Motor/Gearmotor Selection and Application

Until now we have concerned ourselves with motor theory, operation and construction. But like any machine, motors never operate under theoretically ideal conditions. Therefore, when choosing a motor for an application, specific information about the tasks it is to perform must be known and evaluated. Application parameters such as speed, torque, drive train, duty cycle, operating environment, safety requirements, noise factors and thermal protection must all be evaluated against the type of motor being considered and its performance ratings.

This Chapter will focus on how motors and gearmotors are rated and then discuss various methods used to select and adapt motors to meet specific environmental requirements. With this information, the reader will have a better understanding of how to choose the right motor for a given application in order to assure efficient operation and required service life.

7.1 MOTOR AND GEARMOTOR INDUSTRY STANDARDS

In Chapter 5 on motor construction, we discussed the various types of motors and insulation systems as defined by the National Electrical Manufacturers Association (NEMA). NEMA has established the rating procedure for the U.S. motor industry in order to ensure safe optimum operating conditions for motors and generators. NEMA standards, in part, conform to other industry standards established by the American National Standards Institute (ANSI), the Institute of Electrical and Electronic Engineers (IEEE) and the National Fire Protection Association (NFPA).
This standardization allows for maximum interchangeability between motor types produced by different manufacturers. Conformance to the standards assures the motor customer that certain minimum guidelines are in effect for products produced by member companies.

Other organizations have also established standards for motor design to ensure safe operation and conformance to local electrical codes. In the United States, Underwriters Laboratories (UL) develops safety standards for motor enclosures, thermal protectors and controls. Similar standards have been established in Canada by the Canadian Standards Association (CSA).

In Germany, national standards are approved by the Deutsche Institute für Normung (DIN) in conjunction with the International Electrotechnical Commission (IEC). Additional safety test specifications are also established by the Verband Deutscher Elektrotechniker (VDE).

The International Organization of Standardization (ISO) has also set standards

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Fig. 7-1: Common industry standards for electric motors.
for international units of weight and measure, called the Système International d’Unités or SI (metric) system.

Figure 7-1 lists various design and safety standards which apply to fractional horsepower motors and gearmotors.

As mentioned previously, most standards organizations work with others to assure a level of consistency and continuity with their standards. It is beyond the scope of this Handbook to list every standard that is applicable to electric motors. In many cases, the ones listed in Fig. 7-1 contain references to other standards on which they were based. A list of industry associations and testing organizations is also provided in the Appendix. Most of these organizations publish an index of their respective standards.

7.2 MOTOR AND GEARMOTOR NAMEPLATE RATINGS

An electric motor or gearmotor nameplate is an extremely important source of information regarding the capabilities and limitations of the machine. Care must be exercised to operate electric motors and gearmotors in conformance with the ratings expressed on their nameplates.

In other words, the manufacturer will indicate on the nameplate the conditions under which it is felt the product can be operated safely while giving optimum service. See Fig. 7-2. Any variation from these operating condition specifications may cause damage to the motor or gearmotor and create potential safety hazards to personnel.

NEMA defines three basic classes of electric motors for the purpose of rating: general purpose, definite purpose and special purpose. We will consider general purpose motors first, since they constitute by far the largest segment of electric motors.

Rating General Purpose Motors

A general purpose motor is not restricted to any specific application, but is suitable for “general use” under usual service conditions. Usual service conditions, as defined by NEMA, were discussed in Chapter 5, Section 5.5. General purpose motors have standard ratings and provide standard operating characteristics and construction features.

Fig. 7-2: Typical motor and gearmotor nameplates.
The Motors and Generators Standard (MG-1), published by NEMA, defines the various physical and performance characteristics which apply to these motors.

A general purpose motor is designed to develop a certain amount of power while operating continuously within safe temperature limits. The basis for rating, therefore, is a rated power output within prescribed winding temperature limits when operated for an extended period of time under usual service conditions.

The rated horsepower and speed stamped on the nameplate are those values nominally expected at rated power input. Likewise, at the rated power input, the nameplate temperature will not be exceeded when delivering rated load.

The amount of output power that can be developed in a motor is limited by the losses in the motor, resulting from transforming the electrical input into mechanical output. These losses are exhibited in the form of heat, and any attempt by the motor designer or user to increase the output of a motor beyond practical limits will produce excessive losses resulting in a temperature rise beyond safe limits. If the designed rated load or established safe torque of a motor is exceeded on an application, higher operating temperatures and/or premature failure will usually result.

Every motor has a maximum temperature limit dictated by the class of insulation material used in the motor windings, and a maximum ambient temperature listed on the nameplate. These maximum limits should not be exceeded. (See Chapter 5, Section 5.4.) For example, a motor with Class “A” insulation is designed for a maximum continuous winding temperature of 105°C in a maximum ambient temperature of 40°C.

Operation for prolonged periods in overload conditions or high ambient temperatures (above 40°C) will shorten motor life. The rule of thumb is that for each 10°C above the rated maximum temperature, the life of the insulation system will be approximately halved.

Furthermore, prolonged operation at excessive temperatures will have a detrimental effect on the mechanical components not associated with the windings. That is, the life of seal materials and lubricants will be similarly decreased.

The output power capacity of a motor is given on the nameplate in terms of horsepower or watts and is the product of torque, speed and a constant. The formulas are:

\[ \text{Power (horsepower)} = \text{torque (oz-in.)} \times \text{RPM} \times 9.92 \times 10^{-7} \]

\[ \text{Power (watts)} = \text{power (horsepower)} \times 746 \]

\[ \text{Power (watts)} = \text{torque (newton-meters)} \times \text{RPM} \times 0.105 \]

Typical standard horsepower (watts) ratings for fractional horsepower motors are 1/20 (37.3), 1/12 (62.2), 1/8 (93.2), 1/6 (124.3), 1/4 (186.5), etc. Ratings below 1/20 hp (37.3W) are sometimes classified as “subfractional” and are often rated in millihorsepower (for example, 2 mhp instead of 1/500 hp).

In addition to horsepower, the motor speed is usually shown on the nameplate. With horsepower (watts) and speed information, the rated torque can be calculated with the equation(s) above. Some standard 60 Hz fhp AC motor speeds are: 3450, 1725, 1140 and 850 RPM. These are for relatively constant speed drives. The corresponding synchronous speeds for 60 Hz AC motors are 3600, 1800, 1200 and 900 RPM.

If a motor has a gearhead, the output shaft torque rating is usually expressed in terms of torque and takes into account gearhead efficiencies and motor and gear train capabilities. With gearmotors, the motor horsepower should be regarded as primarily a
reference parameter, and the nameplate safe output torque rating should not be exceeded to assure personnel safety and gearmotor life.

Generally, both AC and DC general purpose motors will operate under slight variations in power source voltage and frequency (as described by NEMA), but may not provide the output values defined at rated voltage and frequency.

For some motors, NEMA also defines other operating characteristics for each horsepower and speed rating such as: breakdown torque, starting torque, locked rotor current and allowable speed variations.

NEMA standards do not cover all conditions or all motors, especially in the sub-fractional ratings. In these cases, reputable manufacturers make a practice of paralleling as closely as possible the standards for listed NEMA ratings.

**General Purpose AC Motors:** A general purpose AC motor, as defined by NEMA, is an open construction motor with a service factor rating. The service factor is a multiplier which is applied to rated horsepower to establish a permissible “overload” horsepower under defined conditions (see NEMA MG-1 paragraph 14.36 et al.). The standard fhp motor service factors listed by NEMA range from 1.25 to 1.40. A motor with no service factor indicated on the nameplate is understood to have a service factor of 1.0.

Most U.S. single-phase voltages are 115 and 230 V. Since the standard frequency in the United States and Canada is 60 Hz, this value would be indicated on the nameplate of all motors sold in those countries. In Western Europe, the nameplate would list the European standard of 50 Hz, usually at 220 or 240 V.

**General Purpose DC Motors:**
The basis for rating fhp DC motors includes a “form factor” (ff) value. See Chapter 8, Section 8.5. If the direct current supplied to the motor is very close to pure DC (low ripple), its form factor will be 1.0. As ripple increases, the form factor increases. A fractional horsepower DC motor is not intended to be operated continuously from a power supply that produces a form factor (at rated load) which is greater than the rated form factor. The user should also be aware that the form factor of unfiltered rectified AC and SCR type power supplies changes as a function of the output torque and speed of the motor. Operating a motor continuously at rated load with a form factor greater than rated will cause overheating and may have an adverse effect on commutator and brush life.

DC motors are often used in variable speed applications, which means they may be called on to operate at speeds lower than rated for extended periods of time. There is no consensus among standards organizations that a general purpose DC motor should be capable of operating at reduced speeds (particularly if equipped with a ventilating fan), or at a standstill with only the field energized, without excess temperature rise. It is important, therefore, that the user obtain from the manufacturer information concerning the capability of the particular DC motor under the aforementioned conditions.

In the past, common DC voltages were 115 and 230 V for motors operated from low ripple (1.0 form factor) generator-type power supplies. With the advent of efficient solid-state devices, a 90 V armature and 100 V field became popular for motors operated from an unfiltered, full-wave rectified 115 V supply. Similarly, a 130 V armature and 100 V field are popular for motors operated from filtered, full-wave rectified controls. The form factor will depend upon the particular motor and control combination and may vary by manufacturer.
Rating Definite and Special Purpose Motors

The basis for rating definite and special purpose motors is essentially the same as for general purpose motors. That is, ratings are based on developing a certain amount of power while operating within safe temperature limits (on specific power supplies) to provide long or expected motor life. The differences that do exist are due to differences in the types of applications.

For example, motor operation for definite or special purpose duty is not necessarily assumed to be continuous, as in the case of the general purpose motor; the duty cycle may be intermittent. Also, the output of a definite or special purpose motor is not necessarily expected to be a certain torque at a certain speed—starting torque may be the most important requirement (for example, as in a torque motor).

**Definite Purpose Motors:** A definite purpose motor is designed for use in a particular type of application, or for use under service conditions other than usual. In some instances, definite purpose motors have standard ratings and provide standard operating characteristics and construction features.

The NEMA Motor and Generator Standard, MG-1, lists the performance and construction requirements for certain definite purpose motors (oil burner motors, fan and blower motors, sump pump motors, instrument motors, etc.).

Allowable variations in voltage and frequency, and the proper application of belts, chains and gear drives, are also defined for usual service conditions. Unusual service conditions like those listed in Chapter 5, Section 5.5 must be considered.

**Special Purpose Motors:** A special purpose motor or gearmotor can be considered a one-customer motor. Special purpose motors are developed when an OEM (original equipment manufacturer) defines the operating characteristics or construction features of the required drive such that a general purpose motor cannot be used. Therefore, the motor supplier must design a special motor to meet the OEM design specifications.

A special purpose motor, unlike the general purpose motor and definite purpose motor, may not have standard operating characteristics or standard mechanical features. It is designed for a particular customer’s application, which has not evolved to the point that an industry standard can be written.

Although special purpose motors are not usually catalogued, the basis for rating remains much the same. The motor is again designed to develop a certain output while operating within safe temperature and mechanical limits. Unique circumstances may exist (for example, operating on an intermittent basis). When applied intermittently, a motor may be “beefed up” (a much stronger winding provided without the danger of overheating the motor). For example, high starting torques and faster motor response can be provided for servo and torque motor applications not previously obtainable under continuous duty operation.

It should be noted that NEMA defines the usual ambient service condition as a maximum of 40°C. This is why 40°C is used for “maximum ambient” nameplate rating purposes for general purpose motors. In the case of definite and special purpose motors, the maximum ambient may be only 25°C. The permissible temperature rise of the motor can then be higher without exceeding the maximum recommended insulation temperature. Thus, a stronger motor can usually be supplied if it is known that the ambient is less than usual. Conversely, a higher than normal ambient would restrict
the motor output and may dictate a higher class insulation system and special lubricant and seal materials.

A special purpose motor may even be designed for shorter than normal life, because the motor (as used in the equipment) need not last longer than the equipment. Also, it is sometimes more important to satisfy other requirements such as size and power output at the expense of long life. The choice, of course, is determined by the application after a careful review of all the parameters with the customer.

IMPORTANT≡≡≡≡≡Since definite and special purpose motors are designed for specific applications, they should not be indiscriminately used on other applications. They usually will give satisfactory service only in the application for which they were designed.

Rating fhp Gearmotors

Currently, there are no industry standards for fractional and subfractional horsepower gearmotors. Consequently, there has been a lack of agreement between manufacturers on gearmotor output shaft speeds, mounting methods, life vs. torque ratings and other criteria. Each manufacturer uses a different set of rating conditions.

Before any standard gearmotor ratings can be established, certain conditions for satisfactory performance must be set by the manufacturer. These criteria consist of application particulars and construction features which will ultimately affect the life of a gearmotor.

Duty cycle, ambient temperature, application load characteristics, gear materials, and bearing and gearing lubricants all contribute to the gearmotor’s actual life. When comparing manufacturers’ ratings, one of the most important factors (usually not published) is expected gearmotor life at nameplate rated load. Furthermore, the design of the gearmotor involves material and component selection that optimizes its performance properties for a given application. For example, a gearmotor rated at 60 lb-in. of torque output, based on an expected life of 500 hours, could be totally unacceptable in an application which requires 40 lb-in. torque load for 2000 hours.

