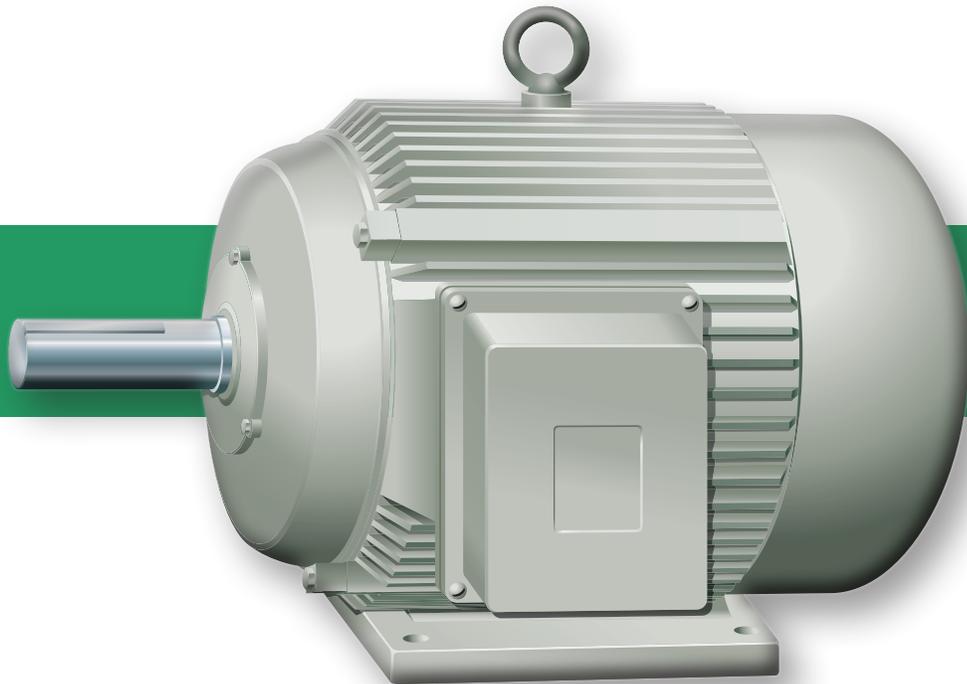


# Getting The Most From Your Electric Motors





# Getting The Most From Your Electric Motors

## Foreword

This booklet will help you obtain the longest, most efficient and cost-effective operation from general and definite purpose electric motors with these characteristics:

- Three-phase, squirrel-cage induction motors manufactured to NEMA MG 1 standards
- Power ratings from 1 to 500 hp (1 to 375 kW)
- Speeds of 900 to 3600 rpm (8 to 2 poles)
- Voltages up to 1000V, 50/60 Hz
- All standard enclosures (i.e., DP, TEFC, WPI, WPPII)
- Rolling element (ball and roller) and sleeve bearings

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# Getting The Most From Your Electric Motors



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# Getting The Most From Your Electric Motors



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## 1. Installation, startup and baseline information

### 1.1 Basic system considerations

A motor system (Figure 1) typically includes the power supply, mounting, coupling, and driven equipment (including its function and output). Consider every system component when selecting a motor, dealing with an application issue, or investigating a failure.

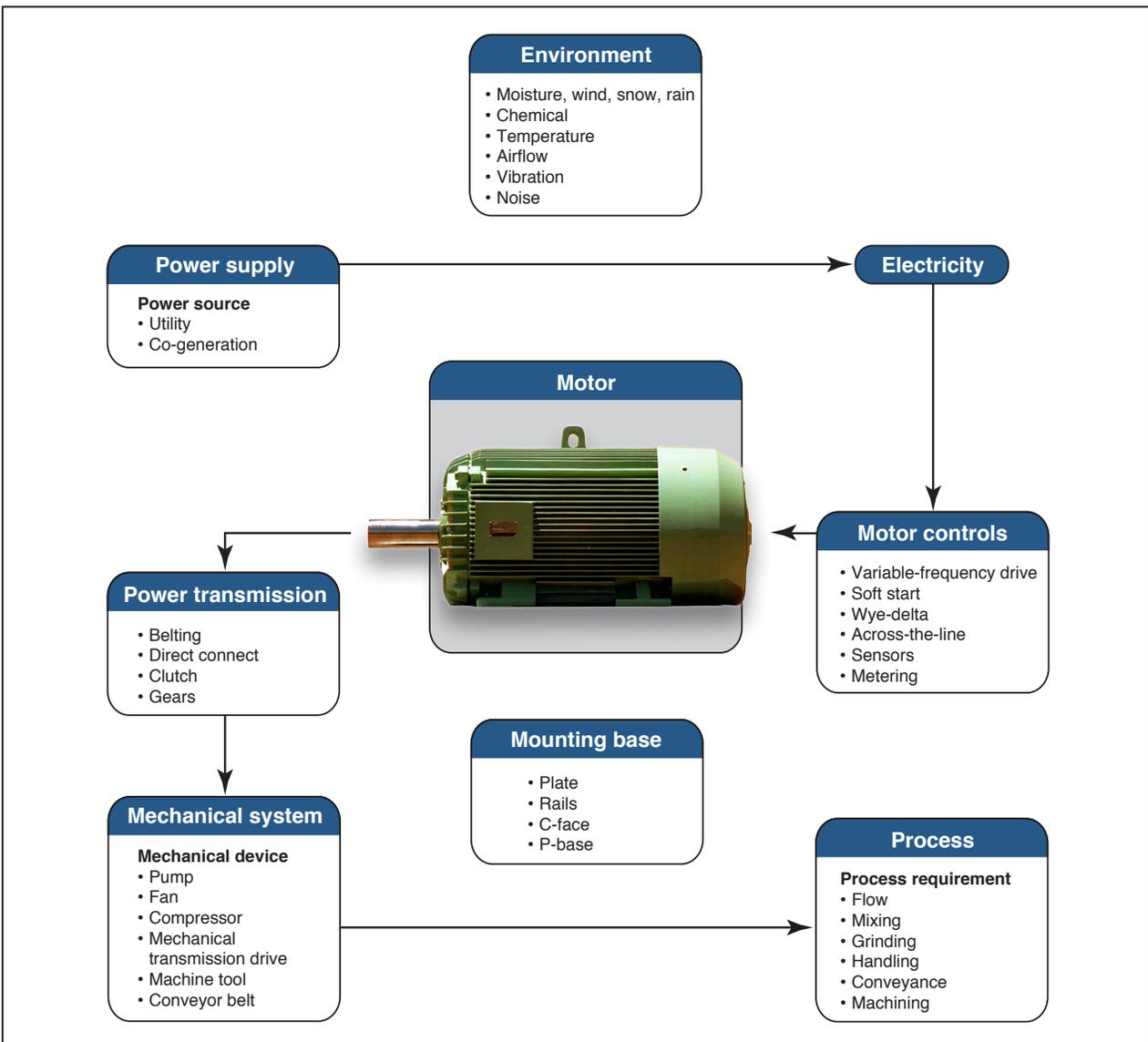


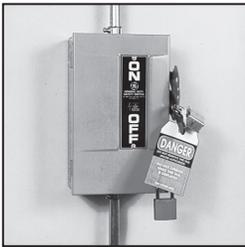
Figure 1. Typical motor and system.

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## 1.2 Installation

The following steps will ensure a quality installation and reliable operation of a repaired or replacement motor. Be sure to document the motor's initial condition as recommended. By comparing these baseline readings with future results it's often possible to spot small problems before they lead to costly motor failures and shutdowns.

### Safety



When preparing to remove or install a motor, put safety first. Wear appropriate personal protective equipment (PPE). Follow applicable electrical codes for wiring, disconnect and emergency stop requirements. Lock out and tag out all potential energy sources before working on the motor. Use safe lifting methods appropriate to the motor's size and weight.

### Motor data and verification

Create a motor data sheet (see Appendix A) for recording the nameplate data and pertinent electrical and mechanical parameters at the time of installation and startup. These baseline values will be invaluable for determining the application's life-cycle cost and recognizing any changes in operating characteristics.

- Confirm that the motor is appropriate for the application by verifying that its mechanical and electrical characteristics (e.g., voltages, currents, circuit configurations, construction and degree of cooling) are suitable for the intended application. (See "Appendix B: How to read a motor nameplate.")
- For an adjustable-speed drive (ASD) or variable-frequency drive (VFD) application, use an "inverter-duty" motor (or provide suitable filtering) and keep the supply cable length within the motor manufacturer's guidelines. Use supply conductors designed for ASD circuits to reduce the risk of overvoltages and transient voltages at the motor terminals, and a shaft grounding system or insulated bearings to prevent damage from stray shaft currents.
- Record the nameplate data. Serial numbers are usually coded to indicate the month and year of manufacture.



