direct-current generator are excited, and a current is passed through its armature winding, a force will be exerted on the latter which will tend to rotate the armature; in other words, **any direct-current generator will act as a motor.** The change in the operating conditions when a given machine changes from generator to motor is best illustrated by considering the case of a shunt generator (as shown in Fig. 32) charging a storage battery. Suppose, for example, that the e.m.f. of the battery is 100 volts. To charge this battery the generator must force current through it against its e.m.f. of 100 volts, and must consequently generate more e.m.f. than that of the battery. Suppose, for illustration, that the e.m.f. of the generator is 110 volts. The net or effective e.m.f. acting in the circuit will be 110 — 100 = 10 volts. Assuming the resistance of the circuit (including battery and armature of generator) to be .2 ohm, the current will be, according to Ohm's law, 10/.2 = 50 amperes. This indicates that the amount of current flowing into the battery depends directly on the difference between the e.m.fs. of the battery and generator. If the e.m.f. of the generator is diminished by adjusting its rheostat or lowering its speed, the strength of the current will diminish and become zero when the e.m.f. of the generator is exactly equal to that of the battery. If the e.m.f. of the generator is lowered any further there will be a reversal in the direction of the current, and the generator becomes a motor, with the direction of rotation unchanged. In this case the battery forces current through the armature of the machine against the e.m.f. which is generated therein; in other words, the battery discharges and gives out energy to the motor. The change from generator to motor is thus accompanied only by a change in the direction of armature current. **When operating as a generator the current flows in the direction of the e.m.f., and when running as a motor the current flows in the opposite direction to that of the generated e.m.f.** In construction and general appearance the motor differs very little from the generator.

If the poles of a motor are excited and the armature is connected to some source of constant e.m.f., a current will flow through the winding, which will produce a torque, tending to rotate the armature; and if the latter is free to turn it will rapidly accelerate. The rotation will generate an e.m.f., which will oppose the flow of current, and, as the armature speeds up, the current and driving torque—which depends directly on the current—will consequently diminish until the latter is exactly equal to the retarding torque; i.e., the load. If the friction could possibly be eliminated, the armature of an unloaded motor would speed up until the e.m.f. generated in its armature would be exactly equal to the voltage applied to its brushes, and no current would flow in its armature. In this case no current would be necessary to keep the armature running, for by assumption there would be no retarding torque, and consequently no driving torque would be necessary. When, however, a retarding torque is applied to the armature, the speed at once diminishes, and consequently the generated e.m.f. The speed will decrease until the difference between the applied voltage and the generated e.m.f. is large enough to force a current through the armature of sufficient strength to produce a driving torque equal to the retarding torque. If Ea represents the generated e.m.f. and E the voltage applied to the brushes or terminals, E — Ea represents the net or effective voltage; and if Ra represents the resistance of the armature, the current will be

$$I = \frac{E - Ea}{Ra} \quad \ldots\ldots\ldots\ldots \quad (16)$$

and by transposing—

$$Ea = E - I\,Ra \quad \ldots\ldots\ldots\ldots \quad (17)$$

Since the mechanical force exerted on a conductor in a given magnetic field varies directly as the strength of the current, it follows that if the flux in a given motor remains constant, the current flowing in the armature will be proportional to the driving force; and, since the latter must be equal and opposite to the retarding force (or load), the armature current will vary directly with the retarding torque But from equation (16) the current varies directly as the difference between the applied voltage and the generated e.m.f. Consequently, if the applied voltage is constant, the generated e.m.f. must diminish in proportion as the load increases; and since the generated e.m.f. depends directly on the speed, it follows that the speed must decrease proportionately with increase of load. The amount of this decrease will depend on the value of Ra, for the smaller the armature resistance, the smaller the difference between E and Ea to give the necessary strength of current The following numerical example will illustrate these points:—

Example 12.—The resistance of the armature of a certain motor is .06 ohm, and it is designed to operate with 200 volts applied to its terminals and to carry 200 amperes. The speed when running light (no load) is 1,000 r.p.m. Assuming that the magnetic flux remains constant, to determine the speed when the load is such as to require 100 amperes to rotate the armature.

$$Ea = E - I\,Ra = 200 - 100 \times .06 = 194 \text{ volts.}$$

Since the generated e.m.f. varies directly with the speed, it follows that the speed will be 1,000 × 194/200 = 970 r.p.m.

If the load were such as to require 200 amperes, the generated e.m.f. would be 188 volts and the speed 940 r.p.m.

If the resistance of the armature were .12 ohm instead of .06, the generated e.m.f. with 200 amperes flowing in the armature would be 176 volts and the speed 880 r.p.m.

In the actual motor the value of Ra is usually small, and consequently the value of the term I Ra in equation (17) is usually small compared to E. The value of Ea, and consequently the speed, will, therefore, vary only a small amount from no load to full load. **It is thus clear that, with constant flux, the speed of a motor will diminish a small amount with increase of load, the decrease depending on the armature resistance.**

In the above discussion it has been assumed that the flux in the motor remains constant. If the flux is diminished, when the motor is carrying a fixed load, the generated e.m.f. will decrease. The result will be an increase of current, as indicated by equation (16); and an increase of current will give an increase of driving torque. If the load remains constant, as assumed, the increased torque will cause the motor to speed up and thus increase the generated e.m.f. and diminish the current to its original value. **Any variation of flux will thus cause an inverse variation of speed.** Advantage is taken of this to regulate or vary the speed of motors in commercial work. For this purpose a rheostat is placed in series with the exciting coils, by means of which the exciting current may be varied.