Expected life is a function of gearmotor design, manufacture and loading. However, tests and experience have proven that the type of gearhead lubricant is an important variable in assigning a life expectancy to a small gearmotor. Typically, grease-lubricated gearmotors are rated to perform satisfactorily (under normal operating conditions) for one year (2000 running hours). Oil-lubricated gearheads are generally rated for satisfactory performance for 5,000 to 10,000 hours at nameplate torque. Also, in recent years, the use of greases approaching the consistency of oil have enabled gearheads to have a life expectancy between 2000 and 8000 hours at rated torque.

Gearmotor Output Torque Rating: For standard gearmotors, the torque rating shown by the manufacturer represents a complete gearmotor rating and reflects the capacity of the weakest link or most limiting gearmotor component. Some of the design limitations considered are: motor input power, strength or wear rating of the gearing, radial and / or thrust capacity of the bearings, and rotor, armature and shaft strengths. Obviously, gearmotor torque ratings should not be exceeded.

For some built-to-order gearmotor applications, a manufacturer may incorporate nonstandard gear materials to provide high shock load capacity on an intermittent basis. In such instances, the nameplate rating of the gearmotor will usually not be increased above its rated value for standard construction since the addition of
nonstandard materials does not always increase the long-term performance of the motor.

**Gearmotor Output Speed Rating:** The speed value shown on the nameplate is established by one of the following methods:

a) For constant or relatively constant speed motors (generally motors with 6% or less speed regulation with respect to load, such as: permanent split capacitor, split-phase, polyphase or synchronous types), the output shaft speed is determined by dividing the rated motor speed by the gear ratio.

b) For variable speed motors (more than 6% speed regulation, such as: series, shunt and induction motors with high slip rotors), output speed rating is determined as follows:

**Case I: The gearmotor is “motor limited”**. In this case, the gearhead has more than sufficient capacity to transmit the rated motor torque. Rated motor speed is divided by the gear ratio.

**Case II: The “package” is “gearhead limited”**. In this case, the gearhead cannot transmit the full rated input torque provided by the motor. The actual speed provided by the motor when the gearhead is loaded to capacity is determined experimentally.

**Note:** Allowance must be made for seal friction if a seal is used on the input side of the gearhead. After the specific motor input speed required to drive the gearhead at its capacity has been determined (which will always be equal to or greater than the motor’s rated speed), it is then divided by the gear ratio. It should be understood that the speed at which a variable speed gearmotor actually operates in a particular application is a function of the load and its uniformity.

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**Hazards of Operating at Other Than Nameplate Values**

Nameplate values stipulate the limits at which a motor or gearmotor can safely operate. To operate the motor either over or under the nameplate rated limit can have adverse effects on motor performance and safety. Some of the restrictions and associated consequences of ignoring them are listed below.

1) **Do not operate motors at voltages beyond ± 10% of nameplate rating.** Higher voltages produce adverse effects on motor temperature, noise and vibration, operation of current-sensitive relays, motor life and capacitor life, and could create nuisance operation of thermal overload protectors. Lower voltages create starting problems with current-sensitive starting relays and could cause thermal overload protectors, with internal heating coils, to trip at winding temperatures which exceed the maximum allowable limits.

2) **Do not operate motors on a nominal power source frequency other than that specified on the nameplate.** With the exception of brush-type motors, motor speed will vary directly with frequency. While it is understandable that original equipment manufacturers would seek to design a machine that operates on several different frequencies, any decrease in speed due to lowering frequency may have an adverse effect on temperature and on the proper operation of centrifugal cutout switches and relays. At higher frequencies, the torque capability is reduced, and starting relays may fail to engage the auxiliary winding. Motor laminations (and the windings installed in them) are specifically designed for operation at nameplate frequency. For
example, the laminations for 60 Hz motors are considerably different than those used for 400 Hz motors. Moreover, motor manufacturers usually do not laboratory test at frequencies more than 5% from that shown on the nameplate. Since the amount and type of noise and vibration emanating from a motor will change directly with frequency, undesirable hum and other resonance effects are quite likely with deviations from nameplate frequency.

Dual frequency (50/60 Hz) motors can be provided by manufacturers, usually at output ratings lower than the standard for a given frame size.

3) **Do not drive a load in excess of nameplate rating.** Where nameplate rating is in horsepower or watts, the rated torque can be readily computed by mathematical equations (relating speed, torque and power). Overload limitations also apply to gearmotors where maximum gearhead torque is shown. Technical assistance should be requested from the manufacturer if overloads are anticipated. Operation at higher torque loads can result in lower speeds, higher winding temperatures, reduced life of windings, gears and bearings, and nuisance operation of thermal overload protectors. In many cases, overloads can create hazards to personnel. Noise and vibration also increase with excessive loading.

4) **Do not operate permanent split capacitor motors at light loads.** An inherent characteristic of permanent split capacitor motors is that they generally run hotter at very light loads than at rated loads. To prevent PSC motors from running “too hot”, they should be matched to the application with respect to load.

5) **Do not exceed nameplate ambient temperature.** Lack of air intake, obstructions to the ventilation flow, and excessive deviations from the nameplate parameters will result in excessive motor temperatures. Operating at excessive temperatures will reduce the motor life, and in general, result in decreases in motor torque and speed. High temperatures may also result in nuisance operation of thermal overload protectors, and motor start failures where current-sensitive relays are employed. These hazards can be avoided by ensuring that the application provides adequate ventilation for the motor.

6) **Do not indiscriminately change the value of capacitance.** This parameter applies mainly to permanent split capacitor motors. Motor start capacitors, used with split-phase motors, are normally specified to achieve maximum starting torque and/or minimum locked current and deviations are not usually made by the user. Changing to a higher value of capacitance will increase the starting torque and in some cases, speed. It can also introduce hazards such as: higher winding temperatures, shortened motor life, nuisance operation of thermal overload protectors, and increases in the level of noise and vibration. The voltage rating of the applied capacitor must also be capable of handling the voltage it experiences during operation. Problems may be encountered with safety testing laboratories (UL, CSA, etc.) if the applied capacitor differs from the value specified on the nameplate. Always obtain assistance from the motor manufacturer when evaluating the proposed deviation and explore the possibility of changing the nameplate rating or developing a more satisfactory motor design.

7) **Do not subject the motor to duty cycles for which it was not designed.** Continuous (cont.) or intermittent (int.) duty, as stamped on the nameplate,
indicates the designed mode of operation for the motor and is generally based on the motor’s insulation system class and the power (watts) that the motor must dissipate as heat when energized. Adverse effects can develop from operating a continuous duty motor in an application requiring a high rate of starts and stops, or from operating an intermittent duty motor continuously.

Generally, an adverse deviation in duty will result in higher winding temperatures with a shortened motor life and the possibility of nuisance operation of thermal overload protectors. Increased frequency of starts could result in failure of electrolytic motor start capacitors and a reduction in the life of motor starting switches or relays.

In summary, a motor is designed to provide satisfactory operation and long trouble-free life when operated in accordance with its nameplate specifications. The motor user should develop an awareness of the hazards that could result from any deviation from these performance characteristics, and if deviations are anticipated, the motor manufacturer should be consulted.

7.3 NOISE AND VIBRATION

Noise, quite simply, is objectionable sound. The human ear responds to two different characteristics of noise—volume (loudness) and frequency (pitch). The noise characteristic of most concern in motor operation is frequency, since motor noise can be very annoying (even at low volume) when its frequency is irritating to the ear. Objectionable vibration and noise differ only in the way they are transmitted. Vibration is transmitted by the motor structure to surrounding parts while noise is transmitted by the surrounding air. The causes of motor noise and vibration can be separated into two general groups: mechanical and electrical. We will discuss mechanical causes first, since their effects are more obvious.

**Mechanical Noise**

Mechanical noise is usually a result of bearings, fans or gear trains. Some of the noise is inherent and can be minimized but not eliminated.

Another source of noise is the result of unbalanced rotation. Most motor manufacturers take precautions to balance internal rotating parts during production. The end user must take precautions to assure that motor loads are balanced. Besides noise, unbalanced rotation can cause premature wear of bearings and shafts which can shorten motor life.

**Dynamic Unbalance:** Dynamic unbalance is caused by the nonsymmetry of the rotating member with respect to mass. Lack of uniform wire spacing in a wound armature, nonuniformity of rotor material or attached fan assembly, or eccentricity of the shaft can all cause relatively noticeable unbalance. In fractional horsepower motors, balance can be corrected to within thousandths of an ounce-inch by dynamic balancing. Standard balance limits are established by manufacturers based on motor type, weight of the rotating member and motor speed.

Special tolerance balancing is also possible, but seldom necessary, after other noise and vibration-causing factors are checked and corrected. An easy way to check for dynamic unbalance, in some motors, is to bring the motor up to speed and then disconnect it from the power source. If vibration is still present during coasting, the problem is likely to be mechanical dynamic unbalance.

**Ball Bearings:** Bearing noise is very closely related to bearing speed and preload. Preload refers to an axial force
applied to a ball bearing to eliminate “rattling” of unloaded balls. This is commonly achieved with spring washers of various configurations which act as the bearing’s outer race. The inner race is constrained axially by the shaft shoulder. The amount of preload necessary to produce minimum noise levels is amazingly low (below two pounds for most fhp motor ball bearings). Refer to Fig. 7-3. Noise-critical applications may require a preload feature consisting of an adjustment screw to transmit the axial force (preload) to the outer race of the ball bearing. See Fig. 7-4. A locking nut maintains the factory-set adjustment screw position.

Even with carefully manufactured and electronically inspected ball bearings, motor noise levels below 40 db are very difficult to achieve, and noise levels approaching 60 db are not uncommon. The slightest variations in ball bearing manufacture can have significant effects on noise level. For this reason, pronounced variations in noise levels (10 db or more) between seemingly identical motors is common.

**Sleeve Bearings:** Sleeve bearings have much lower inherent noise levels, making them the first choice if their load and service limitations can be met. The most frequent problem with sleeve bearing construction is control of thrust washer noise. The intermittent scraping sound from thrust washers is very difficult to control, and the use of a ball/thrust arrangement is often specified where absolute minimum noise is required.

Since sleeve bearings require clearance for proper operation (in contrast to preloaded ball bearings), they are sensitive to radial vibration, which is often experienced with a powerful motor operated at or near electromagnetic saturation, or with a high degree of dynamic unbalance. Under these conditions, and especially if high temperature thins the bearing oil film, “knocking” or “pounding” will occur in the bearing. The motor manufacturer will control shaft-to-bearing clearance tolerances more closely than normal when this condition is likely to occur.

**Fans:** Fans can be a major source of noise, even in low speed motors. Noise from air movement is usually very low in
frequency, at a point where the human ear is less sensitive. However, the swish or rumble of air passing through an exhaust opening can be very annoying. High speed fan design requires special attention to avoid a siren effect, and the fan blades must not be brought in close proximity to a stationary surface.

**NOTE:** Noise-measuring equipment should not be placed in direct line with substantial air flow, to avoid erroneous noise level readings.

**Gear Trains:** Gear trains may or may not contribute to overall noise levels, depending on the type of gearing and the precision with which they were made. Worm-type gearing, with its sliding contact action, is normally considered noiseless. If, however, it has a numerically low ratio with high input speed, even slight deviations from print tolerances can cause noise.

Helical gearing is also quiet because its overlapping teeth produce a smooth transfer of load from tooth to tooth. Spur gearing noise is usually the most difficult to control, especially if maximum ratio per stage of gearing is used. Under these conditions, the small number of teeth in contact at any one time causes a rather abrupt load transfer and resulting noise. This type of noise is worse under load, and generally increases in intensity as the load is increased.

An important factor with all types of gearing is the “backlash chatter” that can occur at very light loads. At light loads, even the slightest tolerance deviations in precision-made gearing will cause very slight momentary speed changes and resulting noise. Loading the gearing more heavily can eliminate the noise. Backlash noise in very lightly loaded gear trains, especially in numerically low ratios, should be considered normal. (In most cases the applied load is sufficient to load the gearing beyond the backlash noise point.)

**Electrical Noise and Vibration**

Although less obvious than their mechanical counterparts, electrical sources of noise and vibration can be just as disturbing. Most of the electrical sources of noise must be minimized at the manufacturing stage since they are directly related to the construction and design of the motor rather than its application.

**Saturation:** Over-saturation of magnetic circuits is one of the most frequent causes of excessive electrical noise and vibration. The magnetic path of any motor is designed to carry a certain amount of flux without undue magnetic stress. If the flux becomes excessive, it will not only result in increased flux leakage, but sets up excessive vibration-inducing stresses on the weakest portion of its path (usually the stator teeth) with a resultant increase in electrical noise and vibration.

