Therefore

$$T_c = \frac{w - y_i}{u_c} = \frac{1}{2\pi r_c n}\left[\frac{w}{y_o} - \frac{y_i}{y_o}\right] y_o$$

$$= \frac{1}{nC}\left[\frac{w}{y_o} - \frac{y_i}{y_o}\right] \qquad \left(y_o = \frac{2\pi r_c}{C}\right)$$

As expected, the length of the SC interval, T_C, is determined by the speed of rotation n, the relative dimensions of bars and brush, and the number of commutator bars.

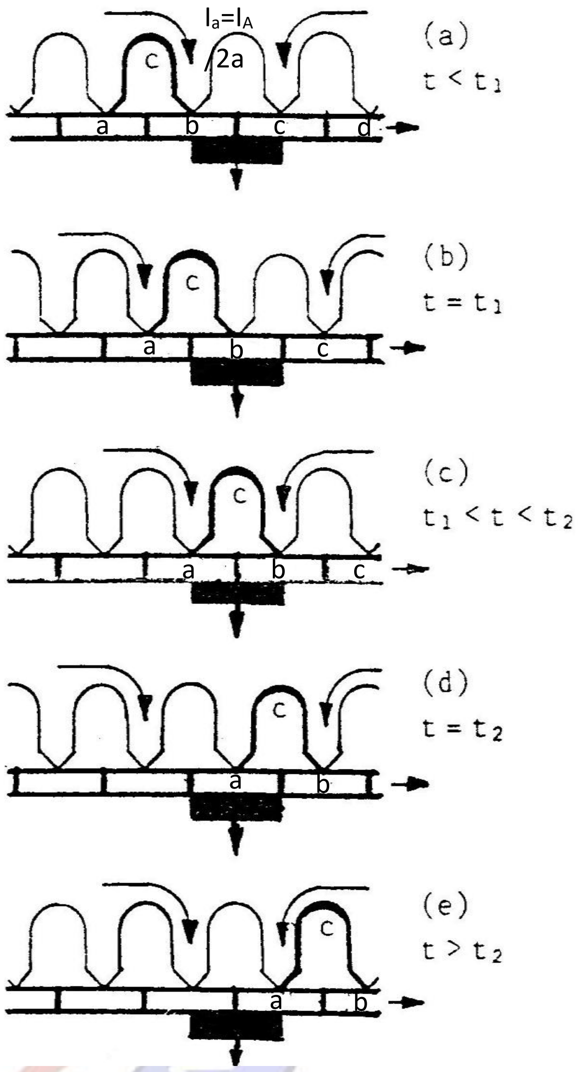

Fig. (6.1)

6.3 Equivalent Circuit of Commutating Coil

During commutation, the coil SC current i_s circulating in a path composed of: the coil itself, risers, bars, contact surfaces, and brush (see fig. 6.4). A simplified equivalent circuit is shown in fig. 6.5 with:

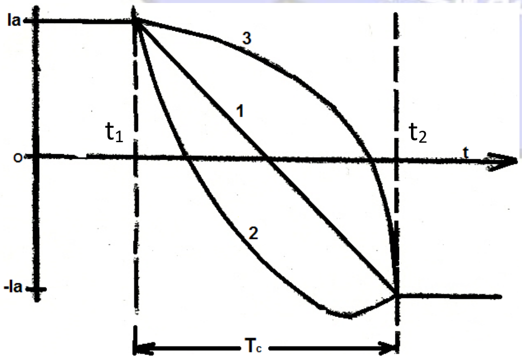

Fig. (6.2)

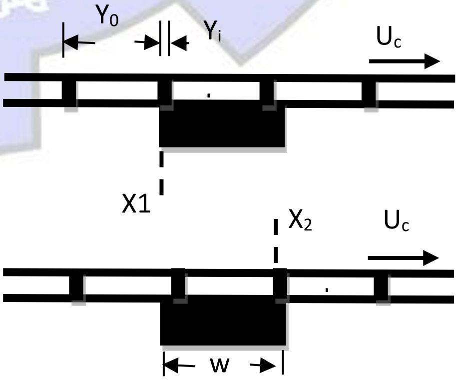

Fig. (6.3)

R_c = coil resistance;

e_c=rotational emf in coil =2N(bℓu);

L_c = self-inductance of coil;

r_1 =contact resistance between brush and trailing bar;

r_2 = contact resistance between brush and leading bar.

