Table 1 . . . . Reasonable Horsepower Design Limits for Standard Motor Voltages

Power Supply	Standard Motor Voltage	Suggested Minimum Horsepower	Suggested Maximum Horsepower
Alternating 1-phase	115	None	1
	230	None	15
Alternating 3-phase	110	None	15
	220	None	200
	440–550	1	1000
	2300	50	6000
	4000	100	7500
	4600	250	8000
	6600	400	None

ventilation using an external blower; or (*d*) a small frame with Class B or H insulation permitting higher temperature rise.

2. *Speed Range.* Where more than one speed or a range of speeds is required, one of the motor types listed in Table 2 may be applicable, depending upon the power supply and the speed range required.

3. *Horsepower Requirement.* The horsepower required by the driven machine determines the motor rating. Where the load varies with time, a horsepower vs. time curve will permit determination of the peak horsepower required. The calculation of the root-mean-square (rms) horsepower indicates

Table 2 . . . . Speed Ranges for Various Types of Motors

Power Supply	Type	Speed Range
Single-Phase a-c	* Brush-shifting repulsion motor	3:1
	* Capacitor motor with tapped winding	2:1
	Multi-speed capacitor motor	2 or 3 fixed speeds
Poly-phase a-c	Multi-speed squirrel-cage	2, 3, or 4 fixed speeds
	* Wound-rotor motor	2:1
	* 2-speed wound-rotor motor	4:1
	Brush-shifting shunt motor	20:1
	* Brush-shifting series motor	3:1
	Squirrel-cage motors with variable frequency supply	Very wide range
	Motor-Generator Set—D-C Drive Motor	Very wide range
	Rectifiers—D-C Drive Motor	Very wide range
d-c	Shunt-wound standard *constant-speed* motor with field control	2:1 in some cases
	* D-C motor with armature control	Wide
	Adjustable-speed motor	From 3:1 to 6:1
	Shunt motor with adjustable-voltage supply	Very wide

* Speed regulation relatively wide. Unsuitable for some loads.

the proper motor rating from a heating standpoint. In case of extremely large variations in load, or where shutdown, accelerating, or decelerating periods constitute a large portion of the cycle, the rms horsepower may not give a true indication of the equivalent continuous load. The motor manufacturer should, therefore, be consulted.

Where the load is maintained at a constant value for an extended period (varying from 15 min to 2 hr, depending on the size), the horsepower rating required will usually not be less than this constant value, regardless of other parts of the cycle.

If the driven machine is to operate at more than one speed, the horsepower required at each speed must be determined.

4. *Torque.* The torque required to operate the driven machine at every moment between initial breakaway and final shutdown is important in determining the type of motor. A torque-speed curve is desirable and sometimes essential.

The *starting torque* or breakaway torque required by the driven machine may be as low as 10 percent, as in the case of medium-sized centrifugal pumps, or as high as 225 to 250 percent of full-load torque, as in the case of a loaded reciprocating two-cylinder compressor. The breakaway torque may vary greatly at different times because of frequency of start, temperature changes, type and amount of lubricant, *etc.* The motor torque available at the shaft must be well above the torque required by the driven machine, taking into consideration these variables as well as the possibility of low voltage and the type of starter used.

The torque required after breakaway for *acceleration to full speed* varies with different driven machines, remaining at a rather high value throughout acceleration for such machines as loaded compressors and plunger pumps. The torque delivered by the motor must at all points, up to full speed, be in excess of the torque required 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:

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

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 on full voltage 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 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

$$[(\text{rpm of rotating member}) \div (\text{rpm of motor})]^2 \qquad (2)$$

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.

ALTERNATING-CURRENT MOTORS

Alternating-current motors are divided into two main classifications: *polyphase* and *single-phase* (see Table 3), according to the type of power supply. They are further subdivided by type of motor winding.