**Distribution of Ampere Turns:** The quietness of motor operation is dependent not only on the strength of the field flux, but also on how it is distributed in the air gap. The ideal distribution is sinusoidal, with the windings (of induction motors) placed around the teeth of a slotted stator so as to produce a sinusoidal flux configuration. More stator teeth produce a more sinusoidal distribution pattern.

Permanent split capacitor type motors, which employ two windings for a more even flux distribution and a true rotating field, are inherently quieter in operation than split-phase start motors, running on one winding with a pulsating field.

**Air Gap:** The radial length of the air gap in induction motors has an influence on motor noise. The air gap in some motors can be increased to reduce noise. In general, larger air gaps are not desirable, since
they will have an adverse effect on motor efficiency. Larger air gaps for the purpose of noise reduction are restricted, therefore, to applications that can tolerate less motor output for a given motor volume.

Quieter operation of brush-type motors can be achieved by increasing or tapering off the air gap at the tips of the field poles. See Fig. 7-5.

Quieter operation of brush-type motors can be achieved by increasing or tapering off the air gap at the tips of the field poles. See Fig. 7-5.

Number of Stator Teeth and Rotor Conductors: There are only certain ratios or combinations of stator teeth and rotor conductors that will produce a quiet running motor. See Fig. 7-6. However, combinations which are optimum for quiet operation tend to sacrifice motor efficiency or torque output. For this reason (unless quietness is the most important factor), motor designs will always be a compromise between desirable motor noise and necessary output and efficiency.

Salient Pole Effect: Reluctance synchronous rotor cores are normally flattened or “notched out.” The areas where ferromagnetic material remains at the outer diameter of the rotor are called salient poles. During motor operation, these poles become areas of relatively concentrated magnetic force. The concentrated magnetic force in the salient poles makes such rotors more susceptible to magnetic imbalance, and closer tolerances must be maintained with regard to rotor position, concentricity and other magnetic symmetry considerations, in order to maintain quiet operation of reluctance-type synchronous motors.

By comparison, hysteresis synchronous motors are inherently quieter because of their nonsalient pole construction.

Number of Stator Poles: A basic stator lamination design is usually employed for all induction winding types of a given fractional horsepower motor frame, regardless of the specific operational speed desired. This is dictated by the number of stator poles wound into the stator lamination. The stator lamination geometry establishes the magnetic path for all winding types and is usually optimized for the most popular operational speed. Four-pole operation is most common. For a given horsepower output, when such a lamination is employed, the magnetic noise is usually less with a two-pole winding. When a four-pole stator lamination is used for six-pole operation, the higher flux density in the air gap generates increased magnetic noise per given hp output.

Frequency of Applied Voltage: Higher harmonics (multiples) of the line frequency are generated by all induction motors and are taken into account during lamination design. Conditions of near saturation or over-saturation magnify the harmonics and produce unwanted electrical noise. In general, the higher the line frequency, the more objectionable the electrical noise generated by the harmonics. At very low frequencies (below 25 Hz), harmonics may cause resonance effects in the motor frame, making it
necessary to use resilient mounting to dampen the vibrations.

**Skewing of Armature or Rotor Cores:** Quieter operation can be obtained when the rotating core is skewed as shown in Fig. 7-7. This permits the rotor conductors or armature winding to enter the magnetic field at an angle, reducing sudden variations in the circuit reluctance and minimizing vibration of the stator and rotor teeth. There are, however, practical limits to the angle of skew that can be used because of difficulties encountered in rotor or armature assembly. Consideration must also be given to the fact that skewing somewhat reduces the speed regulation and efficiency of a motor.

**Commutation and Amperes-Turns Ratio:** Quiet operation of a brush-type motor is dependent upon good commutation. To assure good commutation in wound field motors, a proper ratio of field amperes-turns to armature amperes-turns must be maintained. Motor brushes must be designed to ride smoothly and quietly, and hold sparking to a minimum. Good commutation also depends on the correct grade of brush material to permit an even commutator film build-up on the commutator and a resultant reduction in sparking.

**Armature Slots:** The number of armature slots of a brush-type motor has a direct relationship to the motor’s noise level during operation. A large number of armature slots is considered preferable, with an even number of slots being more conducive to smooth and quiet operation.

### Noise Control

In addition to measures taken by the manufacturer to ensure that motors run at minimum noise and vibration levels, there are several noise reduction procedures that can be followed by the motor user. The general approach to noise reduction can be divided into reduction of noise at its source and reduction of the airborne noise level.

The overall study of motor noise and vibration shows that in addition to the motor design itself, its use or application, its mounting and the presence or absence of sound absorbing or reflecting surfaces near the motor, each affect the measurable level of sound at the various frequencies generated by motor operation.

**Reduction of Noise at Its Source:** Before attempting to reduce noise “at the source” it is important that we understand the relationship between frequency and noise or vibration. This is probably the most overlooked aspect in noise reduction studies.

**Low Frequency Disturbances**

Mechanical low frequency disturbance is confined to rotor or armature unbalance which occurs at the rotational frequency of the motor. In the case of a 60 Hz, 1800 RPM motor, the rotational frequency is 30 Hz. This frequency is actually below the normal hearing range. However, vibrations generated by this frequency can excite audible resonant frequencies in other parts of
Fig. 7-8: Motor frame is coupled to mounting brackets via resilient material. The motor unless preventive measures are taken.

The most effective approach to minimizing the effects of low frequency disturbances is to use resilient mountings and couplings. See Fig. 7-8. Resilient elements such as rubber, felt, cork or springs can be placed under the feet or between the base and body of the motor. The ideal mounting is soft enough so that the natural frequency of the motor and the support system is lower than the minimum disturbing frequency. Because of other considerations (such as deflection of the mounting under load), the ideal mounting condition is not always obtainable. In general, it is best to use the most resilient mounting possible.

In those cases where vibration still presents a problem after resilient mounting, adding weight to the motor assembly may effectively reduce the vibration. For example, doubling the weight of a motor assembly can reduce the amplitude of the vibration by half.

An additional problem, often present in portable equipment, is the use of thin sheet metal panels as mounting surfaces. Thin walled structures can act as diaphragms with resulting “soundboard” effects. Some trial and error in the addition of stiffening members, or crimping, may be necessary to solve problems of this type.

Fig. 7-9: Recorded vibration trace of a typical fractional horsepower motor. (1800 RPM at 60 Hz.)

Generally, electromechanically sourced disturbances for a 60 Hz induction motor are stronger at 120 Hz and usually negligible above 500 Hz.

**High Frequency Disturbances**

The major sources of high frequency disturbances (in the range above 500 Hz) are caused by ball bearings and cooling fans. Brush noise can also be a factor in brush-type motors.

Ball bearing noise is usually the most troublesome noise disturbance in induction motors and almost always occurs in the 1000 to 4000 Hz range. See Fig. 7-9. Usually selecting motors with sleeve bearings will eliminate these problems provided it is compatible with the load requirements. Changing brush materials will help reduce brush noise but this should not be done without consulting the motor manufacturer. See Chapter 5, Sections 5.2 and 5.3. Airborne noise in this frequency range can be effectively lessened by the use of acoustic deadening materials.

**Reduction of Airborne Noise Level:** An increase in distance between the noise source and the listener, or merely changing the relative position of the source with respect to the listener, can serve to decrease the noise level.

Acoustical absorbing materials can be used to control and reduce the noise level. Such materials are very effective in
reducing high frequency noise. However, when acoustical absorbing materials are used, care must be taken to ensure that motor ventilation is not obstructed.

Almost any degree of reduction of airborne sound can be achieved through the use of a “total enclosure” or a combination of several enclosures. Although not as effective as total enclosures, barriers may be used to shield high frequency sound.

It is important to note that motor heating usually requires that total enclosures incorporate some means of ventilation. Carefully designed ventilation ducts, lined with acoustical material, will assure that the sound reduction provided by the enclosure will not be lost by sound transmission through the ducts while motor heat is being dissipated.

7.4 THERMAL PROTECTION

Since motor overheating and possible “burnout” of winding insulation materials is a major cause of motor failure, the effects of heat on motor parts have long been an important consideration in the design and construction of electric motors. No matter how carefully they are designed and applied, temperatures over the maximum allowed for a given insulation system may occur under abnormal conditions (see Fig. 7-11). Therefore, in applications where the load, line voltage, ambient temperature, duty cycle, form factor, etc., are likely to change and result in excessive motor temperature, the addition of some type of thermal protection device is advised.

Thermal protectors are available in a wide variety of designs for specific functions, but all employ some type of sensing device which monitors motor temperature and automatically switches the machine off when a designated temperature level has been reached. These temperatures are based on the class of insulation used in the motor. See Chapter 5, Section 5.4.

**Thermal Protection Devices**

A motor properly designed for the maximum normal load requirements of a specific application will provide the user with the desired motor life, safety and reliability, as long as no abnormal condition arises to increase motor heating. While the causes for abnormal conditions such as increase in the motor load, low or high line voltage, contamination of lubricants, jamming of the driven device, etc., are numerous, the end result is the same—overheating and possible motor insulation breakdown. While the breakdown of the motor insulation system may result in immediate failure of the motor, the underlying cause—overheating—is less detectable. This is especially true with fractional horsepower motors, which are usually “buried” or mounted within an external machine enclosure. Overheating for prolonged periods will create degradation of the insulation system, and bearing and gear reducer lubricants as well. Both types of degradation result in a reduction of normal motor life.

The National Electrical Code (NEC) is one basis for determining whether thermal protection is required. (UL, CSA, VDE and other safety regulatory agency requirements are also factors.) The NEC dictates that a separate overload device (thermal protector) integral with the motor or motor impedance protection shall be provided for a continuous duty motor (one hp or less) if the motor is:

a) automatically controlled,
b) manually started out-of-sight of the motor,
c) manually started and permanently installed,
d) manually started and over 125 volts, and
e) manually started and operated on a branch circuit where branch circuit protection exceeds 20 amperes.

Intermittent duty motors are treated separately. The reader should refer to the latest edition of the Code to avoid any misunderstanding of the subject. Other safety controls are also considered in the Code.

As indicated by the NEC, there are various means by which the motor can be prevented from operating at excessive temperatures. Current-sensitive fuses (usually selected by the appliance or machine manufacturer), special motor design to provide high impedance (commonly referred to as impedance protection), and the use of devices that are sensitive to motor temperature or a combination of motor current and temperature, can be used to give this additional protection.

Temperature-sensitive protectors or thermostats commonly consist of a bimetallic disc, which will cause a normally closed set of contacts in series with the motor winding circuit to open if temperature exceeds a specified level. The difference in the rate of expansion between the two metals, when exposed to heat, causes the disc to change from a concave to a convex shape with a snapping action (opening the contact and de-energizing the motor). These thermostats are capable of being calibrated to specific temperatures, usually within ±5°C.

For motors operated from controls, the bimetallic contacts will activate a logic circuit which disables the motor. The control circuit may provide braking and may even prevent the motor from being automatically re-energized after cooling.

The type of thermostat commonly referred to as an “in-the-winding” or “on-the-winding” protector is shown in Fig. 7-10a. These types may be located in the stator winding slot or winding end-turns. The “on-the-winding” thermostat will automatically reset when the motor has cooled sufficiently. Certain appliances could result in a safety hazard to the operator if automatically re-energized. Therefore, they should not be equipped with automatic reset-type protectors.

A manual reset-type protector, equipped with a reset button that must be depressed before the motor is re-energized (even though the motor has cooled), can be mounted to the motor enclosure. The primary limitation of temperature sensitive protectors is that the mass of their enclosures causes a “thermal lag” which prevents the following of rapidly rising temperatures found under locked rotor conditions in some motor types.

Motor manufacturers also employ protectors which are sensitive to both the motor current and temperature. These protectors (Fig. 7-10b) are designed for placement in the motor enclosure and are available in both manual and automatic reset construction for single or three-phase motors. Basically, these protectors are similar

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Fig. 7-10a: In-the-winding type thermal protectors.

Fig. 7-10b: In-the-enclosure type thermal protectors.
to the thermostats, except that a heater coil is placed in the proximity of the bimetallic disc and connected in series with the disc and motor circuit to rapidly activate the protector under high motor overloads and locked rotor conditions.

Therefore, in the application of a current-temperature sensitive protector, it is essential that consideration be given to the motor operating current and temperature (with respect to the ultimate trip temperature of the protector) and the locked rotor current of the motor (with respect to the short trip time of the protector). The availability of ultimate and short trip time curves from protector manufacturers has greatly simplified the proper mating of protector to motor.

A successful mating is accomplished through analysis of motor, application and protector characteristics. Premature or “nuisance” trip-outs of the protector during normal operation are as intolerable (though less damaging) as failure to prevent the motor from reaching destructive temperatures. It should be obvious that the proper matching of a protector and motor is a tailoring process involving a significant amount of testing.