The circuit of fig.6.5 involves the following simplifications:

-The resistance of riser, bar, and brush is negligible w.r.t. contact resistance;

-Mutual inductance with adjacent coils is neglected;

-Brush assumed to short circuit one coil at a time.

Note that lower-case symbols are used for quantities that are time-varying during T_C; these are e_c, i_s, i_1, i_2, r_1, and r_2; indeed, i_s and possibly e_c reverse during T_C. Also note that from KCL

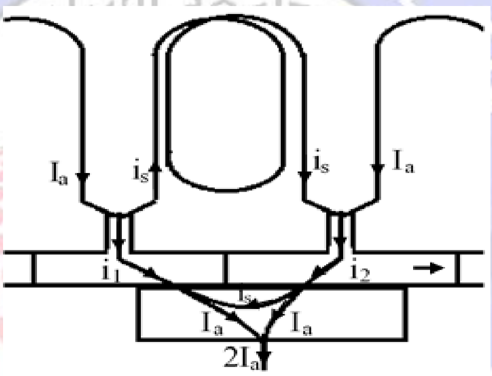

Fig.6.4

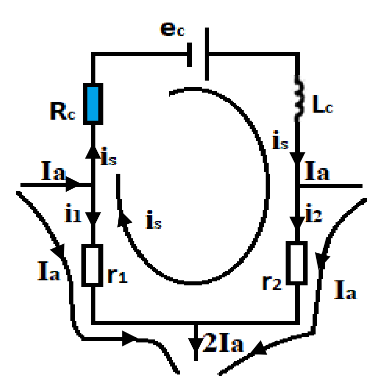

Fig. 6.5

$i_1 = I_a - i_s$ and

$i_2 = I_a + i_s$ So that

$i_1 + I_2 = (I_a - i_s)) + I_a + i_s) = 2I_a$

As expected,

The terminal voltage of the coil v_c is given by

$V_c = e_c - i_s R_c - L_c(di_s/dt)$

The rotational emf e_c is small because field is small around the q-axis (see, for example, fig. 5.5). $L_c(di_s/dt)$ is called the reactance voltage; it is induced by the change in i_s

6.4 Linear commutation (resistance commutation)

In small machines, the coil voltage v_c is smaller than the contact drops $i_1 r_1$ and $i_2 r_2$ we assume that v_c is negligibly small, then the equivalent circuit of fig. 6.5 reduces to that of fig. 6.6. In this case, r_1 and r_2 are in parallel so that by current division:

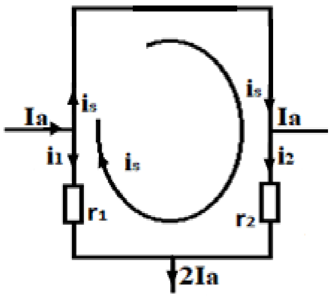

Fig. (6.6)

$$\frac{i_1}{i_2} = \frac{r_2}{r_1}$$

If we further assume that r_1 and r_2 are linear resistances (which in fact they are not), then:

$$\frac{r_1}{r_2} = \frac{A_2}{A_1}$$

Where the contact areas A_1 and A_2 are defined in fig. 6.7. Thus

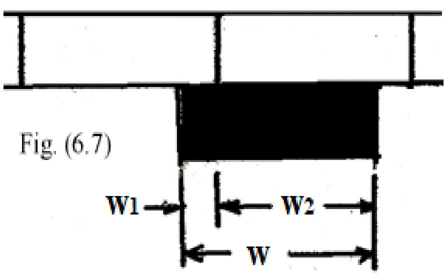

Fig. (6.7)

$A_1 = w_1 \ell_b$, $A_2 = w_2 \ell_b$, $A_b = w \ell_b$

Where ℓ_b = axial length of brush.

$$\frac{i_1}{i_2} = \frac{A_1}{A_2}$$

i.e. the current division between bars is in direct proportion to their respective contact areas. If in the above expression we substitute for i_1 and i_2 in terms of I_a and I_s (see section 6.3), and rearrange, we get:

$$i_s = \frac{A_2 - A_1}{A_b} I_a$$ (Derive this equation)

As the commutator slides against the brush at constant speed, A_1 increases linearly with time, while A_2 decreases linearly with time. Thus, i_s varies linearly from I_a at t_1 to $-I_a$ at t_2, and we have linear commutation as in curve 1 of fig. 6.2. Linear commutation is also called resistance commutation because the current variation is controlled by the contact resistances r_1 and r_2(see first equation in this section).

