The no load and running light tests determine machine losses without loading it. Other tests have been devised to operate the machine at full load conditions without requiring an external load. An example of such tests is the <u>opposition test</u> (Kapp-Hopkinson test) which requires two identical machines. The machines are coupled mechanically, and connected in parallel with each other to the mains, fig. 7.6. By increasing the excitation for one machine and decreasing it for the other, the first will operate as a generator, and the second as a motor :the generator supplies the motor electrically, while the motor drives the generator mechanically; the power input from the mains supplies the losses to keep the system running. By suitable adjustments of the field rheostats, the armature currents can be set to their rated value. With the two machines running at or near rating (current, voltage, and speed), they will develop full-load losses, yet the disadvantages of a load test have been avoided :no external load is needed, and the mains supplies only machine losses, not their full power.

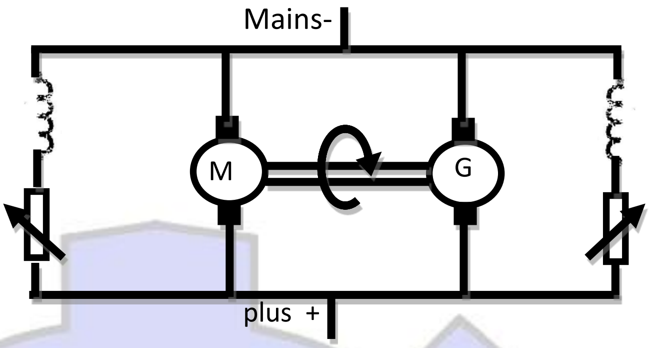

Fig. (7.6) Opposition test

In a <u>heat run</u> (or <u>temperature-rise test</u>), the machine is run at full-load to develop full-load losses; the test takes 20-60 minutes until the temperature reaches steady state corresponding to its rated operating value. The no-load and running light tests cannot replace the load test in a heat run because they do not generate all machine losses simultaneously. An opposition test, on the other hand, can be used in a heat run.

7.7 Efficiency

The efficiency of a machine is defined by

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + LOSSES} = 1 - \frac{LOSSES}{P_{in}} \qquad (7.18)$$

The first expression is general, the second is suitable for generators (P_{out} measured electrically), and the third is suitable for motors (P_{in} measured electrically). The efficiency is a fraction less than unity, and is usually expressed in percent. Table 7.3 lists typical values of dc machine efficiencies,

The overall efficiency defined, above can be analyzed into two component efficiencies corresponding to the two stages of power flow as fig. 7.2:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_c}{P_{in}} \frac{P_{out}}{P_c} \qquad (7.19)$$

For a motor, fig. 7.3, this becomes:

$$\eta = \frac{P_c}{P_{elec}} \frac{P_{mech}}{P_c} = \text{(eff. Of conversion) x (mech. Eff) .} \qquad (7.20)$$

And for a generator, fig. 7.4, it becomes:

$$\eta = \frac{P_c}{P_{mech}} \frac{p_{elec}}{P_c} \text{ =(eff. of conversion) x (elec. Eff.)} \qquad (7.21)$$

7.8 Maximum Efficiency

In section 7.4, the losses were divided into constant and variable losses (see table 7.1); the losses were then expressed as in eqn.7.15. Now consider motor operation :neglecting the small shunt field current, the input power is written:

$$P_{in} = V_t I_A \qquad (7.22)$$

Using the third expression in eqn. 7.18, the efficiency is written:

$$\eta = 1 - \frac{K_0 + K_1 I_A + K_2 I_A^2}{V_t I_A} = 1 - \frac{1}{V_t}(K_0 I_A^{-1} + K_1 + K_2 I_A) \qquad (7.23)$$

This equation gives efficiency as a function of armature current I_A; the general shape of the resulting curve is shown in fig. 7.7 (where line current is approximately equal to armature current).

To locate the point of maximum efficiency, we differentiate equ. 7.23 and equate to zero:

$$\frac{\partial \eta}{\partial I_A} = -\frac{1}{V_t}(-K_0 I_A^{-2} + K_2) = 0 \quad \Rightarrow \quad K_0 = K_2 I_A^2 \qquad (7.24)$$

Thus, maximum efficiency occurs when the copper losses $K_2 I_A^2$ equal the constant losses K_0(or, as an approximation, when variable losses equal constant losses (i.e. neglecting the brush contact loss $K_1 I_A$). Industrial machines are usually designed to have maximum efficiency for I_A between half and full load values (because the machine operates at less than full load most of the time); the exact choice is not critical because the efficiency curve is flat around maximum value, fig. 7.7.

7.9 Importance of Efficiency

For industrial motors, traction motors, and other power-application motor efficiency is quite important, but it is only one of a number of factors that determine how good a machine is; the other factors include power/weight ratio, power/cost ratio, reliability, maintenance requirements, vibration, noise, etc. For sma11 control motors, efficiency is of secondary importance; main factors of interest include accuracy, cost, size, speed of response, reliability, noise, weight, interference, etc.

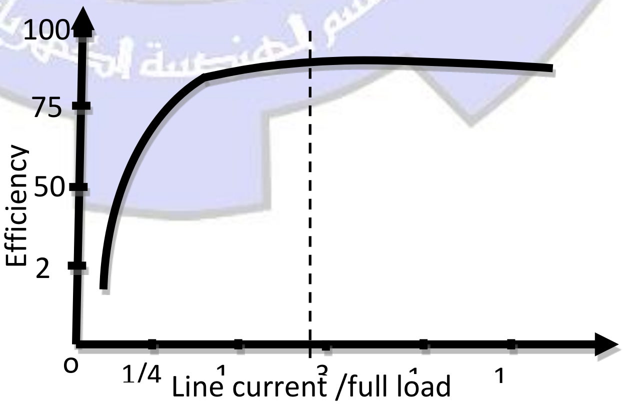

Fig. (7.7) Typical efficiency curve for a dc machine

7.10 EXERCISE:

Unless otherwise stated, assume that (a) winding resistances are given at the working temperatures, (b) the demagnetizing effect of armature reaction is negligible, and (c) the brush contact drop is 2V.

