starting rheostat provided with no-voltage release and circuit-breaker is shown connected to a compound motor. The connections to a shunt or series motor would be the same as shown in the figure, except that in one case there would be no series exciting coils, and in the other case no shunt circuit.

The no-voltage release protects the rheostat as well as the motor, for with this device the contact arm will not remain anywhere between the off position and the running position (unless held there in some way). If held between these two positions, part of the resistance will be continuously in circuit, and, if the motor is loaded, the current will overheat this resistance and perhaps burn it. The resistance is designed to carry the current only for the short interval required for the motor to speed up. If it is desired to leave part of the resistance in circuit with the object of lowering the speed, a "speed-controller" must be used. (See following paragraph):—

Speed Control of Direct Current Motors.—When a motor is used to drive a group of machines, its speed must necessarily be constant (or approximately so), for it would obviously be impossible to vary the speed of the motor to suit one machine without interfering with the others. In this case the variations of speed which may be required for individual machines must be obtained by some speed-changing device connected to each machine. At present, however, the practice is to install a motor to drive each individual machine which requires any considerable amount of power and which operates at various speeds, while small machines are grouped together in convenient groups. In the case of the machine with the separate motor, the speed is always varied through the medium of the motor. If resistance is placed in series with the armature of a motor it will cause a loss of potential. If the voltage acting on the brushes is reduced on the armature. In this case the generated e.m.f. will automatically decrease to satisfy equation (16), and, since the flux remains constant, this reduction in e.m.f. must be effected by a reduction in speed. The speed of a motor may thus be varied by placing a resistance in series with the armature, or by varying the exciting current as previously noted. The speed at which a motor will run when no resistance is used (either with armature or exciting circuit) is known as the "normal" speed. **If resistance is placed in series with the armature, the speed decreases below normal, while if resistance is placed in series with the exciting coils the speed increases.** When a wide range of variation is required both these methods are used. Each of these methods has its disadvantages and its limitations. If the speed is reduced by the first method it will remain constant only while the load is constant. If the load is reduced, the motor at once speeds up. This is a serious disadvantage in the case of a machine with variable load. Another serious disadvantage is the loss of power in the rheostat, which is directly proportional to the loss of potential. If the voltage acting on the brushes is reduced to one-half by means of this resistance, the speed will be reduced to approximately one-half, and one-half of the total power used will be lost in the rheostat. On the other hand, when the speed is increased above normal by placing resistance in series with the exciting coils, the maximum driving torque will diminish directly with the flux, for the torque is proportional to current and flux, and the former is limited by the current-carrying capacity of the armature. **It thus follows that if the flux is reduced, the maximum torque of the motor must diminish in proportion.** A numerical example will illustrate these points:—

Example 13.—(a) A resistance of .4 ohm is placed in series with the armature of the motor specified in Example 12 to determine its speed at full load, and also at half load. (b) If the flux is reduced 10 per cent. to determine the speed with 200 amperes flowing in the armature; i.e., with maximum torque.

(a) Loss of potential in series resistance = 200 × .4 = 80 volts.

Loss of potential in armature resistance = 200 × .06 = 12 volts.

Generated e.m.f. = 200 — (80 + 12) = 108 volts.

Motor runs at 1,000 r.p.m. to generate 200 volts.

Speed to generate 108 volts = 1,000 × 108/200 = 540 r.p.m.

At half load the total loss of potential would be 46 volts.

Generated e.m.f. = 200 — 40 = 160 volts.

Speed to generate 160 volts = 1,000 × 160/200 = 800 r.p.m.

(b) With 90 per cent. flux motor would run at 1,111 to generate 200 volts.

Generated e.m.f. must be 200 — 200 × .06 = 188 volts.

Speed to generate 188 volts = 1,111 × 188/200 = 1,044 r.p.m.

A variable resistance or rheostat designed for use in series with the armature of a motor, whether alone or in conjunction with a resistance for inserting in the exciting circuit, is known as a "speed-controller" or "controlling rheostat," and a single variable resistance for use in the exciting circuit is known as a "field rheostat." The construction of either is similar to that of the starting rheostat. The principal difference between the latter and the speed-controller is that in the controller the resistance is designed to carry the full load current of the motor continuously without overheating, while in the starting rheostat the resistance is designed to carry this current only for the short period required for the motor to attain its normal speed. When field control is used in conjunction with armature resistance, both resistances are mounted in one box, and the whole range of speed is obtained by moving one contact arm. A controller combining both methods is shown connected to a shunt motor in Fig. 40. When a controller is equipped with a no-voltage release, there is a separate spring-actuated arm for this purpose, and when the voltage is cut off this arm carries the contact arm to the off position. This arrangement is shown in Fig. 40. Controllers serve the double purpose of starting and controlling.

On account of the loss of power occasioned by the use of resistance in series with the armature, a system of multiple voltages is sometimes used. This system involves the use of three or four transmission wires carrying different voltages. With this system as many different speeds may be obtained as there are different voltages without losing power. Intermediate speeds may be obtained by using a field rheostat or armature resistance.