Note that we derived linear commutation as an approximation based on two assumptions : negligible v_c and linear contact resistances. These assumptions do not generally hold in practice so that we seldom have linear commutation. Commutation approaches linearity in small machines where these assumptions are approximately true.

6.5 Reactance voltage

Reactance voltage is the voltage induced in the coil due to the time variation of i_s; it appears across L_c in the equivalent circuit of fig. 6.5, and is equal to $L_c(di_s/dt)$. Reactance voltage has a great effect on the commutation process, so that linear commutation. The role of reactance voltage in the commutation process may be described qualitatively as follows:

The reactance voltage is induced by the change of coil current from 1_a to -1_a. According to Lenz's law, the reactance voltage will be induced in such a way as to oppose what is causing it, i.e. it opposes the change in current. Therefore, the reactance voltage retards or delays the change in current.

Due to reactance voltage, then, the current tends to follow a curve above that of linear commutation, for example curve 3 in fig. 6.2; the greater the coil inductance L_c, the higher the curve.

If current reversal is not complete (i.e. current has not reached-I_a) when bar b breaks contact with the brush at t_2, the curve will be as shown in fig. 6.8. This results in sparking which is explained as follows:

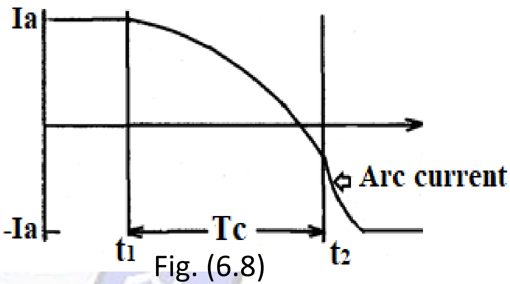

Fig. (6.8)

At t_2 the coil current attempts to jump to $-I_a$ almost instantaneously. This results in very high reactance voltage (why?), which causes breakdown in the air. The arc provides a path between brush and bar b through which current flows to complete its reversal to $-I_a$.

Sparking is harmful because it causes heating and hence wears of both brush and commutator bars. It becomes more severe as load increases (as the armature current I_a increases, so does the path current I_a).

6.6 Treatment of Sparking:

In some small machines, the resistive contact drop is much greater than the reactance voltage so that sparking is limited by the effect of resistance commutation, i.e. commutation approaches the linear case.

In larger machines, some additional means must be found to limit sparking, i.e. to counter the effect of reactance voltage which is the prime cause of sparking as explained above. Modern machines use interpoles, while older machines (and some small machines) use brush shift; these two methods are explained in sections 6.6 and 6.7.