**Attach a digital photo of the nameplate for reference in case of errors in the recorded data.**

- Make sure the motor's bearings are suitable for the driven load (e.g., a drive end roller bearing for a high radial load belted application).

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- Review the manufacturer’s lubrication specifications and make sure the lubrication points are accessible (see “Relubrication of bearings” on Page 16 for more information).
- Using a digital low-resistance ohmmeter (DLRO), record the temperature-corrected insulation resistance of the motor and the line-to-line resistance of the winding (see “Inspection and testing on Page 14).
- Verify that the motor control and overload protection are sized properly for the motor rating.
- Inspect and test motors taken from storage to ensure they haven’t degraded (see Appendix C).

## Environment

- To ensure adequate cooling, keep the motor’s operating environment free of dirt and debris and verify that heated air isn’t recirculated to its air inlet. If necessary, provide an external source of filtered air of sufficient volume.
- Isolate the motor from external vibration whenever practical.

## Motor foundation and base

The foundation and base must adequately support the motor’s weight and withstand its torque forces. Concrete foundations should be level and provide ample structural stiffness and vibration damping properties. The base must absorb vibratory forces without exciting resonance in the mechanical system. Steel bases mounted on concrete should be set in grout and securely anchored. Sliding bases used for belt adjustment must rigidly secure the motor.

Other points to consider:

- Always lift the motor by its lifting lugs (see Figure 2). On larger motors, use all lugs for safety and to prevent frame distortion.
- Mount sleeve bearing motors level to ensure proper oil level readings and bearing lubrication.
- On larger motors, don’t remove the rotor braces that prevent axial shaft movement during shipment until you’re ready to install the motor.

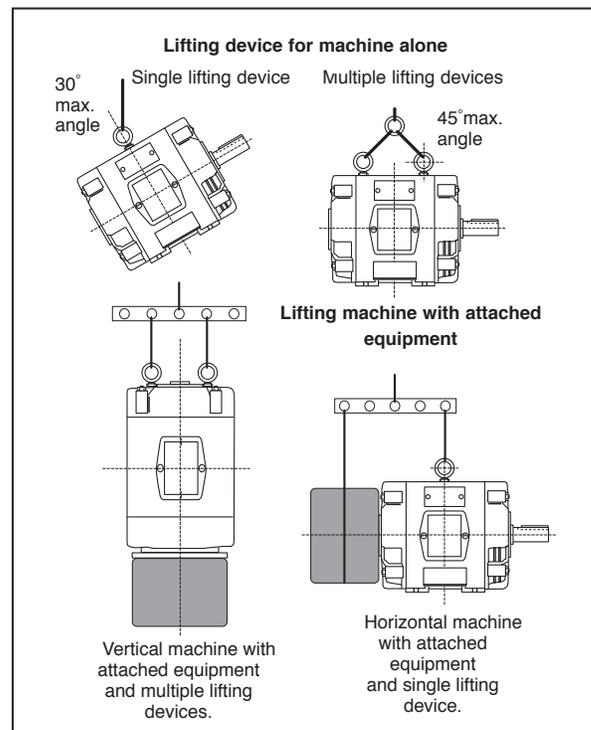


Figure 2. Safe lifting methods.

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## Electrical connections

- Follow all applicable electrical codes.
- Lock out and tag out all potential energy sources before working on the motor.
- To avoid electrical faults, make sure connections are tight (including the equipment grounding conductor if required by code) and appropriately insulated. Don't use wire nuts.
- Record the motor no-load current on the motor data sheet (see Appendix A).
- Install the connection box cover.

## Alignment and vibration

Align the motor to the driven machine, especially if the two are direct-coupled. Misalignment can cause high vibration levels that damage bearings and loosen mountings. Laser instruments are available for aligning both coupled and belted drives. If alignment tolerances aren't available from the machinery manufacturer, use those in Table 1.

- **Soft foot.** Alignment procedures include testing for and correcting a "soft foot"—a common problem where the mounting feet aren't coplanar and therefore do not all sit flat on the motor base (see Figure 3). Unless this problem is identified and corrected with shims (see Figure 4), tightening the mounting bolts could twist the motor frame. See Table 1 for suggested soft-foot tolerances.

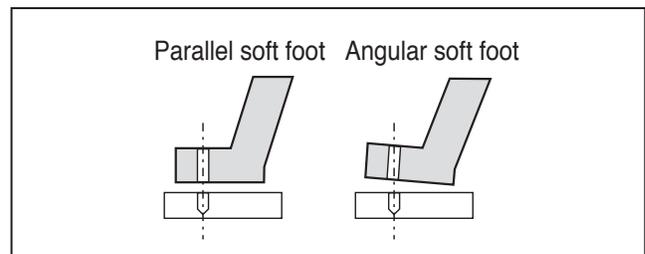


Figure 3. Types of "soft foot."

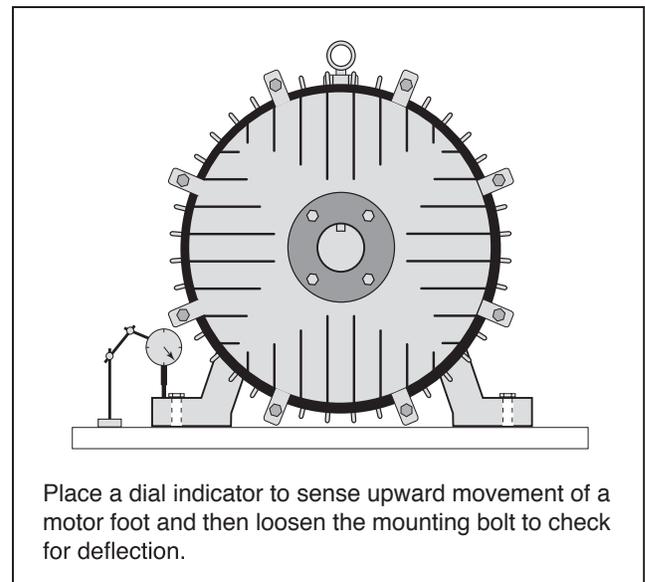
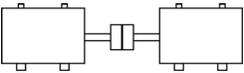
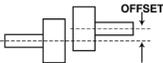
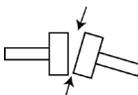
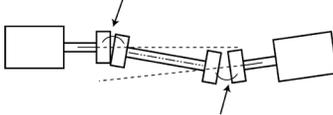


Figure 4. Using a dial indicator to detect "soft foot."

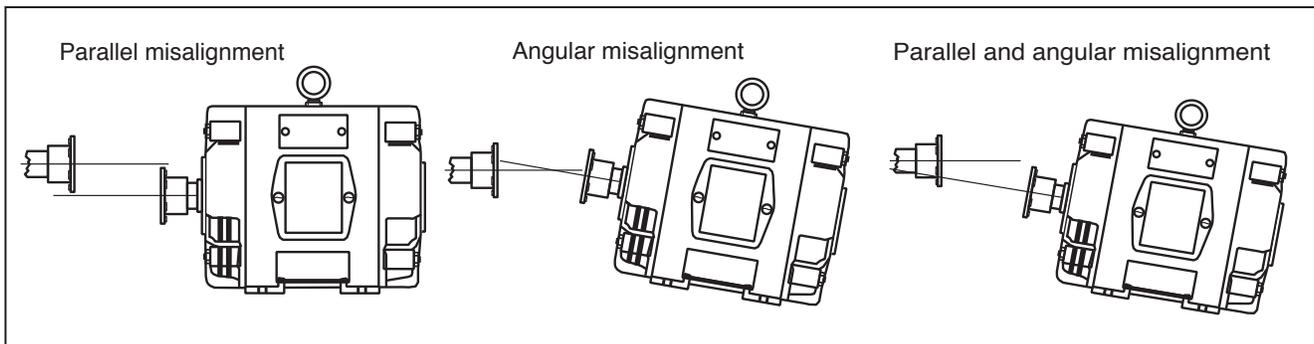
# Getting The Most From Your Electric Motors

**Table 1. Suggested alignment tolerances for directly coupled shafts.**

	RPM	Installation		In service	
		Mils	mm	Mils	mm
<b>Soft foot*</b>	All	±1.0	±0.025	±1.5	±0.038
<b>Short couplings</b>					
<b>Parallel offset</b> 	1200	±1.25	±0.032	±2.0	±0.051
	1800	±1.0	±0.025	±1.5	±0.038
	3600	0.5	0.013	0.75	0.019
<b>Angular misalignment**</b> 	1200	0.5	0.013	0.8	0.020
	1800	0.3	0.008	0.5	0.013
	3600	0.2	0.005	0.3	0.008
<b>Couplings with spacers</b>					
<b>Parallel offset per inch of spacer length</b>	1200	0.9	0.023	1.5	0.038
	1800	0.6	0.015	1.0	0.025
	3600	0.3	0.008	0.5	0.013

\* “Soft foot” describes the condition where the mounting feet are not all in the same plane. Measured in mils (1 mil = .001 in) or millimeters (mm).

