which gives the number of conductors that must be placed in each pole face for full compensation, ie for complete cancellation of armature reaction under the pole face, fig. 5.9d. The value of N_c obtained from eqn. 5.8 is unlikely to bean integer, and a smaller integer number is used because 60 -70 %compensation is usually sufficient. The connection of the compensating winding in series with the armature fig.5.10 means that compensation occurs at all loads; for example, if the armature current I_A increases, the armature mmf increases, but the compensating winding mmf also increases.

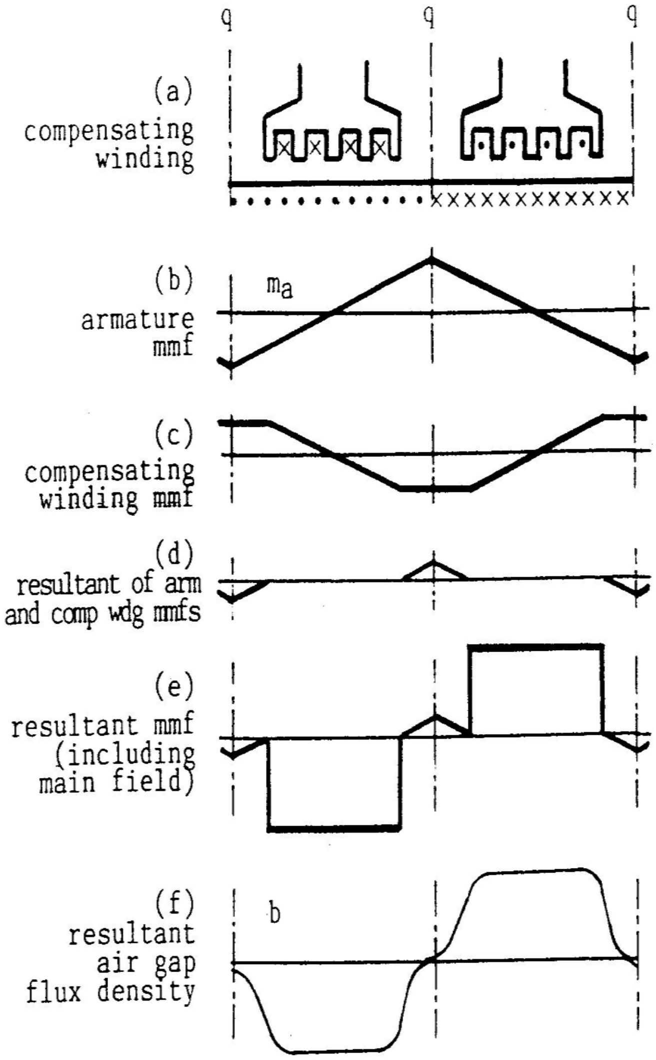

Fig. 5.9 The compensating winding and its effect on the mmf and flux density distributions in the air gap, assuming full compensation.

The compensating winding increases the cost of the machine very much; therefore, it is not used except in very large machines, and in some special-purpose machines, where the high cost may be justified economically.

The orientation of the various windings in fig. 5.10 indicates the axis on which each of them acts. The shunt and series field windings act on the d-axis, which is perpendicular to the brush axis, considered to be vertical through the armature in the figure. The armature and compensating windings act on the q-axis, which coincides with the brush axis.

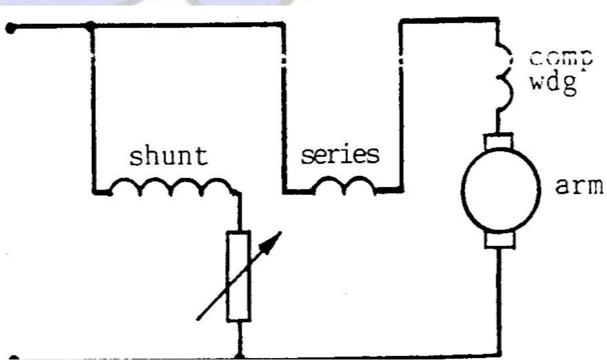

Fig. 5.10 Connection of a compound dc machine, including compensating winding.