When polyphase power is available it is usually found more economical to apply polyphase motors in preference to single-phase motors. A typical 5 hp, 1200 rpm capacitor-start induction-run single-phase motor, for instance, will cost approximately twice as much as the corresponding three-phase *Design B* squirrel-cage motor. In addition, the polyphase motor has the advantage of higher efficiency.

Polyphase Motors

The three types of polyphase motors are: *squirrel-cage induction* motors, *wound-rotor induction* motors, and *synchronous* motors.

Squirrel-cage motors are specified by NEMA standards providing a variety of speed and torque characteristics. *Design A* motors provide normal starting torque at starting current in excess of *Design B* motors, and are suitable for constant speed application to equipment such as fans and blowers. *Design B* motors provide normal starting torque with NEMA starting current values shown in Table 4, which are acceptable by many power companies for full voltage starting. They are used for the same type of application as *Design A. Design C* motors provide high starting torque with starting current same as *Design B*, and are used on compressors started without unloaders, and on reciprocating pumps. *Design D* motors have high slip* and are used with flywheels for widely pulsating loads on equipment such as reciprocating compressors and pumps where other motors would draw high peak currents. *Design F* motors have low starting current and low torques. They are used on power systems of limited capacity. Careful application must be made since the low breakdown torque provides only limited safety margin for overload or low voltage conditions. A drop in voltage, for instance, could cause the motor to stall.

Figs. 1 and 2 illustrate the characteristics of squirrel-cage motors. The motor operates under load from near synchronous speed at light load to about 95 percent synchronous speed at full load. Overloads decrease the speed further until the maximum torque point is reached. If the load torque exceeds this point the motor will stall. The motor torque varies as the square of the voltage. If the voltage drops 10 percent, the motor torque will be only 81 percent of rated value. Both power factor and efficiency are improved if the motor is operating as near rated load as possible. In addition, as shown in Fig. 2, power factor and efficiency are better for higher speed motors.

Hermetically-enclosed polyphase a-c motors are now quite generally used with large centrifugal compressors. The motors are built into the compressors and are cooled by circulation of refrigerant through the motor windings or by circulation of condenser cooling water through the motor housing. In either case, the cooling is excellent and the motor can deliver more power than if it were air-cooled.

Wound-rotor motors are used for applications requiring high starting torque at low starting current, because a wound-

*Refer to Glossary at end of chapter.

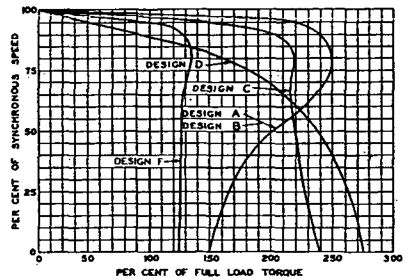

Fig. 1 . . . . Speed Torque Characteristics of Squirrel-Cage Motors

rotor motor with its controller and resistance can develop full load torque when starting with about full load current. For comparison, a squirrel-cage motor would require from 3 to 5 times as much current to develop full load torque at starting. The wound-rotor motor is also used for varying speed service to drive fans, blowers, and other continuous duty apparatus.

The addition of resistance to the secondary winding of the wound-rotor motor changes the speed torque characteristics. The motor speed, with the resistance added, is dependent on load, and consequently, the motor has very poor speed regulation when secondary resistance is added to reduce the speed

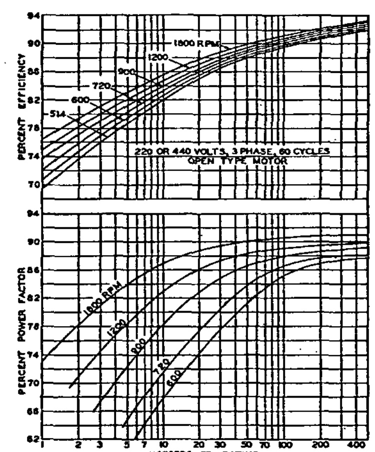

Fig. 2 . . . . Efficiencies and Power Factors for Squirrel-Cage Induction Motors