UL standards UL-519 and UL-547 define the locked rotor and running

<table>
<thead>
<tr>
<th>UL Requirements</th>
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<tbody>
<tr>
<td>1. Maximum acceptable overload and locked rotor temperature limits (thermocouple method).</td>
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</table>

A. Thermally Protected Motors (UL-547)

<table>
<thead>
<tr>
<th>Maximum Temperature</th>
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</thead>
<tbody>
<tr>
<td>Class A</td>
</tr>
<tr>
<td>Running Overload:</td>
</tr>
<tr>
<td>140°C</td>
</tr>
<tr>
<td>Locked Rotor:</td>
</tr>
<tr>
<td>Class A</td>
</tr>
<tr>
<td>a. Automatic Reset:</td>
</tr>
<tr>
<td>200°C</td>
</tr>
<tr>
<td>1) During 1st hour</td>
</tr>
<tr>
<td>2) After 1st hour</td>
</tr>
<tr>
<td>200°C</td>
</tr>
<tr>
<td>1) During 1st hour or 10 cycle (whichever is shorter)</td>
</tr>
<tr>
<td>2) After 1st hour</td>
</tr>
<tr>
<td>150°C</td>
</tr>
</tbody>
</table>
| B. Impedance-Protected Motors (UL-519)

<table>
<thead>
<tr>
<th>Maximum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
</tr>
<tr>
<td>Locked Rotor:</td>
</tr>
<tr>
<td>1) During 1st 72 hours</td>
</tr>
<tr>
<td>2) During 15 day test</td>
</tr>
</tbody>
</table>

*Multiple windings individually monitored.

Fig. 7-11: UL-acceptable overload and locked rotor temperature limits for thermally protected and impedance-protected motors.
overload temperature limits for impedance-protected and thermally protected motors. Refer to Fig. 7-11. These temperatures, which represent maximum limits for motors employing thermal protection, are higher than those normally allowed for a particular insulation class because they are only expected to occur for short durations under abnormal conditions.

A motor properly designed to meet the load requirements of an application would normally operate under much lower temperatures (based on its class of insulation). The maximum acceptable continuous duty temperatures are specified in either UL-1446 for the type of insulation system employed or in the applicable end use standard for the specific product in which the motor is being used.

Although we are still faced with the threat of abnormal conditions attributed to the causes mentioned earlier, plus the never-ending uniqueness of machine operators in creating “improbable situations,” the use of thermal protectors in motors will provide greater assurance of safe, reliable operation and long life of electric motors.

7.5 ENERGY MANAGEMENT

Proper selection, application and maintenance of electric motors is essential to an effective energy management program. With increasing shortages and higher costs, energy management is becoming increasingly important. It is crucial to mankind from the standpoint of conservation of natural resources, energy independence and energy availability. As part of a system, electric motors play a significant role in total energy consumption. However, they cannot be considered alone and are only one of many factors in the analysis of an entire system.

Users and specifiers of electric motors must now, more than ever, understand the proper selection, application and maintenance of drive components. Reprinted below are excerpts from the NEMA Energy Management Guide for the Selection and Use of Polyphase Motors (NEMA No. MG-10) and the NEMA Energy Management Guide for Selection and Use of Single-Phase Motors (NEMA No. MG-11). Contact NEMA for more information.

Efficiency

The efficiency of a motor is the ratio of its mechanical output to its electrical input. It represents the effectiveness with which the motor converts electrical energy into mechanical energy. The efficiency of a motor is a function of the load, horsepower rating and speed, as indicated below.

1) A change in efficiency as a function of load is an inherent characteristic of motors. Operation of the motor at loads substantially different from rated load may result in a change in motor efficiency.

2) Generally, the efficiency of motors, as measured at rated load, increases as the motor horsepower rating increases. That is, large motors are inherently more efficient than small motors.

3) For the same horsepower rating, motors with higher speeds generally have a higher efficiency at rated load than motors with lower rated speeds. This does not imply, however, that all apparatus should be driven by high speed motors. Where speed changing mechanisms, such as pulleys and gears, are required to obtain the necessary lower speed, the additional power losses of the mechanisms may reduce the efficiency of the system to a value lower than that provided by a direct-drive lower speed motor.
A definite relationship exists between the slip and efficiency of an induction motor (the higher the slip, the lower the efficiency) because slip is a measure of the losses in the rotor winding. Under steady load conditions, squirrel cage induction motors with less slip should be used, if the application permits.

Slip of an induction motor is expressed (approximately) in the following equation:

$$\% \text{ Slip} = \frac{N_{NL} - N_{FL}}{N_{NL}} \times 100$$

where: 
- $N_{FL}$ = Full load speed 
- $N_{NL}$ = No load speed

The efficiency of a multi-speed motor at each operating speed is somewhat lower than that of a single-speed motor having a comparable rating. Single-winding multi-speed motors are generally more efficient than two-winding multi-speed motors. Significant energy savings may be possible by operating at low speeds where possible, and at high speeds only when necessary.

Motors which operate continuously or for long periods of time provide a significant opportunity for reducing energy consumption. Examples of such applications are processing machinery, air-moving equipment, pumps and many types of industrial equipment. A small change in motor efficiency can make a significant change in total energy consumed per annum, due to the lengthy operating time.

While many motors operate continuously, some motors are used for very short periods of time and for a very low total number of hours per year. Examples of such applications are valve motors, dam gate operators and industrial door openers. Thus, a change in motor efficiency would not substantially change the total energy consumed since very little total energy is involved.

Viewed from a motor losses standpoint, a modest increase of a few percentage points in motor efficiency can represent a significant decrease in percentage of motor losses. For example, for the same output, an increase in efficiency from 75% to 78.9%, from 85% to 87.6% or from 90% to 91.8% may each represent a 20% decrease in motor losses.

For two similar motors operating at the same specified load but having different efficiencies, the following equation can be used to calculate the savings in operating costs when using motor A rather than motor B:

$$S = (0.746)(hp)(C)(N)(\frac{100}{E_a} - \frac{100}{E_b})$$

where:
- $S$ = savings (dollars per year) 
- $hp$ = horsepower rating of the specified load 
- $C$ = energy cost (dollars per kilowatt hour) 
- $N$ = running time (hours per year) 
- $E_a$ = efficiency (in percent) of motor A at the specified load 
- $E_b$ = efficiency (in percent) of motor B at the specified load

The equation applies to motors operating at a specified constant load. For varying loads, the equation can be applied to discrete portions of the cycle where the load is relatively constant for a reasonable increment of time. The total savings are the sum of the savings for each load-time period. This equation is not applicable to motors operating on pulsating loads or on loads which cycle at rapidly repeating intervals.

**Motor Losses**

An electric motor converts electrical energy into mechanical energy incurring losses which are described here in general terms (for a more accurate explanation of losses, see IEEE Test Codes 112 and 115). These losses are converted into heat, causing the temperature of the windings and other motor parts to rise.
Electrical Losses (vary with load): Current flowing through the motor winding produces losses which are approximately proportional to the current squared times the winding resistance ($I^2R$). Similar losses result from current flowing in the squirrel cage of an induction motor.

Iron Losses (essentially independent of load): These losses are confined mainly to the laminated core of the stator and rotor. The alternating magnetic field, essential to the production of torque in the rotor, causes hysteresis and eddy current losses that increase with frequency.

Mechanical Losses (independent of load): Mechanical losses occur in the bearings, fans and brushes (when used). In open, low-speed motors, these losses are small. However, they may be appreciable in large, high-speed or totally enclosed, fan-cooled motors.

System Efficiency

Since the system efficiency is the combination of the efficiencies of all of the components of the system, good energy management requires a consideration of the total system of which the motor is a part. Typical factors to be considered are covered below.

Motor Rating: The optimum motor rating necessary to handle the load should be determined. Where the load is constant, the appropriate motor rating is readily indicated. A close matching of motor and load generally optimizes the economic considerations. Moreover, the selection of a motor rating adequate for the load is important to avoid unnecessary losses which consume energy and might overheat the motor. The use of motors having an output rating excessively greater than the load causes a reduction in the system power factor, with resultant added losses in the distribution system.

Application Analysis: When the driven machine provides a widely varying load involving a number of stops and starts, a careful analysis of the application can result in savings in energy. Operating conditions such as starts, plug stops, reversals, some forms of braking, etc., all consume energy at rates much higher than when the motor is operating continuously at a rated load. When variable duty cycles are encountered, two actions can be taken to minimize energy usage. The first is to reduce the mass of the moving parts wherever possible, because energy used to accelerate these parts is proportional to the mass or inertia.

Secondly, all aspects of the load should be carefully analyzed. This should involve consultation with the motor manufacturer for recommendations. Motors which are designed for high full-load efficiency may not be suitable for applications involving frequent starting, intermittent duty operation and repetitive pulse loading.

Process and Machinery: The most efficient process and machinery should be selected. Frequently, alternate means are available for doing a job, and a variety of machines often exist that are capable of performing the task. Once these determinations have been made, the appropriate motor rating and design type consistent with system economics can be specified.

First Cost vs. Long-Range Energy Costs: For variable and multi-speed drives, the first cost and long-range energy costs should be carefully evaluated because such systems vary widely in first cost and in operating efficiency, (i.e., the choice of multi-speed or adjustable speed motors as compared to throttling control), or the choice of a high-speed motor with speed reduction as compared to a low-speed motor.
Maintenance

Because the electric motor generally needs little maintenance, it is often neglected. Proper care of the motor will prolong its life and will conserve the material which would be needed for replacement if it fails prematurely. A basic motor maintenance program requires periodic inspection and, when encountered, the correction of unsatisfactory conditions. Among the items to be checked during inspection are: lubrication, ventilation and the presence of dirt or other contaminants which form a heat transfer barrier, alignment of the motor and load, possible changing load conditions, belts, sheaves, couplings, and the tightness of the hold-down bolts.

Sometimes, additional friction develops within the driven machine as a result of a dust build-up on the fan, wearing of parts, misalignment of gears or belts, or insufficient lubrication in the driven machine. These conditions cause the driven machine to become less efficient by making the motor work harder, thus reducing system efficiency and increasing energy consumption.

All motors should be provided with proper overload protection at the time of their initial installation. If the protective device should trip, the cause should be determined immediately. Increasing the trip rating of the protective device should be avoided because it may:

1) conflict with the National Electrical Code,
2) permit overheating of the motor,
3) waste energy,
4) mask the problem, and
5) create hazards to personnel.

To ensure continued efficient operation and long motor life, a regular schedule for inspecting motors and driven equipment should be established.

7.6 LOAD TORQUE MEASUREMENT

In order to determine the size of a motor or gearmotor to optimally drive a given machine, a host of variables must be known. Perhaps the most significant of these is the torque or turning force needed to rotate the machine shaft from standstill through the different stages of its operating cycle.

Torque requirements may vary depending on the machine. In some inertial load devices, maximum torque is required at the start to bring the machine up to speed, while the necessary running torque is a fraction of the starting requirement.

Other machines such as a printer may start with no load applied, and at some point later in the cycle, clutch in the maximum load. See Fig. 7-12. In this application, the average torque must be sufficient to drive the machine without noticeable decreases in drive speed when peak loads are seen by the drive. If the machine can stop at peak load, the drive starting torque must be sufficient to start the peak load. Because these kinds of variations exist, one must know starting and running torque as well as peak loads occurring in the machine cycle. In some cases it is not practical to measure peak requirements, and average running torque must be given.

Whenever possible, it is extremely useful for machine designers to supply the motor manufacturer with load diagrams like that illustrated in Fig. 7-12. Such load vs. time graphs are valuable in selecting a

Fig. 7-12: Load diagram for a machine that starts at essentially no load, with peak loads occurring later in the cycle.
motor with the best set of performance characteristics for a given application.

In making a final load requirement diagram, it is important to consider not only the load cycle itself, but any anticipated changes that may occur over the life of the machine. Most machines will tend to “loosen up” after a break-in period, while some (particularly those in hostile environments) may actually “tighten.” Obviously, the load diagram should reflect the most demanding torque condition of the machine.

NOTE: This discussion concentrates on the determination of torque requirements. Other factors are important in final drive selection, and the Application Guidelines outlined in Section 7.8 should be reviewed before the final selection is made.

There are three principle means by which torque can be measured:
1) the “string and pulley” method,
2) the torque wrench method, and
3) the “test” motor method.

**The String and Pulley Method:**
Affix a pulley to the shaft of the machine to be driven. See Fig. 7-13.

**Fig. 7-13: Simple string and pulley torque measurement method. (Torque = force reading on scale x radius of pulley.)**

**Fig. 7-14: Typical torque wrench.**

Secure one end of a cord to the outer surface of the pulley and wrap the cord around it a few times. Tie the other end of the cord to a spring scale (like those used to weigh fish). Pull on the scale until the shaft turns. The force, in pounds indicated on the scale, multiplied by the radius of the pulley (in inches) gives the torque or twisting effort in pound-inches (if the scale is read in ounces, the result will be in ounce-inches).

Depending upon the application and if used carefully, this method is often successful in determining both starting and running torque. The spring scale reading, when the pulley begins to turn, indicates starting force. If a long enough string can be used, an indication of the average running torque can be obtained. When the torque characteristics of the machine vary in different parts of the operating cycle, the starting torque must be determined at the point where the motor or gearmotor will “see” the highest resistance (torque) to starting.

