D.C Generator

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D.C Generator

D.C. GENERATORS ARE classified according to the method of their field excitation.

(1) *Separate excitation.* The field magnets are excited from an entirely separate d.c. source. Examples of such machines are low-voltage, heavy-current generators used in electro-plating and electro-refining of metals; main generators in d.c. ship propulsion.

(2) *Self excitation.* (a) Shunt; (b) Series; (c) Compound generators.

For each of these types, certain simple relations between armature current, e.m.f. generated, terminal voltage, etc., can be established by the application of Ohm's Law as shown in examples below.

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The Shunt Generator

Field coils wound with many turns of fine wire and connected across the armature.

Uses—Main generators on board ship;
Small installations;
Charging accumulators.

Let V = P.D. at terminals.
V_b = Voltage at brushes.
E = E.M.F. generated.
I_e = Current in external circuit.
R_e = Resistance of external circuit.
I_a = Armature current.
R_a = Armature resistance.
I_{sh} = Shunt field current.
R_{sh} = Shunt field resistance.

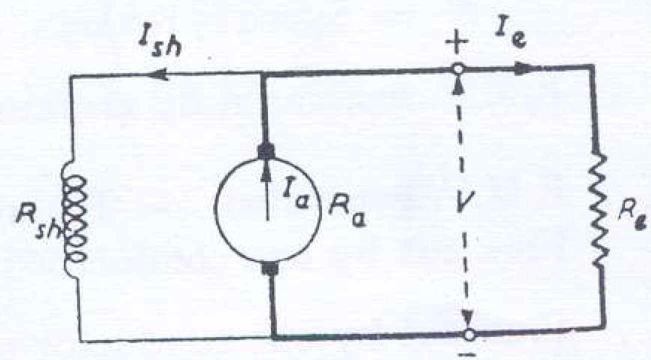

Fig. 55. Shunt Generator

Then $I_e = \dfrac{V}{R_e}$ .... (82

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$$I_{sh} = \frac{V_b}{R_{sh}} \quad (V_b = V \text{ for shunt generator}) \qquad (83)$$

$$I_a = I_{sh} + I_e \qquad (84)$$

$$\text{Volt drop in armature} = I_a R_a \qquad (85)$$

$$\text{E.M.F. generated, } E = V_b + I_a R_a \qquad (86)$$

Example 1. A shunt generator supplies a load of 15 kilowatts at 200 volts through feeders of resistance 0·08 ohm. Resistance of shunt field winding 80 ohms; resistance of armature 0·04 ohm. Find the terminal voltage and the e.m.f. generated.

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$$15 \text{ kW} = 15000 \text{ W}$$

$$\text{Load current} = \frac{15000}{200} = 75 \text{ amperes.}$$

$$\text{Volt drop in feeders} = 75 \times 0\cdot08 = 6 \text{ volts.}$$

$$\therefore \quad \text{P.D.}_t = 200 + 6 = 206 \text{ volts.}$$

$$\text{Field current, } I_{sh} = \frac{206}{80} = 2\cdot575 \text{ amperes}$$

$$\therefore \quad \text{Armature current, } I_a = 75 + 2\cdot575 = 77\cdot575 \text{ amperes}$$

$$\text{Volt drop in armature} = 77\cdot575 \times 0\cdot04 = 3\cdot1 \text{ volts.}$$

$$\therefore \quad \text{E.M.F. generated} = 206 + 3\cdot1 = 209\cdot1 \text{ volts.}$$

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The Series Generator

The field coils are wound with a few turns of wire of large cross-sectional area connected in series with the armature. Before the machine will excite, the external circuit must be closed. Series generators are scarcely ever used except for special purposes, *e.g.*, boosters.