5.6 Brush Shift

The brushes are normally located in such positions that they short circuit the coils which are passing through the q-axis; see for example figs. 3.7 and 3.11. The brush axis coincides with the q-axis, where the brush axis is defined as the location of the coil sides of the coils undergoing commutation, ie the coils whose currents are being reversed through brush short circuit. In the armature cross-section, the brush axis is the point at which the conductor currents reverse direction; normally, this is the same as the q-axis. However, if the brushes are moved from their normal positions, the brush axis will be shifted from the q-axis as shown in fig. 5.11 : note in particular that current reversal does not occur at the q-axis. Such brush shift is usually quite small, and results from incorrect positioning during manufacture, or poor brush fit, or normal parts wear over the machine's life, etc. In some small machines, the brushes are shifted intentionally to improve commutation, as will be explained in chapter 6.

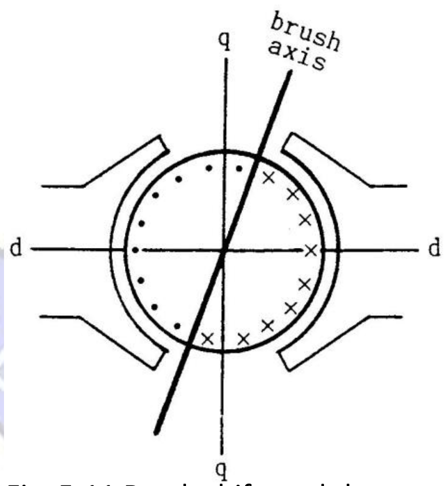

Fig. 5.11 Brush shift, and the resulting distribution of currents in the armature conductors.

Brush shift means that the pseudo-coil formed by the armature conductors does not act exactly on the q-axis, but on the shifted brush axis; that is, the peak of the triangular mmf wave of the armature occurs at the brush axis, which does not coincide with the q-axis, fig. 5.11. The armature mmf may therefore be considered to have two components :a component acting on the q-axis as usual, and a new component acting on the d-axis. Depending on the direction of brush shift relative to the direction of the main field, the d-axis component of armature reaction may aid the main field, or it may oppose it; that is, armature reaction may be magnetizing or demagnetizing. Note that most of the armature mmf still acts on the q-axis; it is 'cross-magnetizing', with a small demagnetizing effect as in section 5.3.1. Also note that brush shift does not alter the distribution of induced emfs in the armature conductor’s reversal of the induced emf occurs at the q-axis and not at the brush axis (more precisely, emf reversal occurs at the magnetic neutral axis).

To check that the brushes are correctly positioned at the q-axis, the machine is connected as a separately-excited generator, and rotated first in one direction, and then in the opposite direction; in both runs, the machine is loaded so that armature current flows, producing armature reaction. The speed, field excitation, and armature current are made the same in both runs. If the brushes are correctly positioned, the magnitude of the terminal voltage turns out to be the same for both directions of rotation. If, however, the brushes are incorrectly positioned, the armature reaction will have ad-axis component which aids the main field for one direction of rotation and opposes it for the other direction; the magnitude of the terminal voltage is then different for the two directions of rotation.

5.7 Exercises

5.1 Redraw fig. 5.4 with the armature current reversed, and compare.

5.2 Using cross-sectional diagrams of a 4-pole machine, show the flux distributions resulting from (i)the main field acting alone, (ii)the armature field acting alone, and (iii)the main and armature fields acting together.

5.3 Using developed diagrams of a 2-pole machine rotating counterclockwise, show that:

a. Armature reaction in a motor (i)increases the flux density under the pole in the direction opposite to rotation, and (ii)shifts the magnetic neutral axis in the direction opposite to rotation.

b. Armature reaction in a generator (i)increases the flux density under the pole in the direction of rotation, and (ii)shifts the magnetic neutral axis in the direction of rotation.