**Torque Wrench Method:** A simple torque wrench can also be applied to the shaft of the machine to be driven. See Fig. 7-14. Turn the wrench as you
would an ordinary pipe wrench, and when the shaft begins to rotate, read the value (in ounce-inches or pound-inches) on the torque wrench gauge. The observed value represents the torque required to start the machine.

This method is generally limited to measuring starting torque or peak torque since it is unsafe and difficult to continuously rotate a torque wrench.

"Test" Motor Method: Both AC and DC test motors or gearmotors can be used to measure a machine’s starting and running torque. This method requires more time and instrumentation, but can be well worth the expense in the long run. It is the best way to optimally match the machine and drive unit, and is popularly used for all high volume OEM applications.

Whether AC or DC drives are used, the method is basically one of experimenting with an “oversize” drive at reduced power levels, recording the experimental readings, and then bench-testing the drive to determine the torque that was being produced at the recorded readings. The method is actually a variation of dynamometer testing a machine (the test motor is, in reality, a substitute dynamometer).

AC Method: Use a torque wrench or “string and pulley” to find the approximate size of the test motor or gearmotor needed. An AC motor or gearmotor whose rated output speed is close to the desired “final” speed of the machine should be obtained. Next, connect the AC drive, powered by a variable autotransformer to the load as shown in Fig. 7-15.

With a voltmeter connected to the line, increase the voltage supplied by the autotransformer until it starts and accelerates the load up to speed. (To check the speed, use a tachometer or stroboscope.) Record the starting voltage at all possible starting locations of the device. Next, back off slowly until the motor breaks down. Read the voltage and supply the data and the test motor (gearmotor) to the manufacturer.

DC Method: The DC method, utilizing a permanent magnet DC motor, provides the experimenter with more latitude in that the speed of the device can be varied. This can be an advantage if the “final” speed of the machine has not yet been decided and experimentation is desired for optimizing.

The DC method requires the measurement of the test motor input voltage and current once the desired operation of the load is achieved. Speed of the DC motor is proportional to voltage while torque is proportional to the current. For maximum accuracy, the actual test motor should be sent to the manufacturer with the voltage, current and speed information for dynamometer testing. The minimum starting torque should also be supplied.

7.7 MOTOR SIZING

While determining the maximum torque requirement for a potential application is important, many other performance characteristics may affect machine operation at different stages of the operating cycle.

The motor speed / torque curve should be examined to determine if the load can be started and accelerated to running speed. When the time accelerate the load...
is a specified requirement, additional acceleration torque must be available in excess of the needs to overcome friction. It is also important to be sure that the motor selected can cope with peak load requirements. The curve shown in Fig. 7-16 contains the basic speed/torque information for a typical AC squirrel cage, nonsynchronous motor.

7.8 APPLICATION GUIDELINES

Proper application of any motor or gearmotor requires careful preliminary planning. The factor which most often determines the success or failure of a motor-driven device is the initial care exercised in matching the load characteristics of the machine to be driven with the performance characteristics of the motor to be used as the driving member. A motor too large or too complex is unnecessarily expensive to purchase and operate, while a motor too small may fail to drive the load under all conditions to be met in the normal course of the application.

The characteristics chart shown in Fig. 7-17 provides a good general guide to the selection of a proper motor with respect to electrical type, but many other factors must be taken into consideration before the final selection is made.

Unfortunately, some of the more important factors are not always apparent and may be recognized only by an applications engineer having years of small motor design experience.

Supplying Application Data

Unnecessary communications, loss of time, excessive development and experimental costs, and repeated trial and error can often be avoided if a machine designer supplies the motor manufacturer with complete application data before the design of a driven machine reaches the detailing stage. Figure 7-18 shows a typical application data sheet provided by motor manufacturers to assist product designers in supplying all information necessary for motor selection. Since this selection process is critical, we will consider each point individually.

1) Product to be Powered? What kind of machine is it and what kind of work will it be expected to do? (For example, main drive for an office copier, reel drive for a magnetic tape deck, etc.)

2) Estimated Quantity? Is the production run to be large or small? This
question is asked because the feasibility of some alternative solutions may depend upon the quantity projected.

3) **What Does the Motor Drive?** The first question defines the end product. This question determines how the motor or gearmotor is related to the operation of the machine. The function of the motor may take on many forms. In its simplest form, the motor may be directly coupled to the load (as in a grinding wheel in a lathe attachment). On the other hand, the motor may be the main source of power for several functions in a machine via chains, gears, belts, etc.

4) **Power Supply?** Since the power available to a plant has, in most cases, already been installed, this is a fixed factor. Here it must be known if AC or DC is to be used, and the line voltage or voltages available. Furthermore, if the source of power is AC, the frequency and number of phases must also be known. If the source of power is not pure DC, the form factor must be known. Sometimes there is a choice of

Fig. 7-17: Motor characteristics chart.
APPLICATION INFORMATION

Company _____________________________________________
Address _______________________________________________________
City ____________________________ state_______ Zip
Code________________________

Name__________________________________________Title_________________
Phone Number________________________Date____________

This form has been prepared to assist you in supplying us with the basic information required to propose a trial motor for your application. The success of the motor selected will depend upon the accuracy and completeness of the information you supply.

1. Product to be powered: ____________________________________________________________________

______________________________________________________________________________________________

2. Estimated quantity requirements: Initial order __________ First year ________________________________

3. What does motor drive?____________________________________________________________________

______________________________________________________________________________________________

4. Power supply: 115 V AC, 60 Hz ( ). _________________ Other ____________________________________

5. Fixed speed ______________ RPM. Allowable variation ______________________________________ %.

6. Variable speed (universal or DC motors only) ____________ to ____________________________ RPM.

7. Direction of rotation viewing drive end of motor or gearmotor: 
   CW ( ) CCW ( ) Reversible ( ) Optional ( )

8. Load requirements and conditions: Load data obtained from present practice ( ), estimated ( ), determined by 
   actual test ( ). If equipment was successfully driven by a Bodine or competitive motor, give complete 
   nameplate data.

   a) Continuous load _____________________________ torque.

   b) Intermittent load _____________________________torque.

   1) Maximum length of time at full load
   2) No-load running time _____________________________ Average time at rest
   3) Maximum momentary or peak torque

   c) Reversing service:

   1) Maximum reversals per minute __________________

   2) Must motor reverse while rotating? ( ) Or from rest? ( )

   d) Shock loads, if any. Describe _____________________________________________________________

   _____________________________

   e) Radial loading:

   1) Directly applied type: Indicate (by sketch on next page, No. 20) magnitude, direction, and point of 
      concentration of loads such as initial belt tension, supported weight, etc. Show front and side views.

   2) Reaction type: Indicate (by sketch on next page, No. 20) how motor is coupled to driven load, giving 
      pitch diameter of pinion, worm, sprocket or pulley, location on shaft, and direction of load. Show front 
      and side views.

   f) Axial loading: What is magnitude and direction of load? (Show by sketch on next page, No. 20). If worm 
      drive is contemplated, include complete worm data.

   g) Direct drive: If load is coupled directly to shaft, describe type of coupling employed __________________

   h) Is motor started under load? ________ If so, what is starting torque required? _______________________

   i) Is load of inertia (flywheel) type?

   j) Is time a factor in bringing load up to speed? __________________________________________________

9. Life expectancy of motor _____________ hours. (Motor life varies with operating and load conditions, and 
   duty. Normal duty is considered to be 8 hours per day, 5 days per week, or 2000 hours per year.)

10. How frequently will motor be serviced? (annually, quarterly, monthly, never)

   a) lubrication________________________________

   b) brushes___________________________________

   c) general cleaning ____________________________

Fig. 7-18: Application data sheet (continued on next page).
11. Space and weight limitations, if any ________________________________________________________

12. Motor mounting: Standard Floor ( ), Other ( ). Show by sketch (in space below, No. 20) if other than
standard floor mounting.

13. Temperature surrounding motor: Max. _____________________________ °F, Min. _____________________________ °F

14. Is equipment designed to provide adequate ventilation to motor? __________ How? __________

15. What is the condition of the air surrounding the motor? (dusty, gritty, humid, acid, explosive, etc.)
_____________________________________________________________________________________________

16. Shaft end play restrictions

17. Shaft dimensions if other than standard
   (If shaft features are complex, show by sketch.)

18. Electrical leads:
   a) Bodine standard acceptable ( ).
   b) Special material or length ( ). Describe ______________________________________________________

   c) Cord ( ). Describe, including type, length, plug or switch specifications, etc. __________
   d) Terminal box ( ).

19. Give additional requirements not covered by the above data such as UL, CSA, sanitary, municipal or
   military, braking, overload protection, degree of quietness, etc. (Describe fully) __________
   ______________________________________________________________________________________
   ______________________________________________________________________________________
   ______________________________________________________________________________________

20. Use this space for sketches as required.

_____________________________________________________________________________________________

Fig. 7-18: Application data sheet (continued from previous page).
there is a choice of currents and voltages. In situations involving unusual voltages or voltage fluctuations, high form factors, or unusual and varying frequencies, special care must be exercised in selecting a motor. The power source, therefore, must be fully defined and understood before proceeding.

5) **Fixed Speed? Allowable Variation?**
The answer to the first half of the question will usually establish whether a motor or a gearmotor is required. The variation allowable will establish the speed constant required; that is, if the motor is to be of synchronous or nonsynchronous type, or if tachometer feedback or openloop control is required.

6) **Adjustable Speed?** Universal (series wound), brush-type DC or brushless DC motors are usually indicated if adjustable speed is required. Brushless DC motors offer excellent speed regulation plus less maintenance and greater torque-per-motor frame size than brush-type DC motors. Series motors can be adjusted over a wide speed range by means of a rheostat, adjustable autotransformer or an electronic speed control. However, due to loss in torque with decrease in voltage, the practical speed range is usually limited. Shunt-wound motors and PM motors used in conjunction with SCR or similarly controlled power sources are better suited for applications requiring relatively constant (with respect to load) but adjustable, speed over wide ranges.

7) **Direction of Rotation?** The National Electrical Manufacturers Association (NEMA) has established that the standard direction of shaft rotation for all DC motors, all AC single-phase motors and all universal motors shall be counterclockwise when facing the end opposite the driveshaft.

Most motor manufacturers have adopted this designation, but some, including the Bodine Electric Company, have historically considered the direction of rotation of motor and driveshafts to be that which is seen when looking at the end of the shaft, and so indicate in their literature.

Since there is inconsistency between motor manufacturers, there is always the possibility of misunderstandings which can result in motors being wound for the wrong direction of rotation. To avoid this, when specifying the direction of rotation of unidirectional motors or gearmotors, always include a point of reference. For example, in the case of a single-shafted motor, a typical specification might read: “Rotation clockwise, facing end of shaft,” or in the case of a single-shafted gearmotor: “Rotation counterclockwise, facing the end of the driveshaft extension.”

Motors or gearmotors with multiple shafts present special communication problems. In these cases a point of reference should be the extension that is depicted as “standard” on the catalog dimension sheet. For example, in the case of a motor, the specification might read: “Rotation clockwise, facing extension at end opposite leads,” or in the case of a gearmotor: “Driveshaft rotation clockwise, facing end of left-hand extension.” Use of the sketch space under Item 20 in the application form (Fig. 7-18) will help to alleviate any possibility of error in complex cases.

8) **Load Requirements and Conditions?**
This question basically asks:
1) what is the power or torque requirement, and
2) how is it determined.

It is quite possible that the design engineer has determined the power requirements analytically or by some
mechanical means, accomplishing the latter by the string and pulley method (Section 7.6) or by actually powering the device with a test motor. If the load were determined by use of a test motor, it is probable that tests were run at rated voltage. There is always the possibility that the test motor developed more power than was actually necessary for the application and that a motor providing less power, and quite possibly less costly, would be adequate for the application.

This possibility can best be established by employing a variable autotransformer and measuring the minimum voltage required to start and drive the load. By means of a brake test on the same or an identical motor, one can then measure the torque developed at the minimum voltage and establish the magnitude of the actual load under starting and running conditions. There is a tendency for design engineers to specify their power requirements in terms of horsepower. It is better, in all cases, to establish the power requirements in terms of torque. This is especially true for gearmotor applications.

8a-b) Continuous Load or Intermittent Load? Once the magnitude of the load has been determined, we are ready to define the duty cycle as continuous or intermittent. By definition, a motor which continues to operate after it has reached normal operating (steady) temperature is operating under continuous duty conditions. Conversely, one which never reaches a steady temperature, but is permitted to cool between operations, is operating under intermittent duty conditions. Intermittent duty motors are given a time rating by the manufacturer. It can be seen, then, that the subparts of question 8a) take on vital significance since the answers determine the extent to which heat generated under load will be dissipated during the time the motor is operating at no-load or at rest.

8c) Reversing Service? It might seem at first that the only reason for this question is to select the winding type. While this is true, reversing service is also an important factor in the mechanical life of gearmotors, and in brush life of DC or series wound motors.

The reply to this question must be weighed with other information provided about the load to determine its relative importance. For example, if the load is inertial and must be reversed, it could produce excessive shock loads on the gear train, possibly necessitating a slip clutch on the output shaft to reduce the shock.