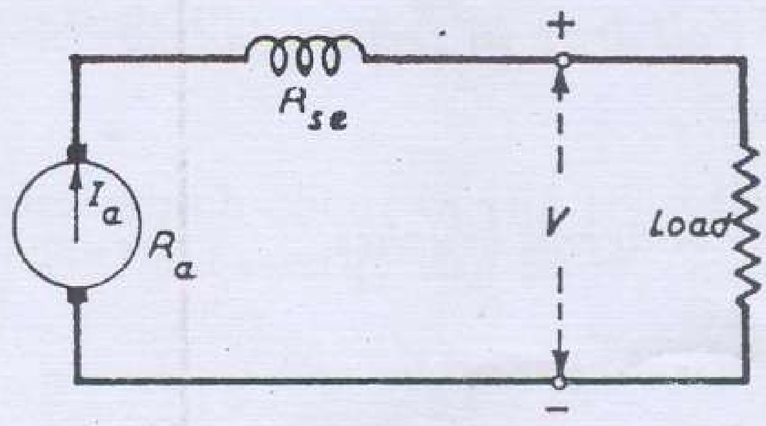

Fig. 56. Series Generator

The Compound Generator

Field magnets excited partly by shunt coils and partly by series. There are two methods of connection: (a) short shunt; (b) long shunt.

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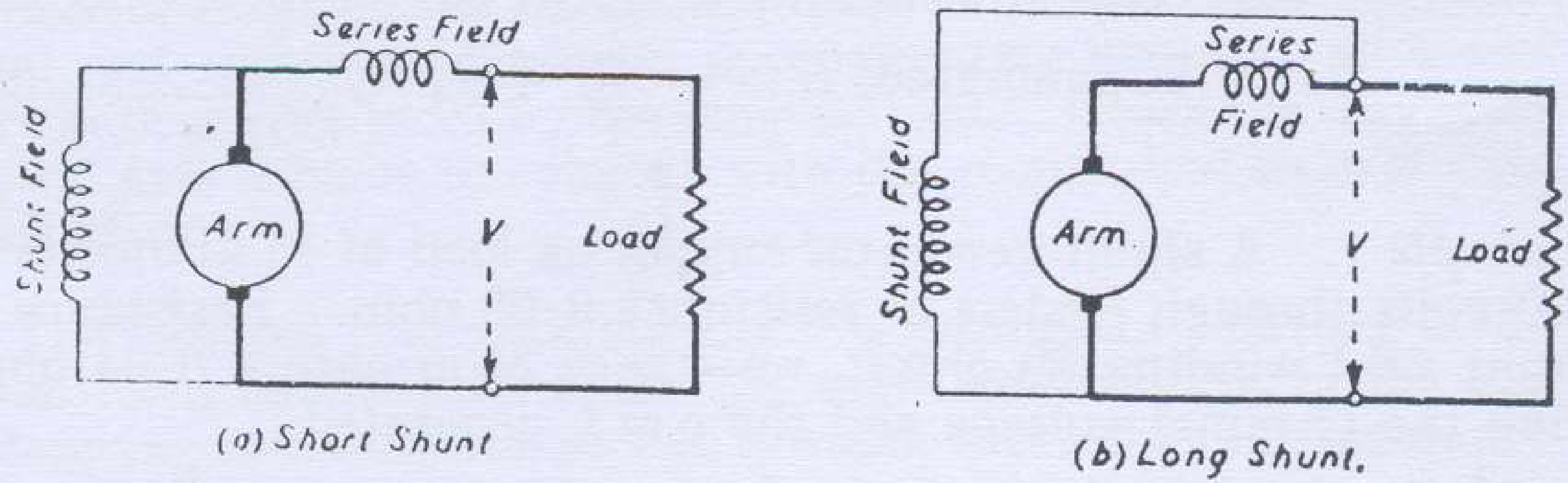

Fig. 57. Compound Generators

Example 2. A short-shunt compound generator supplies 100 amperes at 110 volts. Shunt field resistance 50 ohms; series resistance 0·015 ohm and armature resistance 0·02 ohm. Find the e.m.f. generated.

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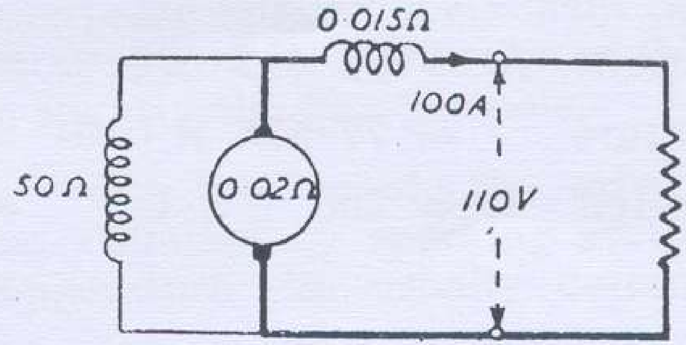

Volt drop in series winding $= I_{se} \times R_{se} = 100 \times 0{\cdot}015$

$= 1{\cdot}5$ volts.