5.4 Using cross-sectional diagrams of a 2-pole machine, show that:

a. In a motor, brush shift in the direction of rotation produces magnetizing armature reaction, while brush shift in the direction opposite to rotation produces demagnetizing armature reaction.

b. In a generator, brush shift in the direction of rotation produces demagnetizing armature reaction, while brush shift in the direction opposite to rotation produces magnetizing armature reaction.

5.5 Draw cross-sectional diagrams, as listed below, for a 2-pole motor rotating clockwise. Show, on each diagram, the q-axis, brush axis, magnetic neutral axis, as well as the currents and emfs in the armature conductors.

a. Motor unloaded; brushes on q-axis.

b. Heavy load on motor, resulting in a 10° shift in the mna; brushes still on q-axis.

c. Motor loaded as in part b; brushes shifted 20° clockwise.

d. Motor loaded as in part b; brushes shifted 20° Counterclockwise.

Study the directions of armature currents and emfs for the various cases, and hence discuss the effects of brush shift. Pay special attention to the region between the brush axis and the mna axis.

5.6 On page 5.5 it is stated that the curves of fig. 5.6 merge at the air gap line because there is no saturation at low excitation; explain in detail.

5.7 Flashover can be considered as a short circuit between brushes; discuss and explain.

5.8 Why is the maximum mmf of the compensating winding less than the maximum mmf of the armature winding? Hence justify eqn. 5.7.

5.9 Explain, with the aid of suitable diagrams, how incorrectly positioned brushes can cause the voltage of a generator to be different for the two directions of rotation.

5.10 Armature reaction can cause demagnetization in two ways; explain.

5.11 A 6-pole dc machine has 95 slots. The armature winding is connected in simple lap with 2 coil sides/slot/layer and 3 turns/coil. The pole face covers 70 %of the pole pitch. The full-load armature current is 600 A.

a. At full load, find the armature mmf at (i)the d-axis, (n)the q-axis, (iii)the pole tip, and (iv)π/3 electrical radians from the q-axis.

b. How many conductors should be placed in each pole face to compensate for armature reaction? What is the resulting maximum mmf of the compensating winding?

5.12 The commutator of a 6-pole wave-wound machine has 29 segments. Each armature coil has 12 turns and carries 80 A. The machine is connected in long shunt cumulative compound : the shunt field winding has 700 turns per pole and carries 20 A; the series field winding has 25 turns per pole. The pole arc is 45 mechanical degrees. Find (i)the main field mmf per pole, (ii)the maximum mmf of the armature, and (iii)the number of conductors per pole face and maximum mmf of the compensating winding.

5.13 A 2-pole machine is designed to have an armature emf of 600 V. The armature has 35 slots with 16 conductors in each slot. Find the maximum allowable number of turns per coil, and the corresponding number of commutator segments.

5.14 The machine of question 4.14 rotates at 1200 rpm with an armature current of 16 A and a field current of 1.0 A. It is found that armature reaction reduces the induced emf by 38 V.

a. Find the main field mmf and the maximum armature mmf.

b. Find the effective reduction in field current due to armature reaction.

c. Find the effective field mmf.

d. Find the reduction in the flux per pole due to armature reaction.

e. Find the conversion power.

5.15 The machine of question 4.14 rotates at 800 rpm with an armature current of 16 A and a field current of 1.4 A. The armature emf is found to be350 V. Determine the demagnetizing effect of armature reaction as(i)a reduction in induced emf, (n)a reduction in effective field current, and (iii)a reduction in the flux per pole.

5.16 A 4-pole dc machine has a hot armature winding resistance of 0.8Ω; the brush contact drops maybe assumed constant at 1.5 V. The OCC at 1400rpm is given in table 5.1.

a. The machine is operated as a separately excited generator at 1400 rpm with the field current fixed at 1.2 A. It supplies a 15 Ω load resistor with 5 KW. Determine the demagnetizing effect of armature reaction as(i)a reduction in emf, and (ii)a reduction in effective field current.

b. The machine is operated as a shunt motor from a 220 V source. It is loaded so that the speed is 1000 rpm and the armature current is15 A. Assuming that armature reaction reduces the flux per pole by 5 %, determine the actual and effective field currents; also compute the motor line current and the developed torque.