\*\* To find the angular misalignment in mils/inch (mm), measure the widest opening in mils (mm), then subtract the narrowest opening in mils (mm) and divide by the diameter of the coupling in inches (mm). Note: Up and down motion of the driving and driven shafts with temperature may be in either direction (see Figure 5).



**Figure 5. Types of angular misalignment.**

# Getting The Most From Your Electric Motors

- **Alignment of directly coupled shafts.** Using the tolerances in Table 1, place shims appropriately under entire motor feet. For most direct-coupled applications, driving and driven shafts should be collinear under full load. If the driven machine operates at a much higher or lower temperature than the motor, expect to provide an initial “at rest” misalignment that will correct itself as the driven machine heats or cools. To confirm the effect, bring the equipment to full operating temperature, shut off the motor and immediately check the alignment, making any correction necessary.
- **Alignment of belt-driven machines.** Poor belt alignment may place excessive axial load on the motor bearings. It also may cause belts to be over tensioned, increasing the radial load on the bearings. Belt alignment is simpler than coupling alignment but still must be done accurately. The correct tool could be a simple straightedge or, for longer center shaft distances, a laser.

Set belt tension to the range specified by the belt manufacturer and check it after one day of operation. Depending on the belt type, belt tension commonly decreases shortly after installation, particularly if the belts are new.

For sheaves with multiple belts, the belts must be matched sets. Otherwise some of them will have insufficient tension, causing them to slip and squeal. Increasing the tension to eliminate the squealing will over-tension the other belts.

- **Vibration levels.** A motor that is properly mounted and aligned will operate with very little vibration—typically below 0.15 in/sec pk (2.5 mm/sec rms) when measured in the horizontal, vertical and axial directions at the motor bearings. Higher readings on new motor installations warrant a thorough vibration analysis. They may indicate mounting or alignment problems, an unbalanced sheave or coupling, or trouble with the driven machine.

Solid, secure mounting and proper alignment will ensure reliable operation and the maximum value from your electric motor. Operating conditions, load, temperature and alignment may change over time, however, so check vibration levels at least quarterly.

- **Shaft-mounted devices and couplings**

- Before installing belts or connecting the load’s half coupling, confirm the motor’s direction of rotation by momentarily applying power.
- Install shaft-mounted devices (half-couplings, pulleys and gears) using appropriate equipment to avoid damaging the device or the shaft.



**If possible, install shaft-mounted devices after the motor has been mounted and shimmed and the direction of rotation has been determined.**

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- Special considerations for sleeve bearing motors:
  - ◇ To avoid bearing damage, use couplings that limit end float.
  - ◇ Install couplings with the rotor at the scribed magnetic center.

# Getting The Most From Your Electric Motors

## Protective guards

Once installation and alignment have been completed and verified, place protective guards on all exposed rotating equipment to assure safe, dependable operation.

## 1.3 Startup procedures

**Motors removed from storage.** Before installing a motor that has been in storage for more than a few weeks:

- Thoroughly inspect and clean the motor to restore it to “as shipped” condition.
- If the motor has been subjected to vibration, disassemble it and check for bearing damage (e.g., false brinelling and fluting). Replace any damaged bearings.
- On grease-lubricated motors, the bearing cavities should have been filled with grease for storage. To protect the windings from contamination, remove the drain plugs before adding the lubricant specified on the lubrication plate. Then purge the old or excess grease from the bearing cavity by running the motor at no load for 10-20 minutes and replace the drain plugs. If any moisture is present in the purged grease, the bearings are probably rust damaged and should be replaced.
- If the motor has been stored for several years, the grease has likely dried out or separated, and the drainpipe is probably plugged up. In that case, it will be necessary to disassemble the motor, clean out the old grease and repack the bearings with the appropriate amount of the specified lubricant (see Pages 16-21 for information on lubricant compatibility and quantity.)
- To prevent winding contamination, drain oil-lubricated motors before moving them. After installation, fill the reservoir with manufacturer’s recommended lubricant.
- Test the winding’s insulation resistance (IR) and dielectric absorption ratio (DAR) as described in “Inspection and testing” on Page 14 and record the results.
- If the IR and DAR test results are satisfactory, perform no-load test operation.
- Then follow the applicable procedures for “Repaired or replacement motors” (below).

**Repaired or replacement motors.** Before putting a repaired or replacement motor in service, briefly start it to check its operation.

- If the motor vibrates or emits unusual noises or odors, immediately de-energize it and look for the cause.
  - Magnetic or electrical problems that may exhibit themselves as vibration or noise will instantly improve when the power is shut off.
  - No improvement in such mechanical running characteristics may indicate an anomaly like rotor or driven load unbalance, or misalignment of the motor and load device.
- If the motor operates normally, allow it to reach full speed before shutting off the power.

# Getting The Most From Your Electric Motors

- Always lock out and tag out the motor before connecting the driven load.
- Once the motor and driven load operate properly, record the full-load voltage and current for all three phases on the motor data sheet for this installation (see Sample data sheet on Page 22). If possible, also record the input power with load.
- If the motor is so equipped, monitor the bearing and winding temperatures until they reach a steady state. Document these values as well as the ambient temperature and humidity.
- For critical applications, record the initial vibration signature of the complete machine as a baseline for a predictive maintenance program (see “Motor/system baselines” below).

## 1.4 Baseline data

Maintenance practices have evolved from reactive to predictive, making it possible to operate with fewer spare motors, smaller staffs, less downtime and lower operating costs. To maximize equipment life, compare baseline installation data (see Sample data sheet on Page 22) with future test results as part of a preventive or (preferably) predictive maintenance program.

Trending the data helps operators recognize changing conditions and prevent catastrophic failures. Should a failure occur, trending could also help identify the cause. (See “Preventive, predictive and reliability-based maintenance” on Page 12.) Local service center professionals can be invaluable resources for this.

### Motor/system baselines

Changes in motor/system vibration readings provide the best early warning of developing problems in the motor or a system component. Other parameters to monitor may include the operating temperature of critical components, mechanical tolerances, and overall system performance, including outputs like flow rate, tonnage and volume.

### Methods for determining motor baselines

Motor-specific baselines include records of electrical, mechanical and vibration tests performed when motors are placed in operation or before they are put in storage. Ideally, baselines would be obtained for all new, repaired and in situ motors, but this may not be practical for some applications.

Baselines for motors often include some or all of the following:

- **Load current, speed and terminal voltage.** Changes in these parameters usually indicate that a vital system component is damaged or about to fail. Other electrical tests may include insulation resistance, lead-to-lead resistance at a known temperature, no-load current, no-load voltage, and starting characteristics.



**Some changes in the current and speed may be normal depending on the type of load.**

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# Getting The Most From Your Electric Motors

- **Motor current signature analysis (MCSA).** This test diagnoses squirrel cage rotor problems (e.g., broken bars or an uneven air gap). It's more accurate if a baseline is established early in the motor's life (see Page 15).
- **Mechanical tests.** These normally consist of measuring shaft runout (TIR) and checking for a soft foot.
- **Vibration.** Although overall vibration readings can be used as baseline data, Fast Fourier Transform (FFT) spectra in all three planes at each bearing housing are preferred (see "Vibration analysis" on Page 16). Shaft proximity probes can be used for determining sleeve bearing motor baselines.
- **Infrared thermography.** This tool can detect changes in the operating temperature of critical motor components, especially bearings.
- **New motor baselines.** Comparing factory terminal winding resistance and no-load amps with data taken under load can be useful when monitoring the condition of a new motor or troubleshooting system problems. Factory baselines are often available from the manufacturer or its website. The accuracy of factory data depends on how it was obtained, but it's usually sufficient for field use.