1. A 6-pole dc machine has 95 slots, the armature winding is connected in simple wave with 2 coil sides per slot per layer, and 3 turns per coil. The pole arc covers 70% of the pole pitch. The full load armature current is 600A.
   a) The armature winding is connected in simple lap; find
      1) The cross- magnetizing armature mmf at the q-axis;
      2) The cross-magnetizing armature mmf at the pole tip;
      3) The number of turns of each interpole coil;
      4) The number of conductors to be placed in each pole face to compensate for armature reaction;
      5) The number of turns of each interpole coil when there is a compensating winding (assume the compensating winding fully neutralizes the armature reaction under the pole);
      6) The cross –magnetizing and demagnetizing armature mmf's (at the q-and d-axis respectively) when the brushes are shifted 6 degrees from the q-axis to improve commutation.
   b) Repeat part (a) for simple wave connection.

NB list your results in a suitable table for case of comparison.

2. An armature has 268 coils and rotates at 900 rpm. Each brush covers 4 commutator segments.
   a) Find the time for one revolution.
   b) Estimate the interval during which a brush short circuits a coil.
   c) Why is your answer in part (b) approximate?
3. A 125 KW, 250V, 1800 rpm, cumulative compound generator is connected in long shunt. The armature, series field, and shunt field winding resistances are 0.025Ω, 0.01Ω, and 30Ω respectively. At rating, the shunt field current is 5 A, and the eddy current, hysteresis, frictions, and windage losses are 2KW, 1.2KW, 1.1 KW, and 700W respectively.
   a. Find the value at which the field control resistor is set.
   b. Find the electrical loss, rotational loss, and the stray load loss.
   c. Find the input horsepower, the prime mover torque, and the generator efficiency.
4. A 3/4 hp shunt dc motor runs on 60 V and draws 12 A line current; the field current is 0.4 A, and the shaft speed is 1780 rpm. The temperature of the armature winding is estimated to be 90 ^{0}c. the armature resistance is 0.32 Ω at 20 ^{0}c.
   a) Find the input power and the conversion power.
   b) Find the developed torque and the load torque.
   c) Find the conversion, mechanical, and over- all efficiency
   d) Find the current at which efficency is maximum, and find the maximum efficency. What assumption is needed for this calculation?
   e) The load on the motor is reduced so that the line current becoms 6 A; the temperature of the armature winding decreases to 70 ^{0}c. (i) find the shaft speed; (ii) repeat part (a), (b), and (c) for the new load.
5. A 20 hp shunt motor is rated at 150 V and 1400 rpm. A no-load test is performed on the macine using a 380 V drive motor to rotate it at rated speed. With the test machine unexcited, the drive motor current and losses are 2A and 260W. with the test machine field excited from a separate source, the drive motor current and losses are 5A and 400W. the armature circuit and field circuit resistances of the test motor are 0.16Ω and 50Ω respectively.
   a. Find the drive motor shaft torque in the two tests.
   b. Find the mechanical losses, core losses, and rotational losses of the test machine.
   c. Find the motor current at rating.
   d. Find the indevedual electrical losses at rating.
   e. Find the conversion, mechanical, and over all efficencies at rating.
   f. Estimate maximum efficiency. Why is your cacultion approximate ?(speed)
6. A 45 KW, 220V, 750 rpm, cumulative compound generator is connected in short shunt; the shunt field current is 10A at rating. The armature circuit and series field resistances were measured at 30 ^{0}c and

found to be 0.062Ω and 0.005Ω respectively. To measure the rotational losses, the machine was run as an unloaded motor : 240V is applied and the shunt field control resistor is adjusted for rated speed; the armature and shunt field currents were found to be 10A and 13A respectively.

a) Find the individual losses at rating.
b) Find the input power and conversion power at rating.
c) Find the conversion, electrical, and over-all efficiencies at rating.
d) Why was the running light test performed at 240 V instead of rated voltage? (emf).
e) Estimate the ratio of series field turns to shunt field turns.

Answers:

1. (a) 9.5 KAT; 6.65 KAT; 20; 22; 6;7.6 KAT, 1.9 KAT.

(b) 28.5 KAT; 19.95KAT; 59; 66; 18; 22.8 KAT, 5.7 KAT.

2. 66.7 ms; 1ms.
3. (a) 20 Ω; (b) 11.19KW, 5.00 KW, 1.25 KW; (c) 191 hp, 756N-m, 87.8%.
4. (a) 720 W, 617.9 W; (b) 3.31N-m, 3.00 N-m; (c) 85.8%, 90.5%, 77.7%. (d) 14.2A, 77.9 %; (e) (i). 1866.5 rpm; (ii). 360 W, 312.8 W; 1.60N-m, 1.30N-m; 86.9%, 81.3%, 70.7%.
5. (a) 3.41N-m, 10.23 N-m; (b) 500W, 1000W, 1500W; (c) 132A; (d) 2658 W, 258 W, 450 W; (e) 83.0%, 90.9%, 75.4%; (f) 75.8%(1432.5 rpm).

(a) 3.34 KW, 0.24KW, 0.43KW, 2.21KW , 2.37KW; (b) 53.6KW,51.2KW; (c) 95.6%, 87.9%, 84.0%; (d) (238V) ; (e) 0.0147