Basically, we should be concerned with the frequency of reversals, and whether the motor must reverse while rotating or from rest. In connection with the latter, there are some applications where the design engineer may specify “Motor must reverse in three seconds.” If this is specified, the inertia of the load must also be given. (See 8i.) One would then analyze feasibility of reversing with different kinds of motors. A sample motor may need to be built to determine if the requirement could be met.

8d) Shock Loads? It is important to establish if shock loads exist in the application. Although we all have an intuitive idea of what shock loading is, formulating a precise definition (without resorting to mathematical terms) is somewhat difficult, and long-term testing by the customer of a drive may be required to establish the suitability or fitness of a drive for the application.
Fig. 7-19: Typical applications imposing axial and radial loads.

The important aspect of all common definitions of “shock” is that they imply a degree of suddenness and severity. The combination of these two parameters will have immense consequence in determining the overall life of a drive system. When describing a shock load condition, it is imperative to state as accurately as possible (in terms of time) the degree of suddenness and (in terms of torque) the severity to which the motor or primarily the gearmotor will be subjected.

Running a drive against a stop is the one most commonly thought of shock condition. However, since shock loading is a matter of degree, the complete load requirements of the application must be studied. Loads which vary significantly and can be classified as shock loads should be described thoroughly (with a torque vs. time diagram, if possible). Common examples of more moderate shock conditions would be clutched inertia loads or cam loads. In the case of the clutch, the amount of inertia and the time of clutch engagement should be reported on the application form. For cam loads, a dimensioned sketch of the cam on the reverse side of the form and a description of the load will greatly assist the drive manufacturer.

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8e) Radial or Overhung Loads? These are loads which are applied in a direction perpendicular to the axis of the shaft. These may be directly applied as shown in Fig. 7-19, or reaction type as shown in Fig. 7-21. Examples of the first type are loads imposed by belt or chain tensioning and loads created by supported weights such as those found in hoist applications. Examples of the second type are loads which are developed when the shaft is coupled to the load through belt or chain drives or through external spur, helical, bevel or worm gearing.

A sketch, like the one in Fig. 7-20, should be used to describe the radial loads to be expected in an application. Figure 7-20 shows an application...
employing a belt and pulley coupling. Given the torque at normal operating speed (Item 8a of Fig. 7-18) and the pitch radius of the driving pulley, the driving force at the point of application can be calculated as follows:

\[ \text{Driving force} = \frac{\text{torque}}{\text{pulley pitch radius}} \]

and,

\[ \text{Driving force} = \text{tension 1} - \text{tension 2} \]

The overhung load to which the driving shaft will be subjected is determined by adding the total initial belt tension applied in a direction perpendicular to the axis of the shaft.

8f) **Axial or Thrust Loads?** These are loads which are applied in a direction parallel to the axis of the shaft. They may be directly applied as shown in Fig. 7-19, or the reaction type as shown in Fig. 7-21.

Axial fans or directly supported turntables and centrifuges are typical applications developing direct axial loads. Reaction type thrust loads are typically found in applications employing helical or worm gearing to couple the motor or reducer to the load.

In most cases, directly applied axial loads are those developed in applications where the motor or reducer shaft is vertical. In the case of plain motors, it must be known whether the shaft will be up or down, since the weight of the rotor must be taken into consideration. The thrust developed in gear reaction loads is the product of the driving force and the tangent of the external gear tooth helix angle. It is necessary, therefore, for the designer to provide information about the actual torque loading and details regarding the external worm or helical pinion in order for the axial load to be calculated.

8g) **Directly Driven Loads?** Properly aligned directly driven loads are those which present only “pure” torque loads to the motor or gearmotor driveshaft and its bearings. If radial or axial loads are present, they are carried instead by bearings in the equipment being driven, in which case the motor is usually coupled to the load by means of a flexible coupling to avoid alignment problems or, in some cases, to reduce shock.

Couplings usually employed for directly driven loads include steel sleeve, multi-jaw, jaw types with resilient inserts and universal joints. Each has its own unique characteristics and knowledge of the type of coupling to be employed is of value in determining if the motor will be properly applied.

8h) **Is the Motor Started Under Load?**

This section prompts a “yes” or “no” answer, but in some unusual cases, it might be answered “sometimes.” There are many applications where the motor normally “sees” little or no load at start but, at certain points in the load cycle, will experience maximum possible starting load. For example, in an electric typewriter application, the maximum load condition normally occurs when the carriage is being shifted. Should the operator turn the machine off, or should the power plug be inadvertently pulled at this load point, the motor must be designed to develop sufficient starting torque to overcome the load when the power is restored. For applications of this type, it is useful to obtain information as to load variations expected throughout the operating cycle.

The answer to the second part of the question (“If so, what is the starting torque required?”) should be a real number expressed in oz-in., lb-in., kg-in. (oz-in. is used in the metric system for axial loads, lb-in. is used in the U.S. customary system for axial loads, and kg-in. is used in the metric system for axial loads).
cm, n-m, etc. This can usually be determined by the string and pulley method. (Refer to Section 7.6.)

8i) Is Load of Inertia (Flywheel) Type? When the reply is “yes,” we should obtain information about the actual load inertia or \( W_R^2 \) (sometimes referred to as \( W_K^2 \)). If the information is

\[
W_T = \frac{T}{R} \\
P_O = t_1 - t_2 = T/R \\
P_T = 0 \text{ (assuming perfect alignment)}
\]

**NOTE**

If conditions do not permit exact measurements of \( t_1 \) & \( t_2 \), the following are generally accepted approximation factors:

- Chain: \( P_O = 1.0 \ W_T \)
- V-belt: \( P_O = 1.5 \ W_T \)
- Timing belt: \( P_O = 1.2 \ W_T \)
- Flat belt: \( P_O = 2.5 \ W_T \)
- Gear: \( P_O = 1.2 \ W_T \)

**NOMENCLATURE**

- \( W_T \) = Tangential force
- \( P_O \) = Overhung load (force)
- \( P_S \) = Separating load (force)
- \( P_T \) = Thrust load (force)
- \( R \) = Pitch radius (length)
- \( T \) = Torque (force x distance)
- \( t \) = Belt tension (force)
- \( \Psi \) = External gear tooth helix (zero for spur gear or chain drive)
- \( \alpha \) = angle of force \( W_T \) along line connecting shaft centers with respect to a defined datum line on a gearhead
- \( L \) = Distance from housing datum

**Fig. 7-21:** Method for calculating overhung and thrust loads on gearmotors: a) for driving belts and chains (top), and, b) for driving via external spur or helical gearing (bottom).
unavailable, it may be necessary to send the device to the motor manufacturer for testing.

Load inertia information is especially important if a salient pole synchronous motor is being considered as the rotary power source. The reason is that the “pull-in” to synchronism torque capability of the motor must be great enough to overcome the WR² or combined inertia of the motor and the driven load.

8) Is Time a Factor in Bringing the Load Up to Speed? This relates mostly to inertial loads which invariably use more power to start and accelerate to running speed than they do to keep running at full speed. The torque required to accelerate the load from stand-still to running speed varies inversely with the time allocated for acceleration. Therefore, it is necessary to know if there is any minimum time limit. If so, the limit should be specified here.

9) Life Expectancy of Motor (Number of Hours)? Life expectancy is extremely important in the selection of the best and most economical motor or gearmotor for the application. In addition to supplying information about total life expectancy in hours, it is important to establish the number of starts and the expected running hours over a given period of time.

An example of manufacturer standards for life expectancy under normal operating conditions are:

a) steady load with no shock,
b) continuous duty, eight hours per day, five days per week,
c) infrequent starts,
d) ambient temperature of 0°C to 40°C,
e) voltage to be within 10% of nameplate rating, and
f) frequency to be within 5% of nameplate rating.

In addition, altitude limits are sometimes specified or implied. The life of most motors may be greatly affected by any deviation from normal operating conditions.

Temperature is particularly important, as motor life expectancy is a function of total temperature. Insulation, lubricant and seals are all affected by temperature. This is illustrated by the following.

1) As a general rule, ball bearing or gear lubricant life is halved for every 25°F (approximately 14°C) increase in temperature. Heat will eventually degenerate most lubricants and seals, leading to leakage, increased friction and extra maintenance.

2) Generally, the motor insulating life is halved for each 10°C increase in total temperature. Therefore, it is apparent that temperature has a direct bearing on the life of a given motor. When considering life expectancy, we should cross-reference the following application considerations that directly affect the motor’s operating temperature:

a) bearings,
b) lubricants,
c) duty cycle,
d) radial load,
e) axial load,
f) mounting,
g) enclosure,
h) ambient temperature,
i) ventilation, and
j) electronic controls.

10) How Frequently Will the Motor be Serviced? Answers to this question in conjunction with information concerning life expectancy, duty and ambient temperature are important in selecting the best bearing and gear lubricant. Similarly, brush selection, in the case of series wound or DC motors, is dependent to a degree upon the service anticipated. If
cleaning is seldom or not expected, a totally enclosed motor may be necessary, depending on the environment.

11) **Space and Weight Limitations?** If space is limited, this becomes a very important consideration. Show the maximum space envelope (using a sketch) and indicate how and where the load should be coupled to the motor or driveshaft. The sketch should also show any space restrictions caused by interference with other components.

In analyzing an application’s space and/or weight limitations, the associated cost elements must be recognized. Here are a few general areas which might be affected.

a) Where a reduction in speed is needed, an integral speed reducer motor should be considered. By combining the motor and speed reducer in one unit, cumbersome and complicated speed reduction transmissions can be avoided. This alone may resolve the space problem.

b) If space and weight for the motor is figured too closely, a totally new redesigned special purpose motor may be required. This could involve extensive engineering and special tooling. One of the most frequent application mistakes is to ignore the potential need for more space to accommodate a larger motor if one is required at a later time.

c) If the design does not afford sufficient motor ventilation to keep the temperature rise within tolerable limits, a larger and more expensive motor may be required.

12) **Motor Mounting?** A sketch should be used if standard mounting cannot be adapted. The standard mounting Position is usually described in a dimension diagram supplied by the manufacturer.

In the “standard” position, the axis of the motor lies in a horizontal plane. For gearmotors in standard mounting position, the axis of the output driveshaft also lies in a horizontal plane. The choice of motor mounting may depend on motor design, operating conditions, space requirements and life expectancy. Factors to be considered include:

a) sleeve vs. ball bearings,
b) oil vs. grease lubrication,
c) ventilation,
d) care and servicing, and
e) special modifications.

In all sleeve bearing motor and/or gearmotor applications, the mounting must be specified. If the unit and/or the output driveshaft is rotated from horizontal to another position, almost without exception a different lubrication arrangement is required (sometimes at additional cost).

The nature of the differences will depend largely upon the choice of mounting and/or whether the application requires an oil-lubricated or grease-lubricated gearmotor.

Special lubrication arrangements can include new location of drain, fill, vent and level indicators, or special oil seals. Mounting the gearhead above the motor is not recommended and should be avoided because of the risk of lubricant leakage down into the motor if a seal fails or wears out. Lubricant leakage into the motor can cause motor failure with additional hazards to personnel and equipment.

13) **Temperature Surrounding Motor?** This is the “ambient” temperature and directly affects a motors life expectancy.
Most locations expose a motor to the normal operating range (0°C to 40°C or 32°F to 104°F). Temperatures above or below this range may create lubrication problems in both motors and gearmotors or insulation problems.

Temperatures lower than normal may require special considerations in order to provide adequate starting torque due to stiffening of bearing and gear lubricants. Also, a time lag may exist in reaching operating speed, which could affect the performance of the driven equipment.

Temperatures higher than normal present lubrication and sealing problems because of viscosity changes in the lubricant. In addition, the maximum operating temperature for the winding insulation system is established on the basis of the motor type and insulation class.

14) Is Equipment Designed to Provide Adequate Ventilation to the Motor?
A motor in a suitable ambient temperature may still overheat if the equipment confines the motor in such a way that its generated heat cannot be dissipated. The ambient temperature in close proximity to the motor should never exceed the nameplate value (normally 40°C).

A motor external to the equipment in a suitable ambient temperature is exposed to circulation of free air and normally would have adequate ventilation. A motor housed within the equipment needs ventilation. Depending upon the degree of confinement, circulating free air may be provided from vents in the equipment housing, or by forced ventilation.

15) What is the Condition of the Air Surrounding the Motor? Dust, grit, humidity and acid fumes can damage motors. Airborne particles may clog ventilation openings, preventing sufficient heat transfer. Moisture and fumes may deteriorate motor components. The answer to this question helps define the type of enclosure, environmental treatment, shaft materials and lubricants required.

Open, ventilated motors are suitable for clean, dry locations where cooling air is not restricted. Enclosed products are suitable for dirty, damp locations. For outdoor use, wash downs, etc., enclosed products must be protected by a cover while still allowing adequate air flow.

In open-type motors, sparking of starting switches in AC motors so equipped, and of brushes in commutator-type motors can be expected during normal operation. In addition, open-type enclosures may eject flame if the insulation fails. Therefore, avoid placing open-type motors, gearmotors, or controls in the presence of flammable or combustible materials.