Voltage at brushes, $V_b = 110 + 1{\cdot}5 = 111{\cdot}5$ volts.

Field current, $I_{sh} = \dfrac{111{\cdot}5}{50} = 2{\cdot}23$ amperes.

Armature current, $I_a = 100 + 2{\cdot}23 = 102{\cdot}23$ amperes

Volt drop in armature $= 102{\cdot}23 \times 0{\cdot}02 = 2{\cdot}0446$ volts.

$\therefore$ E.M.F. generated $= 111{\cdot}5 + 2{\cdot}04 = 113{\cdot}5$ volts.

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E.M.F. GENERATED BY AN ARMATURE

The two important methods of winding the conductors on an armature are (1) *Wave or Two Circuit Winding* (2) *Lap or Multiple Circuit Winding*. These may be represented as follows:—

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(1) *Wave*

There are *two* paths in parallel irrespective of number of poles. Each path supplies half the total current output. Two sets of brushes only are necessary, but it is usual to fit as many sets of brushes as the machine has poles. The majority of low and medium output motors have wave-wound armatures.

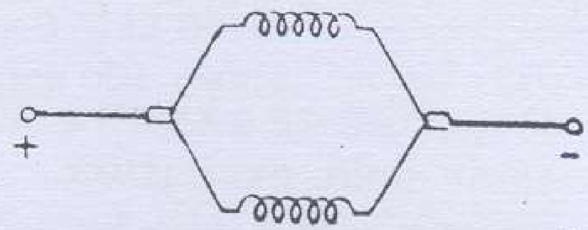

Fig. 58. Equivalent Circuit. Wave-winding, 2-, 4-, 6-, 8-pole machine

(2) *Lap*

There are as many paths in parallel as the machine has poles. The total current output divides equally among them. There are as many sets of brushes as the machine has poles. Nearly all generators and large variable speed motors have armatures of this type.

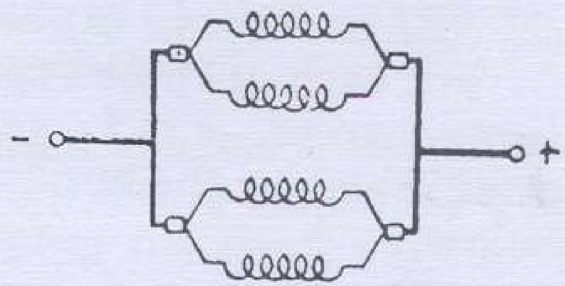

Fig. 59. Equivalent Circuit Lap-winding, 4-pole machine

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E.M.F. generated

Let p = Number of *pairs* of poles.

Φ = Flux per pole.

Z = Total number of conductors on armature.

N = Speed in rev/min. $= \frac{N}{60}$ rev/sec.

E.M.F. generated by armature = E.M.F. generated by one of th parallel paths.

E.M.F. generated = Flux cut per second, volts.

Flux cut by one conductor in making one rev. $= 2p\Phi$.

Flux cut by one conductor per second $= 2p\Phi \times \frac{N}{60}$.

$\therefore$ E.M.F. generated in one conductor $= \frac{2p\Phi N}{60}$ volts.

For a Wave-Wound Armature

No. of conductors in series per path $= \frac{Z}{2}$

$\therefore$ E.M.F. generated $= \frac{Z}{2} \times \frac{2p\Phi N}{60}$

$= p \times \frac{\Phi N Z}{60}$ volts. ....(87)

FOR A LAP-WOUND ARMATURE

No. of conductors in series per path $= \frac{Z}{2p}$

$\therefore$ E.M.F. generated $= \frac{Z}{2p} \times \frac{2p\Phi N}{60}$

$= \frac{\Phi N Z}{60}$ volts. ......(88)

If 'a' is the number of parallel paths through the armature we may write as a *general formula*:—

$$E = \frac{2p}{a} \cdot \frac{\Phi N Z}{60} \quad \text{......(89)}$$

Note that for a given machine, $E \propto N\Phi$.