Baseline data for a newly installed motor could reveal an error (e.g., misconnection for an incorrect voltage) and prevent a premature motor failure. Rather than simply "bumping" a motor for rotation before coupling it to the load, operate it long enough to measure the line current for all three phases, as well as the voltage and vibration levels.



**Comparing the baselines of a failed motor and its replacement could reveal application- or process-related weaknesses in the system.**

- **Repaired motor baselines.** Service centers usually provide no-load and/or full-load (when stipulated) test data for repaired motors, including voltage, current and vibration spectra. Comparing these results with historical baselines and those obtained on site when the motor is returned to service may confirm the quality of the repair or possibly reveal underlying system problems. For example, increased vibration levels in on-site tests might indicate a deteriorating motor base or a problem with the driven equipment rather than a balancing issue with the motor.

For newly repaired motors that have been in operation many years, baseline comparisons are invaluable for root cause failure analysis and may even expose consequential damage from certain kinds of failures (e.g., a broken shaft). To correctly identify cause and effect and prevent a recurrence, always investigate equipment failure at the system level.

# Getting The Most From Your Electric Motors

## How to use motor/system baselines

The maintenance performed during normal motor operation and planned outages ranges from random to regularly scheduled monitoring, although its frequency may depend on the size, location and critical nature of the application. To draw useful comparisons, baseline variables must correlate with those recorded during initial startup or after repairs were made. Here are a couple of examples.

- Trending the baselines of a centrifugal pump motor could alert the operator to a significant change in line current that is indicative of degraded pump efficiency. Repairing or replacing the pump would restore the efficiency of the motor/pump system while boosting production.

**System efficiency = Motor efficiency x Pump efficiency**

$$0.94 \text{ (motor eff.)} \times 0.60 \text{ (degraded pump eff.)} = 0.56$$

$$0.94 \text{ (motor eff.)} \times 0.80 \text{ (repaired pump eff.)} = 0.75$$

- Trending a motor's baseline current for uncoupled operation or the insulation resistance of its winding could prevent a winding failure through early detection of a deteriorating insulation system or a worn out bearing. In such cases, motors can often be cleaned and rebuilt rather than rewound.

## 1.5 Total motor management

Total motor management programs typically track purchases and spares in a database by nameplate information, facility/location, and application. Usually they also track baseline data, maintenance, storage and repair.

Such programs lower costs by reducing downtime (spares are readily available) and decreasing inventory (identification of spares used in multiple locations). A key consideration here is whether the most cost-effective and reliable solution is to store spare motors on site or to outsource storage to a service center or other vendor.

# Getting The Most From Your Electric Motors

## 2. Operational monitoring and maintenance

### 2.1 Application-specific considerations

Carefully evaluate application-specific considerations to assure reliable, energy efficient operation of your motors.

- **Efficiency and motor losses.** For electric motors, efficiency is defined as output power divided by input power, expressed as a percentage:

$$\text{Efficiency} = \text{Output power} / \text{Input power} \times 100$$

A small proportion of the input power is converted to heat rather than work, due to motor losses. These include stator and rotor I<sup>2</sup>R losses, friction and windage losses, and core and stray load losses.

$$\text{Input power} - \text{Output power} = \text{Motor losses}$$

More efficient motors have fewer losses than standard efficiency models, so they use less energy, run cooler and last longer. Motor manufacturers have been categorizing the efficiency levels of motors for marketing and pricing purposes by using terms such as energy-efficient, high efficient or premium efficient to describe their motors.

The Energy Policy Act (EPA) of 1992 mandated minimum efficiency levels for 1 to 200 hp general purpose motors, and the Energy Independence and Security Act (EISA) of 2007 raised these minimums to NEMA Premium<sup>®</sup> efficiency levels while broadening the scope of motors affected. In response, manufacturers have incrementally increased motor efficiency by reducing motor losses.

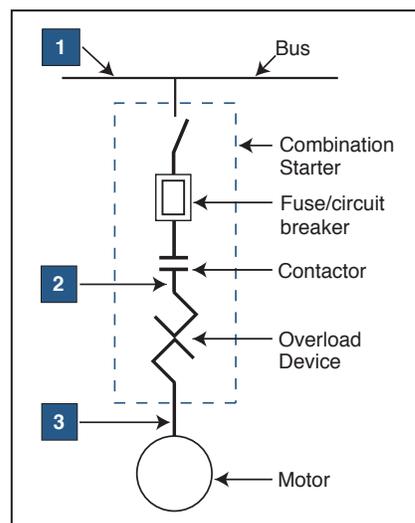
Efficiency is an important consideration for getting the most from your electric motors. For a small additional investment initially, a more efficient model may cost less to operate and last longer.

- **Power factor.** Power factor is the ratio of kW (kilowatts) to kVA (kilovolt-amperes) in an AC circuit, which for a given load (kW) will be between 0 and 1.

Raising a low power factor will decrease the current flow through the motor's power cables and other equipment and therefore reduce heating and thermal aging. It may also reduce energy costs (where applicable) by decreasing or eliminating electrical utility surcharges for low power factor.

Figure 6 shows where power factor correction capacitors could be installed in a motor circuit. Location 2 is usually best for most motors, and Location 3 is usually better than Location 1.

- Locations 2 or 3 are offline when the motor is offline; Location 1 is always energized. This could lead to overvoltages and transient torques if other motors or other inductive equipment are on the bus.



**Figure 6. Locations for power factor correction capacitors for an induction motor circuit.**

# Getting The Most From Your Electric Motors

- Location 3 requires downsizing the protective devices because of the reduced current flow.
- Location 3 could introduce high amplitude switching transients or current surges into motors that jog or switch frequently—e.g., elevator, multispeed, open transition autotransformer or wye-delta start motors, and some part-winding start motors (except so-called extended- or double-delta models). Location 1 is better for such applications.
- **Transient torques, voltages and currents.** Under certain conditions, motors can transiently develop 5 to 20 times rated torque. Common causes of dangerous transient torques (and transient voltages and currents) include:
  - Bus transfers and out-of-phase reclosures
  - Plug reversals
  - Transfer from high to lower speed (multispeed windings)
  - External short circuits
  - Switching of power factor equipment
  - Overcorrection with power factor capacitors
  - Adjustable-speed drives
- **Harmonics.** Some electrical system loads (e.g., electronic power supplies for digital equipment) draw current in distorted waveforms that contain harmonic frequencies—i.e., multiples of the line frequency. Associated harmonic voltages may then be present in motors on the system, causing increased motor losses. Use power quality monitoring equipment to detect harmonics and filters to control them.
- **Starting current and number of starts.** Repeated starting can damage an electric motor due to the additive effects of heating during this high current condition. According to NEMA Stds. MG 1, 12.54 and MG 10, 1.8.1, under normal operating conditions the safe number of starts depends on the motor's load inertia for its horsepower rating and speed (see NEMA Std. MG 1, Table 12-7).

A motor initially at ambient temperature should be capable of two successive starts (coasting to rest between) if its load inertia isn't exceeded and follows a square law load curve, or one start if its initial temperature doesn't exceed its rated load operating temperature. The square law load curve means the required torque varies as the square of the speed and equals full-load torque at full speed.

For unusual operating conditions, consult the manufacturer to determine the suitability of the motor design. If additional starts are required, make sure the motor design can handle it without a detrimental increase in motor temperature. For maximum motor life, keep the number of starts to the minimum required for the application.

## 2.2 Preventive, predictive and reliability-based maintenance

Preventive maintenance (PM) and predictive maintenance (PdM) are familiar terms, but the tasks associated with these methods of maintaining and extending the operating life of electric motors aren't always clear. This section describes activities commonly associated with PM and PdM, as well as a strategy called reliability-based maintenance (RBM).

# Getting The Most From Your Electric Motors

- **Preventive maintenance (PM).** The primary goal of PM is to assess motor health through inspections and tests. For example, the condition of a winding is determined by the megohm value from an insulation resistance (IR) test.

Electrical tests typically include measuring IR (with motor shut down) and individual phase voltages and currents (during normal operation). Measurement of winding resistance, inductance, capacitance and motor current signature analysis (MCSA) are less common (see Pages 14-16).

Mechanical assessments in a PM program usually include vibration analysis (FFT spectra) and, less frequently, alignment (see Pages 4-6 and 16).