Table 5.1 OCC at 1400 rpm.

I_f (A)	Ea (v)
0.0	28
0.1	51
0.2	102
0.3	145
0.4	182
0.6	235
0.8	266
1.0	286
1.5	313

5.17 The dc machine whose OCC is given on table 5.2 has a wdg resistance of 75 mΩ and a constant brush contact drop of 1.5 v. the mag curves at different armature loadings and constant speed 800 rpm are listed in the adjacent table.

I_f (A)	E_A volts		
	IA=100 A	IA=80 A	IA=60 A
3.5	217	219	221
4.0	225.5	228	230.5
4.5	232.5	235.5	238.5
5.0	239.5	243	246.5
6.0	252	256	260
7.0	262.5	267	271.5
8.0	270.5	275.5	280.5
9.0	277	283	288.5
10.0	283	290	296

(a) Plot these curves, together with the OCC, over the field current range shown here.

Table 5.2 OCC at 800 rpm.

I_f (A)	E_A(V)
0	8
0.3	28
0.5	46
1.0	94.5
1.5	143
2	175
2.5	195.5
3.0	211
3.5	224
4.0	234.5
4.5	243.5
5.0	251.5
6.0	265.5
7.0	276.5
8.0	286
9.0	294.5
10.0	302

(b) Determine E_A, E_0, ΔE, I_f, I_f^*, and ΔI_f when the arm current is 80 A and the field current is 8A and speed is 800 rpm. (c) The machine is operating as a generator at 800 rpm determine the terminal voltage when the field current is7 A and the arm current is 60 A

(d) for motor operation at 1000 rpm with the field current of 7.5A if the armature current is 80 A, find the terminal voltage and the conversion power. (e) if the machine is operating as a 900-rpm generator with terminal voltage 260 V and arm current 100 A, find E_A, E_{AOC}, I_f, I_f', ΔE, and ΔI_f. (f) the machine runs as a motor from a 220 V supply. At a certain load, the speed is 650 rpm and the armature current are 90 A find E_A, E_{AOC}, I_f, I_f', ΔE, and ΔI_f. (g) the machine runs as a motor from a 240 V supply. At a certain load, the field current is 8.4 A and the armature current is 60 A find the speed and developed torque. (h)A series field winding added to the machine such that when the speed is 500 rpm and the shunt field current is 3A, the armature emf and current are 150 V and 80 A respectively. find the number of turns of the series field winding. (I) the machine is operated as a shunt motor; it draws 80 A from a 220 V supply. Estimate the speed.

5.18 Question 5.17h and 5.17i appear to be identical, respectively, to questions 4.131 and 4.13m. why are the solutions and answers different?

Answers

5.11 a. (i)0, (ii)9500At, (iii)6650At, (iv)3167At; b. 22 conductors, 6600 At. **5.12**(i)18 KAt, (ii)4.64 KAt, (iii)43 conductors, 3.44 KAt.**5.13** 4 turns/coil, 70 segments. **5.14** a. 725 At, 133 At; b. 0.2 A; c. 0.8 A; d. 1. 786 mWb; e. 7.7 KW. **5.15**(i)33.3 V, (ii)0.37 A, (iii)2.35 mWb .**5.16** a. (i)9V, (ii)0.145A; b. 1.29A, 1.05 A, 16.3A, 29.6Nm. **5.17**b. 275.5V, 286V, 10.5V, 8A, 6.88A,1.12A; c. 265.5V; d. 346.6V, 27.13KW;e. 269V, 282.9V, 13.9V, 4.98A, 4.25A, 0.73A; f. 211.8V, 221.3V, 9.6V, 6.6A, 5.6A, 1 A; g. 660 rpm, 203 Nm; h. 14 turns; i. 678 rpm

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