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

motors are satisfactory for short periods of vertical operation where no thrust is involved.

If shaft is *tilted* for momentary operation, special construction of bearing housings will be required for oil-ring-lubricated sleeve-bearing motors, to avoid loss of lubricant. In case of long periods of tilted operation, bearings suitable for end thrust may be necessary. Ball-bearing motors with grease lubrication are suitable for tilted operation.

Most motors are suitable for mounting with base above a horizontal shaft or to one side of the shaft, provided the end shields are rearranged. If, during operation, the angle of the motor (with regard to the horizontal shaft) changes more than 10 or 12 deg, a ball-bearing motor will usually be required. Sleeve-bearing motors are also applicable within the angle given if modified oil gages are provided.

On portable machines, motors of greater compactness and less weight than standard may be required, and special bearing construction may be needed, except for ball-bearing motors. Direct connection should always be considered where machine speed coincides with available motor speed.

Maintenance, efficiency, power factor, space and initial cost, will determine the choice between *direct connection* and other methods, such as *belt*, *chain* or *gear* drive. When direct connection is possible (where parts of the driven machine, such as shaft or bearings, are common with the motor structure) a *built-in* construction may be advantageous.

Belt Drive. Diameters and widths of pulleys or sheaves and center distances are factors in determining motor-bearing pressures and shaft deflection. Flat belts should not run at greater speeds than about 5000 fpm. Application of flat belting to vertical-shaft motors is difficult.

Chain Drive. The chain manufacturer should be consulted so that the best drive on a basis of quietness and economy of operation may be selected.

Gear Drive. Compactness and arrangement of drive often indicate *gear motors*, which are obtainable in a variety of mechanical constructions with speed ratios of 3 to 1 upwards, and are generally limited to about 75 hp maximum. Where the pinion of ordinary spur gearing is mounted on the motor shaft, two-bearing motors

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.

are limited in horsepower ratings. Maximum pitch-line speed with steel pinions is about 1400 fpm.

The selection of the motor part of a *gear-motor* is the same as for a conventional motor.

Space limitations may affect the choice of motor and require (a) built-in construction; (b) a gear-motor; (c) forced ventilation using an external blower; or (d) a small frame with Class B 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 the proper motor rating from a heating standpoint. In case of extremely large variations in load, or where shut-down, 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, and 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 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