Other PM activities commonly include cleaning and inspection; lubrication and lubricant level checks; and adjustment of belt tension and bolt tightness. Thermal scanning with an infrared thermometer or camera is also used occasionally. Noise levels can be assessed subjectively or with acoustical analysis equipment. PM judgments are then based on the results of each activity.

- **Predictive maintenance (PdM).** Predictive maintenance forecasts when to perform corrective maintenance (action), or when to expect a failure. Also called condition monitoring, PdM consists of trending and assessing most of the activities associated with PM.

PdM usually trends electrical activities like IR and polarization index (PI) tests and sometimes motor circuit parameters, current and voltage levels, and MCSA results. Trending of mechanical routines normally includes the vibration spectra and occasionally thermal scan test results.

As an example, if the megohm value of the winding insulation was initially acceptable but trending lower, that trend can be used to schedule corrective maintenance before the IR value drops dangerously low, or to predict when it will be too low to operate the motor safely.

- **PM versus PdM.** PM judges machinery condition using a single set of readings and observations. If the assessment is obvious or easily compared to acceptance parameters, the action to be taken, if any, is clear. For instance, a broken shaft obviously needs immediate repair, while insulation resistance of zero megohms suggests a motor should be rewound.

The advantage of PdM is that it trends tests and assessments to project when corrective action will be needed or the time to failure. Nonlinear increases in vibration and misalignment, for instance, probably would precede a broken shaft. By trending these readings, it's possible to spot and correct conditions that otherwise would result in shaft failure. Likewise, trending IR test values can detect deteriorating insulation, so the motor can be cleaned and rebuilt rather than rewound.

- **Reliability-based maintenance (RBM).** RBM, also called reliability-centered maintenance (RCM), is a logical method for determining the best combination of maintenance activities to enhance equipment reliability and safe operation. These include cleaning and lubrication as well as repair or replacement of failed components.

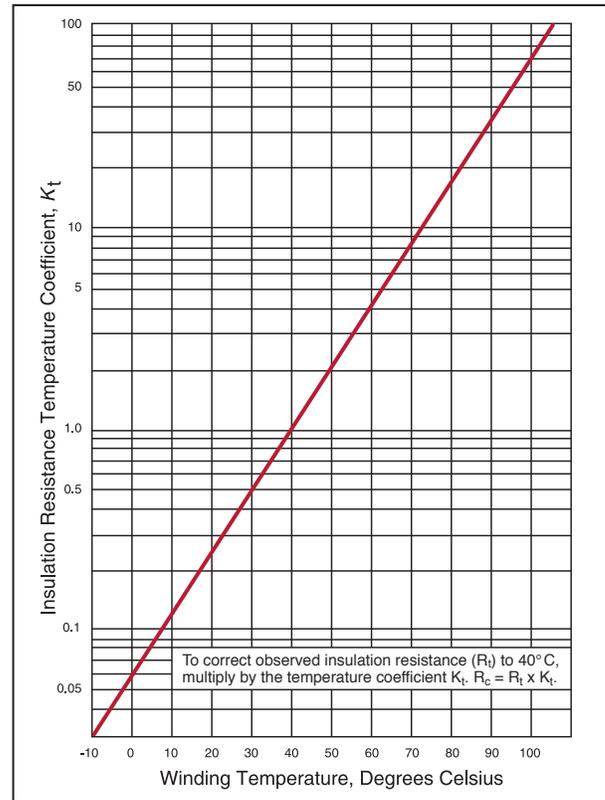
Reliability expresses the probability that a motor will perform properly for a specified time, under stated conditions. RBM reduces maintenance to the most cost-effective activities, so it requires understanding of motor failure characteristics, manifestations and consequences.

# Getting The Most From Your Electric Motors

## 2.3 Inspection and testing

Whether the preferred approach is PM, PdM or RBM, there are a number of inspection activities and testing tools from which to choose.

- **Inspection.** This important activity can detect missing, broken or damaged parts, blocked airflow paths, and contaminants. During PM or PdM services minor adjustments can be made (e.g., to belt tension or loose bolts), and accumulated dirt or contaminants can be removed from accessible locations. Thermal scanning using an infrared thermometer or camera can detect abnormal operating temperatures.
- **Insulation resistance (IR) test.** This offline test applies 500 volts DC between the winding and the frame (ground) for 60 seconds, typically with a megohmmeter. If the phases of the winding can be isolated, such as with a wye-delta connection, test each one separately. Table 2 shows the minimum acceptable IR values.



**Figure 7. Insulation resistance temperature correction.**

**Table 2. Recommended minimum insulation resistance to ground, when measured at or corrected to 40°C.**

Minimum insulation resistance	Type of machine
$IR_{1min} = 100$ megohms	Most AC machines with form-wound stator coils built after about 1970
$IR_{1min} = 5$ megohms	Most machines with random-wound stator coils and form-wound coils rated below 1 kV

Notes:  $R_{1min}$  = Recommended minimum insulation resistance of machine's entire winding in megohms at 40°C  
 kV = Machine's terminal-to-terminal rated voltage, in rms kilovolts

Correct the insulation resistance reading to a 40°C base temperature as follows:

$$R_c \text{ 40°C} = K_t \times R_t$$

Where:

$R_c \text{ 40°C}$  = Insulation resistance (in megohms) corrected to 40°C

$R_t$  = Measured insulation resistance (in megohms)

$K_t$  = Temperature correction coefficient (from Figure 7)

# Getting The Most From Your Electric Motors

- **Dielectric absorption ratio (DAR) test.** The DAR indicates the condition of the winding by comparing its insulation resistance at one time period to that of another, shorter time period. Measure the insulation resistance at 30 seconds and 60 seconds with a digital meter. To determine the DAR, divide the 60-second reading by the 30-second reading. Refer to Table 3 to assess the condition of the winding.

**Table 3. Dielectric absorption ratio (DAR) assessment.**

60:30 seconds (DAR)	Condition
< 1.1	Poor
1.1 to 1.24	Questionable
1.25 to 1.3	Fair
1.4 to 1.6	Good
> 1.6	Excellent

- **Winding resistance measurements.** To check for high-resistance connections or possible misconnections, measure the winding resistance between leads with a bridge or digital low-resistance ohmmeter (DLRO).
- **Winding inductance and capacitance measurements.** Specialized test equipment can compare inductance and capacitance between pairs of winding leads to check for any unbalance. Although there are no industry acceptance standards for unbalance, manufacturers' manuals offer some guidance.
- **Motor current signature analysis (MCSA).** This test diagnoses rotor problems by detecting rotor currents induced into the stator windings and comparing the amplitude of 2X slip frequency side bands with the center frequency of 50 or 60 Hz. A clamp-on current transformer (CT) on the motor leads or CT control leads provides a signal for display on a spectrum analyzer, typically an FFT vibration analyzer. For the test to be effective, the applied load must provide sufficient slip to separate the side bands from the center frequency. Although no industry acceptance standards exist for MSCA tests, values in manufacturers' manuals offer some guidance. Detectable problems include those shown in Table 4.

**Table 4. Rotor problems detectable by MSCA tests.**

Rotor problems	Symptoms
Rotor cage faults	High 1X operating speed vibration with sidebands at the pole-pass frequency
Cracked rotor bars	Pole-pass sideband frequencies at multiples of the operating speed
Open or loose rotor bars	<ul style="list-style-type: none"> <li>• High vibration levels at the rotor bar-pass frequency*</li> <li>• 2X frequency sidebands around rotor bar-pass frequency</li> <li>• Multiples of rotor bar-pass frequency</li> </ul>

\* Rotor bar-pass frequency equals the number of rotor bars times the operating speed.

# Getting The Most From Your Electric Motors

- **High-potential and surge tests.** High-potential and surge tests assess the condition of the motor's insulation system by applying above rated voltage (an overpotential) to the windings. Overpotential tests could cause a winding fault and result in downtime, so they shouldn't be part of a PM or PdM program (Figure 8). Although these tests usually do not damage sound windings, they could cause electrically weakened windings to fail on test or shortly afterward. Never use overpotential tests without a back-up plan. It's better for a motor to fail under controlled conditions than in service.
- **Vibration analysis.** The most common mechanical test for PM and PdM is vibration analysis using an FFT spectrum analyzer. FFT converts vibration data into vibration spectra (waveforms of amplitude versus frequency) over a wide frequency range (Figure 9). For horizontal motors, the readings are usually taken radially in the horizontal and vertical planes of both bearings, and axially at a minimum of one bearing housing. NEMA standards for vibration limits apply only to uncoupled motors—i.e., not to installed motors. Values in independently written technical papers and test equipment manufacturers' manuals offer some guidance.