6.7 Interpoles (Commutating Poles)

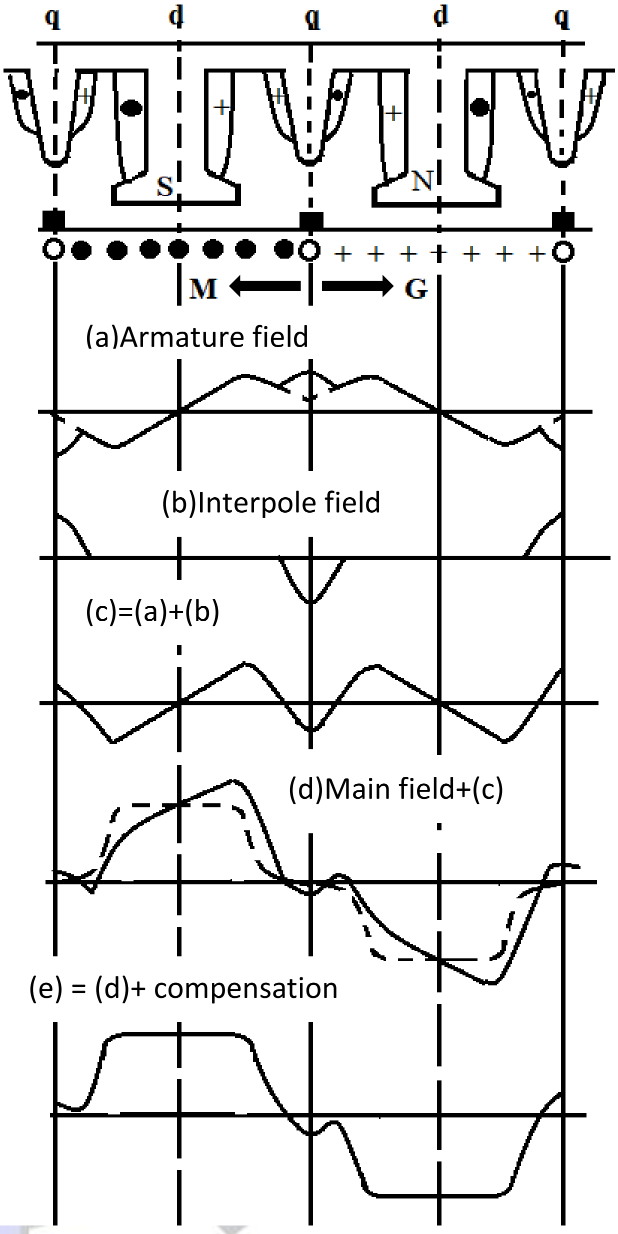

Fig.6.9

Nearly all integrating machines have interpoles. Interpoles are narrow pole with air-gap placed between main poles, as in fig. 6.9. There coils are connected in series with the armature so that the interpole field is proportional to armature current I_A (the large air gap prevents saturation in the iron). The interpole field acts on commutating coils at the q-axis. The interpole mmf M_i is given by

$$M_i = N_i I_A$$

Where N_i is the number of turns in each interpole coil. The number of turns N_i is chosen to make the interpole mmf some 25 %greater than M_{am}, the cross-magnetizing armature mmf at the q-axis (see section 5.1); thus $M_i = 1.25 M_{am}$ so that $N_i = 1.25(NC/4pa)$

In this way, M_i is made to serve two purposes :(1) It fully neutralizes the armature reaction field, and (2) the additional 25 %neutralizes the commutating coil flux (which induces the reactance voltage). This is clear in figs. 6.9 a, b, and c :the interpole field not only reduces the q-axis field to zero, but drives additional flux in the negative direction to neutralize reactance voltage. Fig. 6.10 d and e show the resultant field in interpole machines, without and with compensating windings; compare them with figs. 5.5 and .6.9

(NB interpoles treat arm reaction in the q-axis, while compensating wdgs treat arm reaction under the poles).

As the machine is loaded, the armature current I_A increases so that armature reaction and reactance voltage increase; but the interpole field is also proportional to I_A, and will increase automatically to neutralize armature reaction (in the q-axis) and reactance voltage. Interpoles will continue to do their job properly for either mode of operation, motor or generator, and for either direction of rotation, forward or reverse.

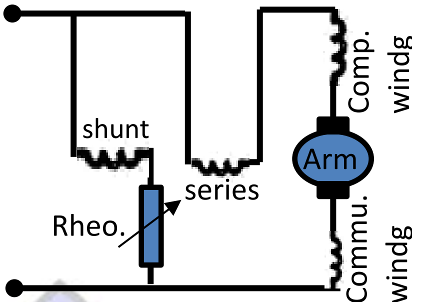

Fig.6.10

Fig.6.10 shows the general connection of a dc machine. Not all windings shown are present in all machines. Interpole or commutating wdgs are found on integral horsepower machines (rated power greater than one hp); compensating wdgs are found on large machines and on some special machines; many machines have only one main field wdg, shunt or series; compound machines have both. The terminals of main field wdgs (shunt and series) are usually brought out to the terminal box to allow user manipulation; the terminals of compensating and commutating wdgs are not brought out to the terminal box so that they are permanently connected in series with the armature.

6.8 Brush Shift

A second method for improving commutation to limit sparking is to shift the brushes from the q-axis. The principle is as follows:

Recall figs. 5.4 and 5.5 which show how the magnetic neutral axis (mna :b=0) moves away from the q-axis due to armature reaction. If now the brushes arc shifted in the same direction, they will be in a region where the armature field opposes the main field. At some location the two fields cancel out; placing the brushes at this location eliminates the rotational emf e_c (see fig. 6.5). This is not enough because there still is the reactance Voltage. To neutralize reactance voltage, the brushes are shifted a little further in some direction; the sides of commutating coil will then be subjected to a small (but nonzero) field that opposes the coil flux which induces the reactance voltage. If the opposing fluxes can be made equal, the reactance voltage is eliminated.

As a method for improving commutation, brush shift is not as good as interpoles because it has the following disadvantages:

1. As the load on the machine changes, the arm current 1_A changes so that AR and the mna shift also change. For correct operation, the brush shift must be changed accordingly, which is impractical. In practice, the brushes are placed in a position that gives minimum sparking at rated load, so that there may be considerable sparking at other loads (eg no-load!)