Example 3. An eight-pole, lap-wound armature has 960 conductors and a flux per pole of 20 mWb. Calculate the e.m.f. generated when running at 500 rev min.

E.M.F. generated $= \frac{\Phi N Z}{60} = \frac{20 \times 10^{-3} \times 500 \times 960}{60}$

$= 160$ volts.

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Example 4. If the armature in above example were wave-wound, what would be the e.m.f. generated?

$$\text{E.M.F. generated} = p \times \frac{\Phi N Z}{60} \text{ volts.}$$

$$= 4 \times \frac{20 \times 10^{-3} \times 500 \times 960}{60} \text{ volts.}$$

$$= 4 \times 160$$

$$= 640 \text{ volts.}$$

Losses and Efficiency

A generator is a machine for converting mechanical energy into electrical energy. When such a conversion takes place, certain losses occur which are dissipated in the form of heat. The temperature of the machine increases until a steady state is reached when the rate of generation of heat is equal to the rate at which it is dissipated by radiation, conduction and convection. Most of the insulation used in a machine is of a fibrous nature—cotton, compressed paper, cambric etc., and such materials deteriorate if subjected to temperatures above about 100°C. The temperature of the surrounding air determines the maximum temperature to which any part of a machine will rise; it is this latter temperature

Losses and Efficiency

which determines the maximum current output, and therefore the kW rating.

The losses which occur may be grouped under two headings:—

(1) *Copper Losses* (sometimes called Electrical Losses).

(2) *Iron and Friction Losses* (sometimes called the Rotational Losses).

Copper Losses

(a) Armature copper loss $= I_a^2 R_a$ watts.

(b) Field copper loss—in shunt winding $= I_{sh}^2 R_{sh}$ watts.
in series winding $= I_{se}^2 R_{se}$ watts.
in interpole winding $= I_a^2 R_i$ watts.

(c) Loss due to brush contact resistance (between surface of brush and surface of commutator). Usually taken into account by including brush contact resistance with armature resistance.

Losses and Efficiency

Iron Losses (sometimes called Core Losses) include:—

(a) Hysteresis loss in armature.

(b) Eddy current loss in armature and pole shoes;

∴ Hysteresis loss $\propto N\ B_{max}^{1\cdot 6}$;

Eddy current loss $\propto N^3\ B_{max}^2$

Friction Losses include:—

(a) Brush friction.

(b) Bearing friction.

(c) Windage of rotating armature.

The Power Stages

The energy changes and losses which occur in the transformation of mechanical energy into electrical energy can be represented diagrammatically as in Fig. 60.

Losses and Efficiency

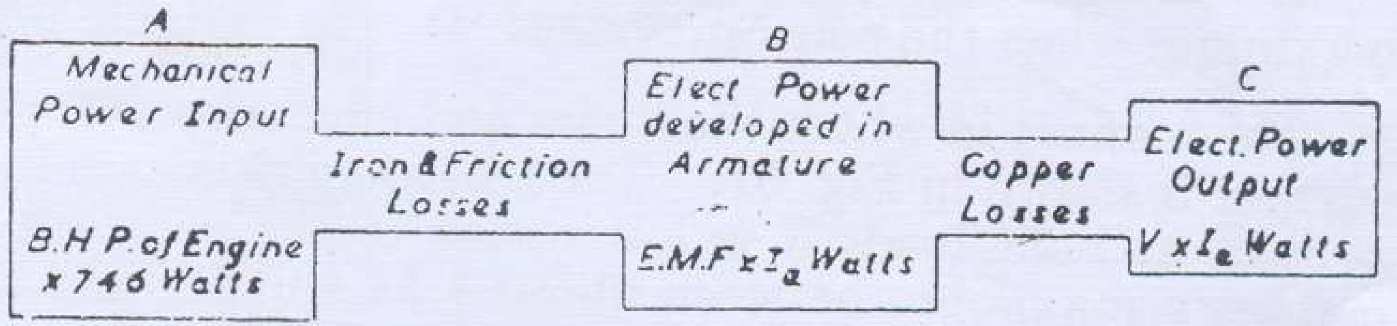


Fig. 60. Power Stages for Generator

$A - B$ = Iron and Friction losses.

