by the driven machine. The greater this excess torque, the faster will be the acceleration. The approximate time required for acceleration from rest to full speed is:

$$\frac{(\text{rpm}) \times WR^2}{T \times 308} \text{ (in seconds)} \qquad (1)$$

where

(rpm) = full-load speed in revolutions per minute.
T = average torque available for acceleration, foot-pound.
WR^2 = inertia of rotating parts, pound-foot square.

If the time to accelerate is greater than about 20 sec, special motors or starters may be required to avoid overheating.

5. *Inertia of Driven Machine.* The inertia or flywheel effect WR^2 of the rotating parts of the driven machine affects the accelerating time and, therefore, the heating of motors and control, particularly where reversing duty or frequent starting is involved.

Where synchronous motors are applied, the WR^2 must be known, since the pull-in

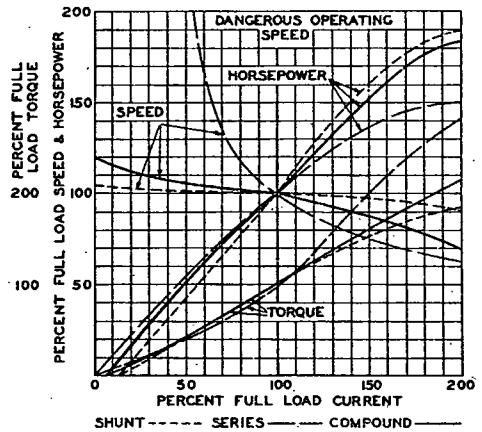


FIG. 1. CHARACTERISTICS OF DIRECT CURRENT MOTORS

torque required of this motor varies approximately as the square root of the total WR^2 of motor and load.

The WR^2 of a rotating member of the driven machine which operates at a speed different from that of the motor may be converted to an equivalent value at the motor shaft by multiplying by

$$\left(\frac{\text{rpm of rotating member}}{\text{rpm of motor}}\right)^2 \qquad (2)$$

6. *Frequency of Starting.* The frequency of starting the driven machine affects the motor and control by increasing their heating, particularly where accelerating time is prolonged by high WR^2 and high load torques. In general, driven machines starting more than 4 to 6 times per hour may require special motors and control.

DIRECT CURRENT MOTORS

Direct current motors are classified (see Table 5) according to type of winding as: *shunt wound, compound wound,* and *series wound.*

Shunt Wound motors, being suitable for application to fans, centrifugal pumps, or similar equipment where the amount of starting torque required

is relatively small, are used for the majority of direct current applications in the field of heating, ventilating, and air conditioning. They may be used on reciprocating pumps and compressors if started under unloaded conditions.

Without auxiliary control the shunt wound motor is designated as *constant speed.** Fig. 1 illustrates the characteristics of direct current motors, showing speed, horsepower, and torque as a function of current. The speed regulation* of small size shunt wound motors from $\frac{3}{4}$ hp to 5 hp is 12 percent as specified by *NEMA*, while on larger motors it is 10 percent.

Compound Wound motors are required for application to reciprocating compressors, stokers, reciprocating pumps when started under loaded conditions, and other similar equipment requiring high starting torque. The characteristics of this type of motor are such that for starting torques above full-load torque the starting current required is somewhat less than for the shunt wound motor. Compound wound direct current motors are normally used whenever frequent starting makes high starting and accelerating torque desirable. Without auxiliary control, compound wound motors are designated as *varying speed,** and have a speed regulation of 25 percent.

Series Wound motors find only limited application in a few special cases and are available in a limited range of sizes. The motors are used where extremely high starting torques are required, and must be applied only to direct coupled continuous loads due to the fact that the speed of the motor becomes dangerously high when the motor is operated at a light load.

Typical d-c motor specifications are shown in Specification A at end of chapter.

CONTROL FOR DIRECT CURRENT MOTORS

Direct Current motors are usually started through starting controllers employing a resistance in series with the motor armature which is gradually cut out as the motor comes up to speed. Motors up to 2 hp may be line-started providing the inrush current causes no serious voltage fluctuations in the power supply line.

Constant Speed and Varying Speed Motors. As shown in Fig. 2, the recommended practice for manual starting of motors over $\frac{1}{2}$ hp requires the use of a fused safety switch or circuit breaker and a face-plate type starter. For automatic push button starting a safety switch or circuit breaker and an automatic starter are recommended.

Adjustable Speed motors are normally shunt wound and are operated at various speeds by varying a resistance connected in series with the motor field. A maximum range of speed of about 5 to 1 can be obtained by this means. Rated speed regulation is 22 percent for motors of this type from 2 to 5 hp; 15 percent is standard in larger sizes. The *NEMA* practice on rating adjustable speed d-c motors is defined in the Glossary at the end of the chapter.

The control for the adjustable speed motor consists of the addition of a field rheostat for speed control to the equipment specified for the constant speed motor.

*Adjustable Varying Speed** motors are d-c motors in which the speed is varied by the addition of resistance in series with the armature. The speed of the motor by this means is always less than the rated full field

*Refer to Glossary at end of chapter.