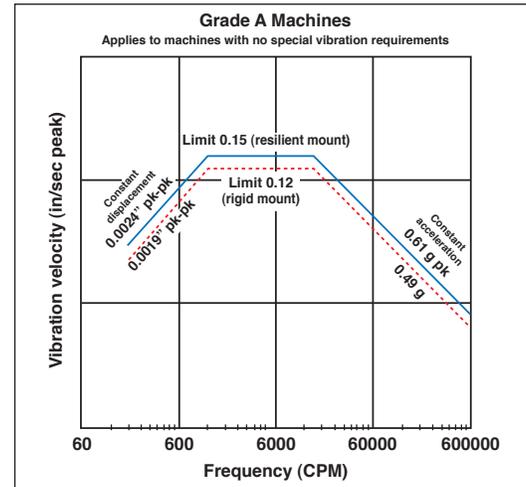
**Figure 8. Do not use overpotential tests as part of a PM or PdM program.**

## 2.4 Relubrication of bearings

Experience shows that faulty bearings account for more motor failures than any other single cause. To assure long, reliable motor operation, regularly monitor bearing lubricant levels, checking for leaks and contamination.

Determine the correct relubrication interval and the lubricant type and grade based on the motor's lubrication plate and the manufacturer's recommendations (if available). Otherwise, follow the guidance provided here.

- **Function of lubricants.** Bearing lubricants perform several critical tasks, including:
  - Separating rolling or sliding surfaces
  - Reducing wear
  - Minimizing the coefficient of friction (i.e., reducing heat)
  - Removing heat generated by friction
  - Blocking the ingress of contamination
  - Preventing corrosion



**Figure 9. NEMA unfiltered vibration graph.**

# Getting The Most From Your Electric Motors

- **Grease-lubricated bearings.** Unless they're "sealed for life" grease-lubricated bearings require periodic relubrication through the grease fittings. Select a compatible grease, quantity and relubrication interval based on the following guidelines.
- **Grease compatibility.** Not all greases and additives are compatible, so it's extremely important to determine what type of grease is in the bearing and to relubricate with a compatible grease. The effects of grease incompatibility range from mildly increased bearing wear to catastrophic machine failure, depending on the application and the type and degree of incompatibility.



**Signs of lubricant or additive incompatibility may include: unusual increases in heat generation; metal wear; vibration or noise emission; unusual color shifts in the lubricant; a sudden increase in foreign particles; leaks due to viscosity changes; foaming; formation of emulsions; appearance of fluid separation or gels in sight glasses.**

Use Table 5 as a starting point for assessing grease compatibility, keeping these points in mind:

- ◇ Don't mix incompatible greases.
- ◇ Don't mix greases if compatibility is borderline.
- ◇ Even if Table 5 indicates compatibility, it's always best to ask both manufacturers. Don't mix the greases if there's any hint of uncertainty.

Different formulations of the same oil may be incompatible, so relubricating with the same basic grease (e.g., polyurea with another polyurea) could still cause problems. Lubricants may also contain additives besides thickeners, some of which are incompatible. **The best practice is to use the same grease that's already in the bearings—provided it's suitable for the application.**

**Table 5. Grease compatibility chart.**

	Al c o m p l e x	Ba c o m p l e x	Ca s t e a r a t e	Ca 1 2 h y d r o x y	Ca c o m p l e x	Ca s u l f o n a t e	Cl a y n o n s o a p	Li s t e a r a t e	Li 1 2 h y d r o x y	Li c o m p l e x	P o l y u r e a	P o l y u r e a S S
	1	2	3	4	5	6	7	8	9	10	11	12
1. Aluminum complex	I	I	I	C	I	B	I	I	I	C	I	C
2. Barium complex	I	I	I	C	I	C	I	I	I	I	I	B
3. Calcium stearate	I	I	I	C	I	C	C	C	B	C	I	C
4. Calcium 12 hydroxy	C	C	C	I	B	B	C	C	C	C	I	C
5. Calcium complex	I	I	I	B	I	I	I	I	I	C	C	C
6. Calcium sulfonate	B	C	C	B	I	I	I	B	B	C	I	C
7. Clay non-soap	I	I	C	C	I	I	I	I	I	I	I	B
8. Lithium stearate	I	I	C	C	I	B	I	I	C	C	I	C
9. Lithium 12 hydroxy	I	I	B	C	I	B	I	C	I	C	I	C
10. Lithium complex	C	I	C	C	C	C	I	C	C	I	I	C
11. Polyurea conventional	I	I	I	I	C	I	I	I	I	I	I	C
12. Polyurea shear stable	C	B	C	C	C	C	B	C	C	C	C	I

This information is to be used only as a guide. Consult the manufacturer of each product before mixing different greases.

# Getting The Most From Your Electric Motors



Clean the grease fitting and remove the drain plug before inserting grease. Relubricate with the recommended quantity of grease for the bearing size and then run the motor at least 30 minutes with the drain plug out to purge old or excess grease from the chamber.

- Grease quantity.** Over-filling the grease cavity may cause grease shear—i.e., friction heating that degrades the lubricant by separating the oil from the base components. Excess grease can also contaminate the motor’s insulation system, resulting in premature winding failure. Use this equation to estimate how much grease to add during relubrication:

$$G = 0.11 \times OD \times W \text{ (English units), or } G = 0.0048 \times OD \times W \text{ (metric units)}$$

Where:

G = quantity of grease (fluid ounces or grams)

OD = bearing OD (inches or mm)

W = width of bearing (inches or mm)

Sample calculation of grease quantity for a 318 ball bearing:

OD = 7.48" (190 mm)

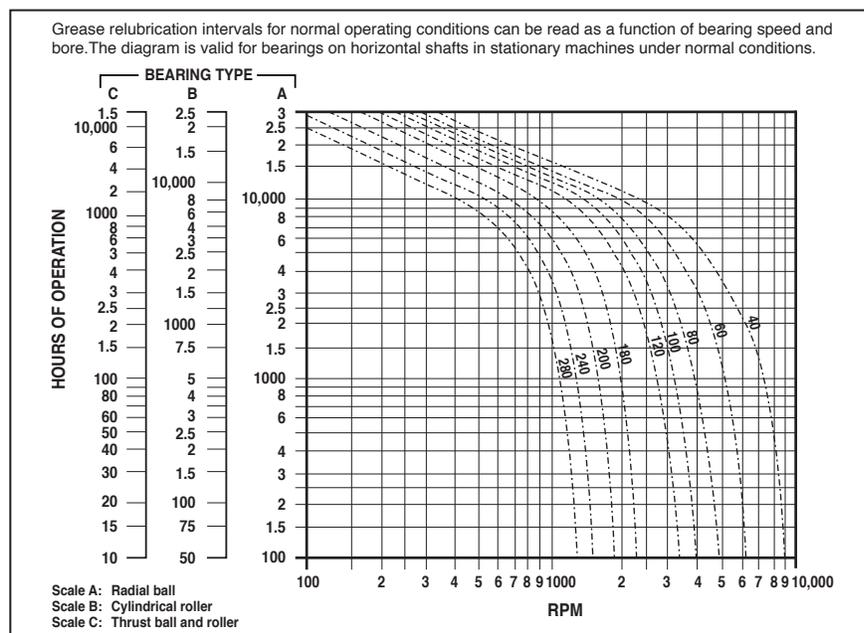
W = 1.69" (43 mm)

G = 0.11 x 7.48" x 1.69" = 1.39 oz, or G = 0.0048 x 190 mm x 43 mm = 39 grams

- Grease relubrication intervals.** Grease relubrication intervals for normal operating conditions are a function of bearing speed and bore size. Determine the relubrication interval from Figure 10 as follows:

- ◇ Find the motor’s rpm on the horizontal axis.
- ◇ Draw a vertical line from the motor’s rpm to the curve that represents the bearing’s inside diameter (in millimeters), or the next smaller dimension.
- ◇ From that point, draw a horizontal line to intersect the hours of operation (relubrication interval) for the applicable bearing type.

Abnormal operating conditions (e.g., high temperature, vibration and contaminants) may require more frequent



**Figure 10. Grease relubrication intervals for rolling element bearings on horizontal shafts in stationary machines.**

# Getting The Most From Your Electric Motors

relubrication. Other than experience with the application, there are no simple rules for determining how much to increase the relubrication frequency for such conditions.