$B - C$ = Copper losses.

Losses and Efficiency

Commercial or Overall Efficiency $\eta_c = \frac{C}{A}$ ....(90)

Mechanical efficiency $\eta_m = \frac{B}{A}$ ....(91)

Electrical efficiency $\eta_e = \frac{C}{B}$ ....(92)

These are always expressed in the form of a percentage. Unless otherwise stated the commercial efficiency is always understood.

Note that commercial efficiency, $\eta_c = \frac{C}{A} = \frac{\text{Output}}{\text{Input}}$ .... (93)

$$= \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

$$= \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

Constant and Variable Losses

Constant and Variable Losses

The losses may also be grouped as follows:—

(a) Those which remain substantially *constant* at all loads.

(b) Those which *vary* with the load.

In the case of a shunt or compound machine, the constant losses include:—

(a) Iron and friction losses.

(b) Shunt field loss.

and the variable losses include: —

(a) I^2R loss in the armature.

(b) I^2R loss in the series winding.

(c) I^2R loss in the interpole winding.

Constant and Variable Losses

It can be shown that for a given machine, the efficiency is a maximum when the constant losses = the variable losses.

The manner in which the losses and efficiency change with load current is shown in Fig. 61. The efficiency rises rapidly from zero at n.l.; at light loads it is low owing to the constant losses. It reaches a maximum between about $\frac{3}{4}$ f.l. and f.l., and above f.l. it decreases, due to the rapid rise in the variable losses. The maximum efficiency which can be obtained depends on the output, voltage and speed. A greater maximum efficiency can be obtained with (i) a machine of large output than with one of small output (ii) a high voltage machine than with a low voltage machine (iii) a high speed machine than with a low speed machine.