Most totally enclosed products are not explosion-proof. Explosion-proof motors, gearmotors and controls should be used for hazardous locations (flammable/explosive gas, vapor, dust). When dealing with hazardous locations, an approved explosion-proof product is the recommended approach. Exceptions are allowed by the National Electrical Code. NEC and NEMA safety standards should be studied thoroughly before exercising this option.

Moisture increases the electrical shock hazard. Open-type motors should always be protected from moisture. Totally enclosed motors will reduce the hazard if all openings are sealed.
16) Shaft End Play Restrictions? Standard “end play” (or axial shaft freedom) of rotor (or armature) shaft and gearmotor driveshaft is controlled by the manufacturer during assembly. Some typical end play specifications are as follows.

On sleeve bearing supported shafts:
   a) Soft spacing washers limit motor and armature end play to within 0.005 to 0.020 inch.
   b) Reducer driveshafts are limited to within 0.005 to 0.020 inch end play by means of hardened washers of varying thickness.

On ball bearing supported shafts:
   a) The ball bearings of rotors or armatures are preloaded by means of spring-type washers to provide quiet bearing operation under cold and normal operating temperatures. This results in essentially no free end play of the shaft unless a sufficient axial force is applied.
   b) The ball bearings of the secondary shaft and the driveshaft of many gearmotors are spaced to a minimum of end play by flat steel washers of various thicknesses as required.

On needle bearing supported shafts:
   a) In this type of bearing, the drive shaft acts as the inner race of the bearing and consequently is similar in free end play to that of a sleeve bearing. The sections of the shaft in the journal area are hardened. End play is typically limited to within 0.005 to 0.020 inch by means of spacer washers.

In rare cases, requests are made for more closely held end play than standard tolerance for sleeve bearing supported shafts. Any limited end play requirement would necessitate special gauging fixtures for assembly and final inspection checking. It is not practical in production to space a sleeve bearing assembly to zero end play. In subfractional horsepower motors, added frictional losses resulting from a zero end play tolerance could mean the difference between success and failure. Additionally, within a short period of time (providing the motor does not overheat and fail), the washers or bearing faces will wear away and end play will develop regardless of precautions.

17) Shaft Dimensions if Other Than Standard? This detail on the application form causes little or no problem unless a designer wants a special feature such as a cross-drilled hole located “x” inches from the bearing hub or centered to something less than up to .006 TIR. The normal method of dimensioning the location of a cross-drilled hole, a cross-milled flat or the shoulder of a reduced diameter on a shaft extension is from the end of the shaft, and the normal tolerance is ± 0.005 inch (0.196 mm). Ball bearing supported shafts have no free end play and the normal tolerance of the extension is ± 0.032 inch (0.8 mm). When checking the length of a sleeve bearing supported shaft, the measurement should be made with the shaft pulled out. Under these conditions, the tolerance is the same as above.

18) Electrical Leads? This item offers a choice of connections from the motor to the power source. Popular lead materials generally consist of individually tinned copper strands. Insulation is polyvinyl chloride or x-linked polyethylene. If the designer requires something different, the number of strands and the
type and color of insulation should be included. Of course, the motor manufacturer’s standard leads are the most economical choice.

19) **Give Additional Requirements Not Covered by the Above Data Such as UL, CSA, Braking, Overload Protection, and Quietness.**

Considering the unlimited application possibilities involving small motors and gearmotors, it would be impossible to cover every application consideration in one questionnaire. This space provides information for any special requirements not covered in the form. A continuation sheet should be attached if needed. The following comments apply to some of the specific examples listed.

a) **UL, CSA, etc.** Many applications require compliance with one or more of these organizations’ standards. Their specific requirements should be made known to the motor manufacturer at the outset. At times, there are charges to the motor manufacturer for “third party” approvals.

b) **Braking** Frequently, the power transmission must be braked or stopped by some mechanical or electrical means. Complete data describing the method of braking required is essential (for example, frequency of braking time required to stop), and whether or not holding torque must be present after the motor has been stopped.

c) **Overload Protection** This may be a requirement of the testing or standards writing organization (as in No. 19a.) Four basic types of overload protective devices are normally used with fhp motors: fuses, overload relays, thermostats and inherent overheating protectors. See Section 7.4. Fuses and relays are sensitive to motor current only. Thermostat devices, usually in direct contact with motor windings, respond to temperature only. Inherent overheating protectors respond to the total heating effect whether it is caused by temperature alone, current alone or the combined effect of both. Caution must be exercised if “automatic” reset protectors are used = they can reset without warning and be hazardous to personnel.

d) **Quietness** - This is a complex problem including both mechanical and electrical design. See Section 7.3.

Although the foregoing is by no means a complete analysis of all the factors, it should provide a guideline for motor selection. It should again be stressed that the more time spent on this planning phase to provide the motor manufacturer with accurate, relevant information about the device to be driven, the easier it will be to match the right motor to the application.

### Applying fhp Gearmotors

When gearmotors are specified, there are many factors to consider in addition to those mentioned previously. This is due to the gearing and the effects it has on other parts of the system.

**Inertial, Reversing and Overrunning Loads:** Inertial loads with high reduction ratios often produce extreme torque multiplication between input and output shafts.
The motor and gearhead must be sized to sustain the torque developed when starting or stopping this type of load. Reversing an inertial load should be avoided unless the gearing is disconnected from the load, and the load braked before reversal.

Overrunning loads can be inadvertently imposed on the gearhead. For example, power failure or disconnect on an elevating device driven by a gearmotor can cause the load to drive the gearmotor in reverse. If backdriving of a gearmotor is contemplated, the manufacturer should be contacted since many gearheads can be easily damaged by backdriving.

Service Factors for Gear- ing: Service factors are correction factors which compensate for nonstandard load conditions and are applied to torque, overhung and thrust load ratings of gearing. These factors compensate for variable and shock loads. The service factors are not as well defined for gearmotors below approximately 1/8 hp as they are for larger units, and judgement should be exercised in their application. Unfortunately, there is no common agreement among small motor and gearmotor manufacturers to the magnitude of various service factors.

Service factors, developed through experience, are useful for estimating the severity of the actual duty, compared with average duty. The service factors (Fig. 7-22) as indicated for classes of service defined, are provided as application guidelines. They should be multiplied by the uniform steady, or average torque of the load resulting in “equivalent required torque.”

Equivalent required torque = service factor x uniform steady torque.

Equivalent required torque should not exceed rated torque of the gearmotor.

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>8 Hr.</th>
<th>24 Hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform Steady</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Light Shock</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Moderate Shock</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Heavy Shock</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Fig. 7-22: Service factors for various types of loads.

Figure 7-21 provides formulas for calculating overhung and thrust loads on gearmotors. The following application guidelines also apply to the classification of load type.

Uniform Load = A load which does not vary appreciably during operation or changes gradually. Blowers or chart drives would be in this category.

Moderate Shock = A load which varies significantly during operation or is applied rapidly. Clutched loads of low inertia or cam loads would likely be in this category.

Heavy Shock = A load which varies greatly in a relatively short time. Inertial loads braked or reversed through nonlocking gearing would be in this category.

Extreme Loads Not Covered = An impact load or high speed, high inertial load driven by self-locking gearing cannot be covered by service factors and must be referred to the motor manufacturer.

No matter how well a motor or gearmotor is constructed, improper application can result in poor performance or complete failure. The foregoing illustrates the proper approach in the evaluation of the load to be driven by a motor or gearmotor. To aid in the selection procedure, most manufacturers can provide a selection worksheet which serves as a convenient checklist for both the customer application engineer and the manufacturer.
The use of electric motors and generators is potentially hazardous. The degree of hazard can be reduced by proper design, selection, installation and use, but hazards cannot be completely eliminated. Hazard reduction is the joint responsibility of the user, the manufacturer of the driven or driving equipment and the motor manufacturer.

Many motors, gearmotors and speed controls are designed and manufactured to comply with applicable safety standards, and in particular with those issued by ANSI, NEMA, UL and CSA. In addition, many overseas standards are being followed. In particular, IEC (International Electrotechnical Commission) standards are gaining influence.

Furthermore, many products are “third party approved” with respect to construction. Motors, gearmotors and controls recognized by UL are designated with a code on their nameplates. The use of codes is unique to each manufacturer. Each manufacturer must be consulted as to the status of their “third party approval,” if any.

However, since even well-built apparatus can be installed or operated in a hazardous manner, it is important that safety considerations be observed by the user. With respect to the load and environment, the user must properly select, install and use the apparatus. For guidance on all three aspects, see Safety Standards Publication No. ANSI C51.1/NEMA MG-2*.

Selection

Before proceeding with the installation, the user should review the application to confirm that the proper drive has been selected. This should be done after thoroughly reading and understanding Section 7.8 and all applicable safety standards. If in doubt, contact the manufacturer.

Selections or application suggestions made in this Handbook are intended only to assist the reader. In all cases, the reader is solely responsible for determining a product’s fitness for application or use.

Installation

It is the responsibility of the equipment manufacturer or the person installing the motor to take diligent care in installing it. The National Electrical Code (NEC), sound local electrical and safety codes, and when applicable the Occupational Safety and Health Act (OSHA) should be followed when installing apparatus to reduce hazards to persons, other equipment and property.

Inspection

Examine the motor for damage from shipping before connecting. Do not attempt to turn the output shaft of a gearmotor with an externally applied torque arm.

Connection

Follow the nameplate for voltage, frequency and phase of power supply. See the accompanying wiring diagram for connections and rotation (and capacitor, if required). Make sure that the motor, gearmotor or control is securely and adequately grounded. Failure to ground properly may cause serious injury to personnel. (If the wiring diagram shipped with the drive unit is lost or missing, contact the manufacturer.)

Wiring

For wire sizes and electrical connections, refer to the National Electrical Code (NEC) article covering motors, motor circuits and controllers, and/or applicable local safety codes. If extension cords are used, they should be kept short for minimum voltage drop. Long or inadequately sized cords can cause motor failure, with hard starting loads when current draw is at its highest.

Before starting the motor:
1) Check all connections and fuses.
2) Be sure keys, pulleys, etc. are securely fastened. **Proper guards should be provided to protect personnel from hazardous rotating parts.**
3) Other mechanical considerations include proper mounting and alignment of products and safe loads on shafts and gearing. Do not depend on gear friction to hold loads.

When starting the motor:
1) Test-start the motor or gearmotor in an unloaded state. (Because of possible reaction torque, the drive should be securely mounted when started, even when unloaded.)
2) If the drive unit does not start promptly and run smoothly, disconnect it at once.
3) If you are unable to correct the problem, contact your purchase source or the manufacturer, describing the trouble in detail. Include the serial number, type and other nameplate data. Do not dismantle the product unless authorized by the manufacturer; removing screws voids many warranties.

Operating

The chance of electric shocks, fires or explosions can be reduced by giving proper consideration to the use of grounding, thermal and overcurrent protection, type of enclosure and good maintenance procedures.

The following information supplements the foregoing safety considerations. This information is not intended to be all-inclusive, and other applicable sections of this Handbook as well as local and national safety codes should be referenced and understood before operating electric motors.

1) Do not insert objects into motor ventilation openings.
2) Sparking of starting switches in certain AC motors, and of brushes in commutator-type DC motors, can be expected during normal operation. In addition, open-type enclosures may eject flame in the event of insulation failure. Therefore, take all necessary precautions to avoid, protect from or prevent the presence of flammable or combustible materials in the area of open-type motors, gearmotors and controls.
3) When dealing with hazardous locations (flammable or explosive gas, vapor, dust), make certain that an approved, explosion-proof or dust-ignition-proof motor is specified.
4) When dealing with any environment that is unusual such as high humidity, high altitudes, low humidity, exposure to weather, etc., make certain that the proper motor has been specified. Refer to Section 5.5 for environmental classifications of motors.
5) Moisture will increase the electrical shock hazard. Special care should be exercised whenever moisture is present to avoid electrical shock.
6) Products equipped with thermal protectors are required to be labeled “
Thermally Protected.” If severe overloading, jamming or other abnormal operating conditions occur, such heat-sensitive protectors operate to open the electric power supply circuit. Motors/gearmotors with automatic thermal protectors must not be used where automatic restarting of the drive unit could be hazardous, in that clothing or parts of the human body could be in electrical or physical contact with a machine that starts unexpectedly when the thermal protector cools down. “Manual reset” protectors or suitable electric supply disconnect devices/procedures should be used where such hazards could be created.

7) Motors/gearmotors which employ capacitors can develop more than nameplate voltage across the capacitor and/or capacitor winding (depending upon design). Suitable precautions should be taken when applying such motors.

8) Abnormal conditions, such as cut-out switch failure, or partial winding failure due to overheating, etc., can, on rare occasions, cause certain types of AC motors/gearmotors to start in a direction reverse from normal. The chances are highest when the motor’s rotor “sees” a relatively light load. One-way clutches or similar devices are advisable if such a remote risk is not tolerable in the intended application.