- **Oil-lubricated bearings.** Select a compatible oil, viscosity and relubrication interval based on the following guidelines.
  - **Oil compatibility.** Oil vendors use many different additives, some of which aren't compatible. Incompatible oil additives can cause the same kinds of problems as incompatible greases, so the best practice is to determine what type of oil is in the reservoir and to relubricate with the same oil—provided it's suitable for the application. If it's necessary to use different oil, ask both manufacturers if the oils are compatible. Don't mix oils if there's any hint of uncertainty.
  - **Oil viscosity for rolling element bearings.** Table 6 provides guidelines for selecting the correct oil viscosity for rolling element bearings in horizontal motors, based on:
    - ◇ Bearing operating temperature (°C or °F)
    - ◇ Bearing pitch diameter ( $d_m = (ID + OD) / 2$ ) in mm
    - ◇ Operating speed (n) in rpm
    - ◇ Bearing loading level (light/normal or heavy/impact)

**Table 6. Effect of temperature on selection of oil viscosity for rolling element bearings in horizontal motors.**

Proper kinematic viscosity—ISO viscosity grade light/normal load or [heavy/impact load]			
Operating temperature °C (°F)	$d_m n$ value		
	600,000 or higher	300,000 to 600,000	300,000 or lower
-30 ~ 0 (-22 ~ 32)	15, 22 or 46 (all loads)	15, 22 or 46 (all loads)	15, 22 or 46 (all loads)
0 ~ 60 (32 ~ 140)	7, 10 or 22 [N/A]	32 [56 or 68]	56 [68]
60 ~ 100 (140 ~ 212)	22, 32 or 56 [N/A]	32 or 56 [56 or 68]	56 or 68 [68 or 100]
100 ~ 150 (212 ~ 302)	N/A (all loads)	56 or 68 [68 or 100]	56 or 68 [100 to 460]

**Example.** To determine the correct oil viscosity for a 6210 ball bearing operating at 3600 rpm at 90°C (194°F) under normal loading conditions—i.e., the ratio of the bearing's dynamic capacity to the applied load ( $C_r / P_r$ ) is between 0.06 and 0.12 ( $0.06 < C_r / P_r < 0.12$ ):

- ◇ Calculate the bearing pitch diameter:
 
$$(ID + OD) / 2 = d_m \text{ (in mm)}$$

$$(50 + 90) / 2 = 70 \text{ mm}$$
- ◇ Determine the  $d_m n$  value by multiplying the bearing pitch diameter by the operating speed:
 
$$d_m \text{ (mm)} \times n \text{ (rpm)} = d_m n$$

$$70 \times 3600 = 252,000 \text{ } d_m n$$

# Getting The Most From Your Electric Motors

- ◇ Select the appropriate viscosity from Table 6 (in this case ISO VG 56 or VG 68 bearing or turbine oil).

For vertical motors, use Table 7 as a guide for selecting the correct oil viscosity, regardless of bearing size and speed. (Note: If the motor lubrication plate specifies synthetic oil, DON'T substitute other oil.)

**Table 7. Vertical motor rolling element bearing oil viscosity.**

Ambient temperature range	Angular contact ball thrust bearings		Spherical roller thrust bearings	
	Up to 38°C (100°F)	Above 38°C to 60°C (100°F to 140°F)	Up to 4°C (40°F)	Above 4°C to 60°C (40°F to 140°F)
ISO VG	32	68	68	150



**WARNING:** If the unit has water-cooling coils, they must be operational. Otherwise, oil viscosity could decrease below the requirement for safe bearing operation.

- **Oil viscosity and lubrication intervals for sleeve bearing motors.** The clearance between the shaft journal and the bearing bore is critical with sleeve bearings. Any short-term, metal-to-metal contact can increase the bearing temperature, and the associated “wiping” can quickly degrade the bearing, possibly causing catastrophic failure. To maintain sleeve bearing clearances, follow the lubrication guidelines in Table 8.

**Table 8. Sleeve bearing oil viscosity and lubrication intervals.**

Ambient starting and operating temperature range °C (°F)	Shaft speeds (rpm)	ISO Viscosity range	Lubrication interval
Below 10°C (50°F)	All	Consult manufacturer	---
10°C to 32°C (50°F to 90°F)	Above 1800	32 to 68	5000 operating hours or 1 year, whichever comes first
	Up to 1800	68 to 100	1 year
Above 32°C (90°F)	All	Consult manufacturer	---

- **Oil relubrication intervals.** Select relubrication intervals based on the manufacturer’s instructions (if available). Otherwise, use the intervals provided in Table 8.

# Getting The Most From Your Electric Motors

Frequent starting and stopping, damp or dusty environments, extreme temperatures and other severe service conditions warrant more frequent oil changes than shown in Table 8. Contact the manufacturer regarding oil change intervals for specific situations, or regularly check the oil for contaminants or discoloration and replace it as needed. Another way to determine oil replacement intervals is to have a laboratory analyze oil samples periodically.



**Take oil samples with the motor shut down to avoid removing too much. When replacing the oil, fill the reservoir to the “standstill” level that’s normally shown on the sight glass.**

# Getting The Most From Your Electric Motors

## Appendix A: Motor and baseline installation data

### Sample data sheet

Motor ID no.	Facility	Date	
Manufacturer	Model	Type	Serial no.
Frame size	Enclosure	Voltage	RPM
Hp / kW	Full-load amps	Full-load efficiency (%)	<input type="checkbox"/> 1 phase <input type="checkbox"/> 3 phase
Code letter	Design letter	Insul. class	Motor weight
DE bearing no.	ODE bearing no.	Application(s)	
Date installed _____	Baseline data	Vibration spectra	Alignment data
No-load amps _____ watts _____	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Motor condition / status <input type="checkbox"/> New <input type="checkbox"/> Repaired <input type="checkbox"/> Storage		Motor location	
Reason for replacement			
Repair history			
Comments (if any)			

#### PHYSICAL INSPECTION (check applicable)

<input type="checkbox"/> Damaged or missing parts	<input type="checkbox"/> Exterior paint coating deficient	<input type="checkbox"/> Shaft blocking missing or inadequate
<input type="checkbox"/> Lubricant leakage	<input type="checkbox"/> Shaft protective coating deficient	<input type="checkbox"/> No visible defects
Description of any defects or anomalies _____		

#### STATIC TESTS (MOTOR OFFLINE)

##### INSULATION RESISTANCE TEST N/A N/P

Result	Test voltage	Resistance (megohms)
<input type="checkbox"/> Pass	_____ Volts DC	1-min _____ MΩ
<input type="checkbox"/> Fail		10-min _____ MΩ

##### DIELECTRIC ABSORPTION RATIO TEST N/A N/P

Result	60:30 sec (DAR)	Condition
<input type="checkbox"/> Pass	< 1.1	Poor
<input type="checkbox"/> Fail	1.1 to 1.24	Questionable
	1.25 to 1.3	Fair
	1.4 to 1.6	Good
	> 1.6	Excellent

Measure insulation resistance (IR) at 30 seconds and 60 seconds with a digital meter. Divide 60-second reading by 30-second reading.

##### HIGH-POTENTIAL TEST N/A N/P

Result	Test voltage (indicate AC or DC)
<input type="checkbox"/> Pass	_____ Volts <input type="checkbox"/> AC <input type="checkbox"/> DC
<input type="checkbox"/> Fail	

##### SURGE TEST N/A N/P

Result	Test voltage
<input type="checkbox"/> Pass	_____ Volts
<input type="checkbox"/> Fail	

##### SINGLE-PHASE ROTOR TEST N/A N/P

Result	Current (amps)	Ratio (max. / min.)
<input type="checkbox"/> Pass	Max. _____	_____
<input type="checkbox"/> Fail	Min. _____	

##### WINDING RESISTANCE TEST N/A N/P

Result	Resistance (indicate ohms or milliohms)		
	Leads 1 - 2	Leads 2 - 3	Leads 3 - 1
<input type="checkbox"/> Pass	_____	_____	_____
<input type="checkbox"/> Fail	<input type="checkbox"/> Ω <input type="checkbox"/> mΩ	<input type="checkbox"/> Ω <input type="checkbox"/> mΩ	<input type="checkbox"/> Ω <input type="checkbox"/> mΩ

If more than 3 leads, identify lead connections (e.g., 1-6, 2-4, 3-5, etc.)

