must increase. But the decrease of current will be accompanied by a decrease of flux, and to maintain the generated e.m.f. the speed must increase in proportion as the flux diminishes. **The series motor will thus speed up very rapidly as the retarding torque is diminished.** If it were possible to reduce the retarding torque to zero the speed would be infinite. For this reason care must be exercised to prevent all the load being thrown off a series motor. If there is any possibility of this happening by accident, a speed-limiting device should be attached to the motor.

Since the driving torque of a motor varies directly with the strength of the current and with the density of the flux, it follows that if the permeability were constant,

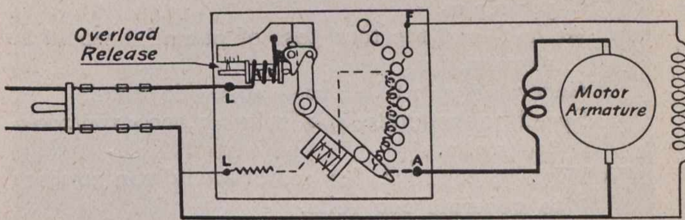

FIG. 39

the driving torque would vary as the square of the current, for in this case the flux would vary directly with the current. In the actual machine the permeability is practically constant up to the point where the magnetic circuit begins to saturate. Beyond this point the flux increases only a small amount. To maintain the generated e.m.f., the speed must increase as the flux decreases, and with constant permeability the flux varies directly with the current. Approximately, then, the speed of the series motor varies inversely with the current.

From the above it will be clear that the series motor is suitable in cases where it is necessary to have a large starting torque combined with slow speed, and an increase of speed with a decrease of load. These are the requirements in nearly all classes of railway service, and also in hoisting work, although in the latter case it is usually necessary to have a speed limit. Otherwise the motor would "run away" with a very light load. In the case of an elevator, for example, it takes a larger torque to start and accelerate it than it takes to run it, but it is not desirable to have the elevator run at a very high speed with a light load and a very slow speed with a heavy load. In a case of this kind the characteristics of both the shunt and series motor are required in a moderate degree, and to obtain these the "compound wound" motor is used. The series winding increases the starting torque, and the shunt winding fixes a lower limit for the flux, and consequently an upper limit for the speed. This type of motor is used in all cases where the starting torque must be fairly high, and the speed must not exceed a certain maximum.

Referring to Example 12, it will be noted that the current capacity of the motor in question is 200 amperes. If more current is forced through it the heat generated will cause the temperature of the armature to rise beyond the allowable limit, and if the current exceeds this amount for any considerable period of time, the resulting high temperature may damage the armature by burning the insulation on the conductors. In this particular case the current will not exceed the limit so long as the generated e.m.f. (sometimes referred to as the "counter" e.m.f.) does not fall below 188 volts. As there is no generated e.m.f. when the motor is at rest, it follows that some provision must be made to keep the current within a prescribed limit when the motor is being started; i.e., until the speed is sufficient to generate the required e.m.f. of 188 volts. This is effected by placing a resistance in series with the armature, and as the motor speeds up this resistance is gradually cut out. Resistances made up specially for this purpose are known as "starting rheostats." The connections of one of these rheostats to a compound motor are shown in Fig. 38. It will be noted that the contact arm of the rheostat is acted on by a spring which tends to pull the arm into the "off" position as shown by the dotted line, and away from the "running" position as shown by the full line. When the arm is in the "off" position, the circuit is open. As the arm is rotated in the clockwise direction, it first touches the outer button, marked "f," and thus closes the exciting circuit; when it comes in contact with the fourth large button the armature circuit is closed with all the resistance in series with it; and finally, when the arm reaches the "running position" the resistance is all cut out. The arm is held in the running position by means of the electromagnet, which is excited by a small coil connected either in series with the exciting circuit of the motor or directly across the line. In the figure it is shown connected directly to the line and in series with the armature resistance, together with an additional high resistance which reduces the strength of the current. The object of the spring and electromagnet is to prevent an excessive flow of current through the armature of the motor in case the line voltage should happen to be turned off for a brief interval and then turned on again. If this should happen the motor would slow down and perhaps stop: and if the contact arm of the rheostat remained in the running position, there would be an excessive flow of current through the armature when the line voltage is turned on. This is prevented by the action of the spring which pulls the contact arm to the off position as soon as it is released by the electromagnet, the strength of which falls quickly to zero when the line voltage is shut off. This arrangement is known as a "no-voltage release," and it is now the practice to place it on every starting rheostat, except the smallest sizes.

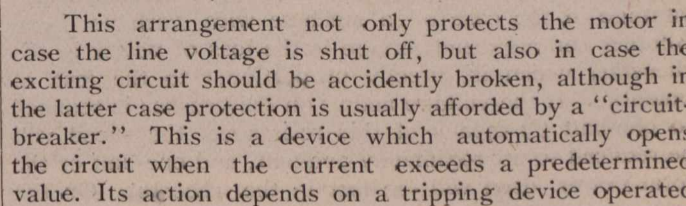

FIG. 40

This arrangement not only protects the motor in case the line voltage is shut off, but also in case the exciting circuit should be accidently broken, although in the latter case protection is usually afforded by a "circuit-breaker." This is a device which automatically opens the circuit when the current exceeds a predetermined value. Its action depends on a tripping device operated by a solenoid, which is excited by the current passing to the motor. This arrangement is often mounted on the starting rheostat, and is then known as an "overload release." It will break the circuit as soon as the current exceeds the fixed limit, due to overload or any other cause, and the breaking of the circuit will cause the contact arm to move to the off position. In Fig. 39 a