9) Some additional considerations in applying speed controls include:
   a) Chassis controls should be properly guarded or enclosed to prevent possible human contact with live circuitry.
   b) Individual manufacturer’s specifications should be checked, but in general, the ambient temperature should not exceed 40°C (104°F) for encased-type controls. For chassis-type controls, maximum permissible ambient temperature is usually 50°C (122°F).
   c) As in the case of motors/gearmotors, controls must be properly grounded to prevent serious injury to personnel.

**Maintenance**

Different motors require different types of maintenance and care. Specific maintenance requirements are outlined in Section 7.10.

For general safety purposes, however, the area around an electric motor should be kept free from dust and dirt or from obstructions which could interfere with proper ventilation.

In addition, before servicing motors or gearmotors employing capacitors, **avoid any contact with the capacitor terminals until it has been discharged.** The capacitor should be discharged in accordance with safety instructions provided with the motor. If instructions are not available, contact the motor manufacturer for more information.

**7.10 CARE AND SERVICING**

With the availability of new and better insulating materials and the extensive use of grease-lubricated (“lubricated for life”) ball bearings, quality electric motors have become more reliable and maintenance-free than ever before. However, in order to help obtain the best service from an electric motor, a few helpful guidelines are given below.

**IMPORTANT:** Before servicing or working on equipment, disconnect the power source. (This applies especially to equipment using automatic restart devices instead of manual restart devices, and when examining or replacing brushes on brush-type motors/gearmotors.)
Regular Inspection and Maintenance

Small motors usually operate with so little trouble that there is a tendency to neglect them. Wherever possible, most motors should be inspected twice a year to detect wear and correct any other conditions which might lead to excessive wear or premature failure. Special attention should be given to the following common causes of motor failure.

Changing Load Conditions: Sometimes additional friction develops gradually within the driven machine and thus imposes an overload on the motor which will cause overheating. Overload conditions should be promptly corrected. It is also important to protect motors with properly rated fuses. If overloads are likely, then an overload protector should be specified when selecting the motor. See Section 7.4, Thermal Protection.

Motor and Load Alignment: When the motor shaft becomes misaligned with its load, damage to both the shaft and the bearings can occur. In some instances, the driven machine may also be damaged.

Excessive Overhung Loads: Belt and pulley and other similar drives which subject the motor shaft to radial (overhung) loads must not be adjusted too tightly or placed too far out on the motor shaft. Otherwise, they can cause excessive bearing wear and/or shaft failure.

Excessive Axial Thrusts: Loads and couplings must be connected so that excessive axial pressure is not exerted on motor bearings that will cause premature failure.

Load Must Not Lock on Gear-motors: A torque-limiting clutch should be provided if there is a possibility that the output shaft might be locked or jammed.

Such locking quickly builds up tremendous forces within the gearhead, stripping gears or damaging other components. If a flywheel is necessary, consideration should be given to attaching it to the high speed motor shaft extension. If a flywheel or high inertia load is used on a slow-speed gear-motor shaft, it tends to keep the shaft turning after the motor has stopped, causing the same effects on a gearhead as locking the driven shaft.

Inadequate Wiring: When installing a new motor or transferring a motor from one installation to another, it is advisable to check the wiring. Adequate wiring (depending on the voltage, current, environment and distance from the power source) should be used to feed electrical power to the motor. (Consult the National Electrical Code.) Replacement of old, obsolete wiring will prevent future breakdowns and possible hazards to personnel.

Contamination: Next to overloading or abuse, contamination is probably the most common cause of motor failure. Ordinary dust and dirt can restrict ventilation and coat motor windings, cutting down on heat dissipation. This clogging can lead to continuous overheating and eventual insulation breakdown. Dirt can also cause wear in such moving parts as bearings.

Moreover, dirt which is electrically conductive in nature can cause grounding or shorting of motor windings. Contaminants can cause additional problems in motors having brushes and commutators or internal centrifugal switches. Therefore, if it is not possible to keep the motor reasonably clean, a totally enclosed motor should be considered.

Worn Brushes: Brushes are expected to wear, but they should not wear excessively. The wear rate of brushes is dependent on many parameters (armature speed, amperage conducted, duty cycle,
humidity etc.). For optimum performance, brush-type motors and gearmotors need periodic user-maintenance. The maintenance interval is best determined by the user. Inspect brushes regularly for wear. Periodically remove carbon dust from the commutator and inside the motor. This can be accomplished by occasionally wiping them with a clean, dry, lint-free cloth. Do not use lubricants or solvents on the commutator. If necessary use No. 0000 or finer sandpaper only to dress the commutator. Do not use solvents on a nonmetallic end shield or other motor parts if the product is so equipped.

Whenever a brush is removed for inspection, care should be taken to put it back in its original position. Changing brush alignment or position will result in poor contact between brush and commutator surfaces. This can cause excessive sparking with accompanying loss of power and damage to both the commutator and brushes. Brushes worn to a length less than 1/4 inch (7 mm) should be replaced with the same brush type.

Rapid wear of brushes is a symptom of trouble or misapplication. Rapid wear after a period of successful commutation may indicate that the commutator is badly worn. Resurfacing of the commutator may be necessary and should be performed by a qualified service shop or returned to the service department of the manufacturer.

**Lubrication:** Under normal operating conditions, the relubrication of sleeve bearings, ball bearings and gearboxes should be performed according to the manufacturer’s recommendations. Under more severe conditions (higher ambients or increased exposure to contaminants), shorter service intervals should be established through frequent user-inspections. A word of caution: excessive oiling can do more harm than good if not restricted to a specific area. Excess oil can contaminate windings, commutators and internal switches.

**Ball Bearing Lubrication:** Ball and roller bearings require only small amounts of lubricant. Calculations show that 1/1000 drop of oil will lubricate all the surfaces of a 10 mm bearing. For ball bearing lubrication in electric motors, grease is generally preferred over oil for long maintenance-free service. This is due to the availability of improved ball bearing greases, simplified bearing housings and elimination of the “human error factor” which is frequently responsible for too much, not enough or the wrong kind of lubricant. Prelubricated bearings and the elimination of grease fittings help improve ball bearing life.

Premature bearing failures are caused by one or more of the following conditions:
1) foreign materials from dirty grease or ineffective seals,
2) grease deterioration due to excessive temperature or contamination, and
3) overheated bearings resulting from over-lubrication or overload.

Some danger signals are:
1) a sudden increase in the temperature differential between the motor and bearing,
2) running a gearmotor at temperatures higher than that recommended for the lubricant. The rule of thumb is that grease life is halved for each 25°F increase in operating temperature, and
3) an increase in bearing noise, accompanied by a bearing temperature rise, indicating a serious bearing malfunction.

**Sleeve Bearing Lubrication:** Lubricants are used with ball or roller bearings to dissipate heat, prevent rust and prevent foreign matter from contaminating the bearings. Sleeve bearing lubricants, on
the other hand, serve a different purpose. The lubricant must actually provide an oil film that completely separates the bearing surface from the rotating shaft member and ideally, eliminates metal-to-metal contact.

Because of its adhesion properties and its viscosity (or resistance to flow), oil is “dragged” along by the rotating shaft of the motor and forms a wedge-shaped film between the shaft and the bearing. See Fig. 7-23. The oil film forms automatically when the shaft begins to turn and is maintained by the motion. The rotational motion sets up pressure in the oil film wedge which, in turn, supports the load. This wedge-shaped film of oil is an absolutely essential feature of effective, hydrodynamic sleeve bearing lubrication.

![Fig. 7-23: Oil film in a hydrodynamic sleeve bearing.](image)

Without it, no significant load can be carried without subsequent high friction loss, heat generation and resultant destruction of the bearing and/or shaft. When an adequate oil film is maintained, the sleeve bearing serves as a guide to accomplish shaft alignment. If the oil film fails, the bearing may function as a temporary safeguard to prevent damage to the motor shaft and other rotating members.

Good lubricants are essential to low maintenance costs. Top grade petroleum-based oils are recommended as they are substantially noncorrosive to metal surfaces. They are free from sediment, dirt and other foreign materials, and are stable with respect to heat and moisture. Their performance-to-cost ratio is very good.

An oil film consists of layers. The internal friction of oil, resulting from the sliding action of these layers, is measured as viscosity. The oil used should provide enough viscosity to prevent wear and seizure at ambient temperature, low speeds and heavy loads for any given application. Relatively light oils are recommended for use with fractional horsepower motors since they offer minimal internal friction, permit fuller realization of the motor’s efficiency and minimize the operating temperature of the bearing.

High ambient and operating temperatures have a destructive effect on sleeve bearings lubricated with standard temperature range oils because the bearing operates at temperatures beyond the oil’s capability. Such destructive effects include reduction in oil viscosity, an increase in corrosive oxidation products in the lubricant and a reduction in lubricant quantity. Special oils are available for high temperature and low temperature motor applications. The care exercised in selecting the proper lubricant for the expected extremes in bearing operating temperatures will have a decided influence on motor performance and bearing life.

Although sleeve bearings are less sensitive to a limited amount of abrasive or foreign materials than ball bearings, good maintenance practices recommend that oil and bearings be kept clean. In very small motors, dirty or insufficient oil can add enough friction to cause the bearings to seize (especially after cooldown). Frequency of oil changes will depend on local
conditions. A conservative lubrication and maintenance program should call for periodic inspection of the oil level and cleaning and refilling with new oil every six months.

NOTE: Sleeve bearing motors may tend to lose their oil film when stored for extended periods (one year or more).

**Lubrication of Gearmotors**

Oil provides the best combination of lubricating properties for gearmotors and is nearly always used in 1/10 hp and larger gearmotors designed for industrial service. Long service life (over 10,000 hrs.) requires a circulating fluid lubrication system.

All lubricants minimize friction, resulting in lower heat generation and load support. The fundamental characteristic of oil is its free flow and constant presence at the tooth surfaces of a gearhead during operation, thereby providing a consistent and continuous lubricating film under load.

The lubricant used in parallel shaft gearmotors (which usually employ spur or helical gearing) is relatively less critical than for right angle worm-gear types. Usually, a straight mineral oil suffices if the proper oil level is maintained. Some fhp gearmotors use hydraulic-type oils to decrease gear-shaft or journal wear.

Right angle gearmotors with worm or other types of sliding contact gearing require careful attention because the lubricants reach higher operating temperatures due to lower inherent efficiency. (“Inefficiency” is converted into heat which is absorbed by the lubricant.) Such lubricants generally have higher viscosity and contain protective additives.

Despite its advantages, oil is not commonly used in smaller gearmotors because of sealing problems. Smaller gearmotors characteristically do not have large gasket surfaces and may not have sufficient power to withstand the increased friction of a contact seal on the rotor shaft. Therefore, grease is used as a compromise in most small gearmotors under 1/4 hp (186.5 watts).

When compared with oil, grease provides less consistent lubrication to the gear teeth under load. Grease does, however, provide flexibility in mounting and minimizes the risk of leakage. Grease also eliminates periodic visual oil level inspections. The use of “stiff grease” eliminates the need for vent hole shipping plugs and their subsequent removal at the final destination. However, if a semi-fluid grease is used, vent hole plugging will be required to prevent leakage during shipment.

Grease requires a shorter service interval, primarily because of reduced lubricant circulation. Wear of the gear train parts is invariably higher when grease is used as a lubricant and the rate of wear increases as stiffer greases are used. Moderate life (approximately 2,000 hrs.) can be achieved with grease lubrication in a well-designed gearhead enclosure.

**Relubrication:** Oil relubrication under normal operating conditions primarily involves maintaining the oil at a recommended and indicated level. Loss of oil by evaporation or leakage is minimal over long periods of time under normal conditions which lengthens the relubricating cycle for an oil-lubricated gearmotor.

Relubrication periods for greaselubricated gearmotors are shorter and require complete removal of the old lubricant in the gear housing, proper cleaning of the residue and replenishing with the recommended quantity and type of grease (manufacturer’s recommendation should always be followed). With proper maintenance and loading, life of the grease in the gearmotor under normal conditions of operation can
be appreciable. Manufacturers take careful steps to match the lubricant with the elastomers used in the oil seals as well as the requirements of the gearing and bearings in a particular gearmotor design.

**Operating Temperature:** Lubricant life in gearmotors is directly dependent on temperature. Generally, within the normal operating ranges, lubricant life doubles for every 25°F decrease in temperature.

Gearmotors operating in high or low ambient temperature ranges require special lubricants or lubricating systems. Gaskets, motor insulation and lubricant life may be seriously affected by temperature extremes. When other than normal ambient temperatures (0°C to 40°C or 32°F to 104°F) are expected, the gearmotor manufacturer should be consulted.

**Mounting Considerations:** Distribution or circulation of gear housing lubricant is critical to gearhead life. Splash or special oiling gears are effective methods of oil lubrication. Grease cannot be circulated in this manner, however. So in cases where bearings and gears must be lubricated with grease, felt wicks are often used to transfer oil from the grease to the bearings. In other designs, gears are grease-lubricated and the bearings are externally oil lubricated.

Special applications which involve rotating a gearmotor about an axis, or tilting it periodically, will require modified sealing and venting arrangements to prevent lubricant leakage. The special mountings, modified castings, additional oil seals or special lubrication systems will add to the cost.