Constant and Variable Losses

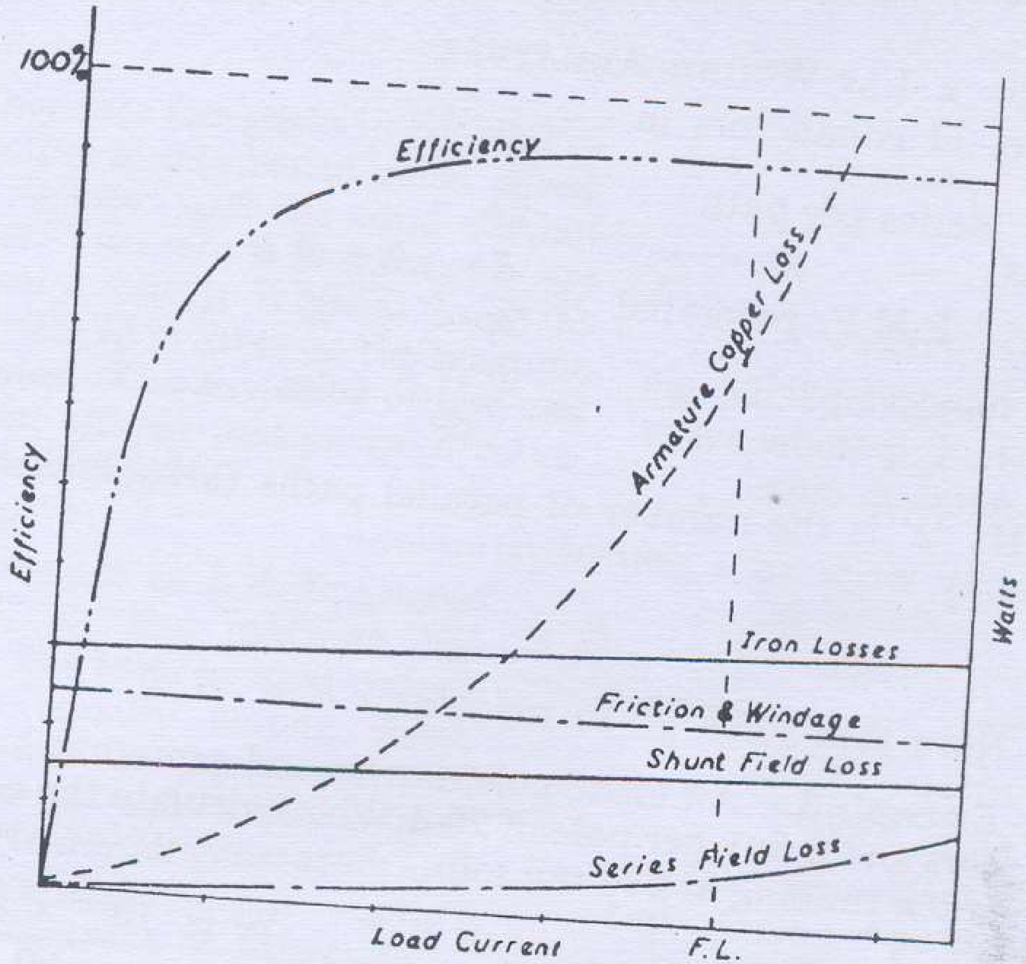


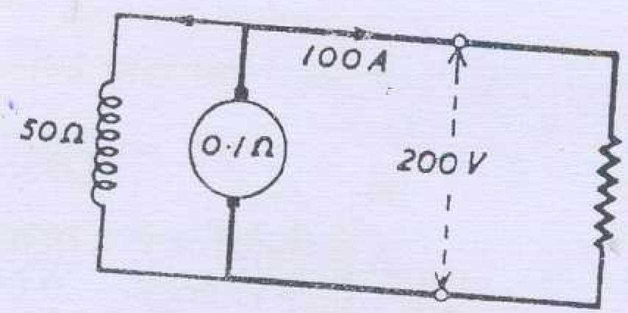
Fig. 61. Variation of Losses and Efficiency with Load Current

Constant and Variable Losses

Example 5. A shunt generator supplies 100 amperes at a terminal voltage of 200 volts. The prime mover is developing 32 b.h.p. Shunt field resistance 50 ohms, armature resistance 0·1 ohm, Find (a) the copper losses (b) the iron and friction losses (c) the commercial efficiency.

$$I_{sh} = \frac{200}{50} = 4 \text{ A.}$$

$$\therefore \quad I_a = 100 + 4 = 104 \text{ A.}$$



Volt drop in armature

$$= 104 \times 0{\cdot}1 = 10{\cdot}4 \text{ volts.}$$

$\therefore$ E.M.F. generated

$$= 200 + 10{\cdot}4 = 210{\cdot}4 \text{ volts.}$$

(a) Mechanical power input $= 32 \times 746 = 21{,}882$ watts

(b) Electrical power developed in armature $= 210{\cdot}4 \times 104 = 21{,}882$ watts

$\therefore$ Iron and friction losses $= 1\,990$ watts

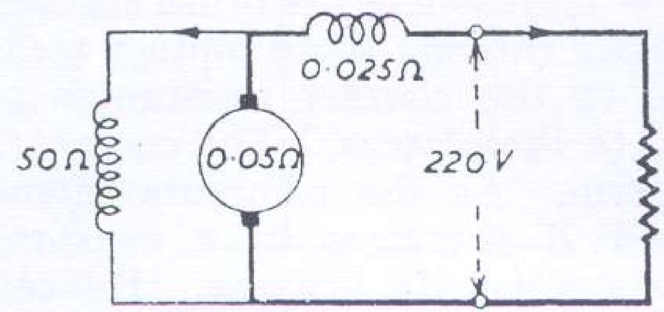
(c) Electrical power output $= 200 \times 100 = 20{,}000$ watts

$\therefore$ Copper losses $= 1{,}882$ watts

Constant and Variable Losses

$$\text{Commercial efficiency } \eta_c = \frac{\text{Output}}{\text{Input}} = \frac{20000}{23872} \times \frac{100}{1}$$
$$= 83 \cdot 8 \text{ per cent.}$$

Example 6. A short-shunt compound generator supplies a current of 100 amperes at 220 volts. The resistance of the shunt field is 50 ohms, of the series winding 0·025 ohm and of the armature 0·05 ohm. Iron and friction losses amount to 1 kW. Find (a) the e.m.f. generated; (b) the copper losses; (c) the b.h.p. of the prime mover; (d) the commercial efficiency.



Constant and Variable Losses

Volt drop in series winding $= 100 \times 0 \cdot 015 = 2 \cdot 5$ volts.

$\therefore \quad V_b = 220 + 2 \cdot 5 = 222 \cdot 5$ volts

$$I_{sh} = \frac{222 \cdot 5}{50} = 4 \cdot 45 \text{ amperes}$$

$\therefore \quad I_a = 100 + 4 \cdot 45 = 104 \cdot 45$ amperes.

Volt drop in armature $= 104 \cdot 45 \times \cdot 05 = 5 \cdot 22$ volts

$\therefore$ E.M.F. generated $= 222 \cdot 5 + 5 \cdot 22 = 227 \cdot 72$ volts

(c) Electrical power output $= 220 \times 100 = 22{,}000$ watts

(b) Electrical power developed in armature $= 227 \cdot 72 \times 104 \cdot 45 = 23{,}790$ watts

$\therefore$ Copper losses ((b)–(c)) $= 1{,}790$ watts

Iron and friction losses $= 1{,}000$ watts

(a) $\therefore$ Mechanical power input $=$ output $+$ losses $= 24{,}790$ watts

$\therefore$ B.H.P. of prime mover $= \dfrac{24790}{746} = 33 \cdot 24$ h.p.

Commercial efficiency, $\eta_c = \dfrac{22000}{24790} \times 100\% = 88 \cdot 74$ per cent

Armature Reaction

Armature Reaction

The effect of armature current on the distribution of the main magnetic field of an electrical machine is called *armature reaction*. Distortion of the field, due to armature current, causes an increase in eddy current and hysteresis losses in the armature core. Distortion of the field across the air gap causes a decrease in total flux because of saturation at the trailing edges of the poles.

Exercise

1. A shunt generator supplies a load of 5·5 kW at 110 volts through a pair of feeders of total resistance 0·042 ohm. Armature resistance 0·1 ohm; shunt field resistance 40 ohms. Find the terminal voltage and e.m.f. generated. (112·1 V; 117·4 V)

2. The e.m.f. generated in the armature of a shunt generator is 625 volts when delivering its full load current of 400 amperes to the external circuit. The field current is 6 amperes and the armature resistance is 0·06 ohm. What is the terminal voltage? (600·64 V)

3. The output of a shunt generator is 500 amperes at a terminal voltage of 225 volts. Armature resistance 0·02 ohm; shunt field resistance 50 ohms. What is the e.m.f. generated? (235·1 V)

Exercise

4. The terminal voltage of a 150-kW shunt generator is 600 volts when delivering its full load current. Armature resistance 0·08 ohm; shunt field resistance 80 ohms. Find the e.m.f. generated.
(620·6 V)

5. A short-shunt compound generator delivers 100 amperes at a terminal voltage of 200. Armature resistance 0·2 ohm; series field resistance 0·04 ohm; shunt field resistance 51 ohms. Find the total current output of the armature and the e.m.f. generated.
(104 A; 224·8 V)

6. A short-shunt compound generator supplies a load of 15 kW at 200 volts through a pair of feeders of total resistance 0·1 ohm. Armature resistance 0·04 ohm; series field resistance 0·03 ohm; shunt field resistance 80 ohms. What is the e.m.f. generated?
(212·8 V)

Exercise

7. A short-shunt compound generator supplies a load at 100 volts through a pair of feeders of total resistance 0·05 ohm. The load consists of four motors, each taking 40 amperes, and a lighting load of 200, 60-watt lamps. Armature resistance 0·02 ohm; series field resistance 0·05 ohm; shunt field resistance 50 ohms. Find:—

   (a) Load current. (280 A)

   (b) Terminal voltage. (114 V)

   (c) E.M.F. generated. (133·6 V)

8. A long-shunt compound generator has a full load output of 100 kW at 250 volts. Armature resistance 0·05 ohm; series field resistance 0·03 ohm; shunt field resistance 55 ohms. Find:—

   (a) Armature current. (404·5 A)

   (b) E.M.F. generated. (282·3 V)