##### ACCESSORIES TESTS N/A N/P

Working	Device type
<input type="checkbox"/> Yes	Space heaters
<input type="checkbox"/> No	

##### OUTPUT SHAFT EXTENSION RUNOUT N/A N/P

Result	Shaft extension runout	
<input type="checkbox"/> Pass	_____ (in or mm)	Measure with a dial indicator.
<input type="checkbox"/> Fail		

##### OUTPUT SHAFT EXTENSION DIAMETER N/A N/P

Result	Shaft extension diameter	
<input type="checkbox"/> Pass	_____ (in or mm)	Measure with a micrometer.
<input type="checkbox"/> Fail		

Static test comments (if any) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Note: N/A means "not applicable; N/P means "not performed.



# Getting The Most From Your Electric Motors

## Appendix B: How to read a motor nameplate

### Overview

When buying or replacing a motor, pay close attention to the nameplate terminology that describes its performance characteristics and application. A seemingly minor detail like “Design” could govern your choice. Familiarity with nameplate terminology may also help you solve unexpected performance issues.

### Required information

Although more details may be provided, NEMA Std. MG 1, 10.40 requires the following information on the nameplates of polyphase induction motors (see Figure B1):

- **Frame designation (FR).** This is typically a 2- or 3-digit number followed by one or more letters that identifies important mounting dimensions—e.g., shaft height and foot hole mounting pattern).
- **Manufacturer’s type (TYPE).** Manufacturers may use the optional “Type” block on the nameplate to designate a product family or some other qualifier that identifies the motor’s fit, form or function.

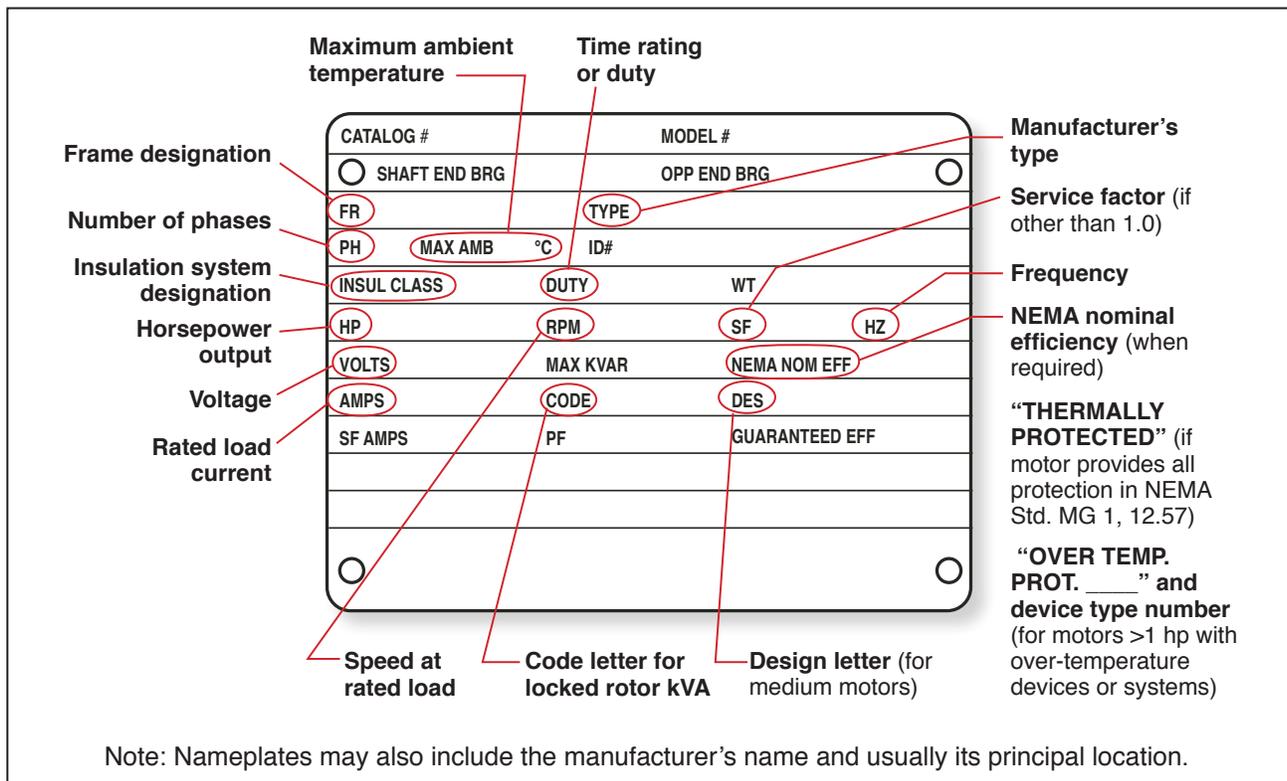


Figure B1. Typical NEMA nameplate with required information highlighted.

# Getting The Most From Your Electric Motors

- **Horsepower output (kW).** Usually given as hp or kW, this is a measure of the motor's mechanical power—i.e., its ability to deliver the torque required for the load at rated speed.

$$\text{hp} = 0.746 \times \text{kW}; \text{ conversely, } \text{kW} = 1.34 \times \text{hp}$$

- **Time rating or duty (DUTY).** This designation specifies the length of time that the motor can carry its nameplate rating safely. Usually this is “continuous” (Cont), which NEMA defines as indefinitely. The duty for motors used intermittently (e.g., on cranes, hoists and valve actuators) is usually expressed in minutes. See NEMA Std. MG 1, 10.36.
- **Maximum ambient temperature.** This is the maximum allowable temperature of the surrounding air to ensure that the motor's operating temperature won't exceed the insulation system limit. The standard ambient temperature is 40°C (104°F). See NEMA Std. MG 1, 12.44, Note I.



**The ambient temperature rating is sometimes confused with temperature rise. The temperature rise isn't normally given on the nameplate, but the insulation class is. The temperature rise rating is based on a combination of factors such as motor enclosure, insulation class, and service factor.**

- **Insulation system designation (CLASS, INS. CLS., INSUL CLASS).** This indicates the motor winding's thermal endurance using industry standard letter designations such as A, B, F or H. The higher the letter in the alphabet, the higher the safe operating temperature, and the longer the winding will last at any given operating temperature.
- **Speed at rated load (RPM).** This is the speed at which rated horsepower output is delivered to the load (full-load speed). This will be slightly less than synchronous rpm—i.e., the speed of the stator's revolving magnetic field. The difference between the two is the “slip speed” or “slip rpm.” Table B1 gives typical full-load speeds for small and medium motors.

**Table B1. Comparison of synchronous vs. full-load speed of 60 Hz motors.**

Synchronous Speed	Typical full-load rpm
3600	3450
1800	1750
1200	1140
900	850

Reducing slip rpm increases motor efficiency, so more efficient designs usually have higher full-load speeds. This could make energy efficient replacement motors problematic for some applications. Centrifugal pumps and fans, for example, typically demand power input that varies as the cube of the rpm, which means a small increase in speed produces a much larger increase in power. Carefully consider this before selecting a more efficient replacement motor for such applications.

# Getting The Most From Your Electric Motors

- **Frequency (HZ).** The standard frequency is 60 Hz in North America and usually 50 Hz elsewhere. If the nameplate shows more than one frequency, it should display frequency-dependent characteristics for each. The increasing use of variable-frequency drives (VFDs) calls for a frequency range on the nameplate. If only one frequency appears on the nameplate, consult the manufacturer before applying the motor on a VFD. NEMA Std. MG 1 allows motor frequency variation of only  $\pm 5\%$  for non-VFD applications.
- **Number of phases (PH).** Single or three phase. The motors within the scope of this booklet are three phase, which have three alternating current (AC) power lines supplying the motor.
- **Rated load current (AMPS).** Rated load current in amps is at nameplate horsepower (hp) with nameplate voltage and frequency. Exceeding the nameplate current rating, even on only one phase, will reduce the winding's thermal life.

Don't try to determine loading from motor current. Motor current isn't directly proportional to load. Unbalanced line voltages, undervoltage conditions or both can cause current to deviate from nameplate amperes. For a matched current system on VFD applications, review both motor and drive.

- **Voltage (VOLTS).** NEMA Std. MG 1 defines standard voltage ratings for three-phase motors. Some common ratings are 200, 230, 460 and 575 volts.

NEMA Std. MG 1 allows motors to operate at  $\pm 10\%$  of the nameplate voltage rating, while pointing out that this may degrade performance (e.g., efficiency). For instance, if applied voltage is reduced 10%, the motor will develop at least 20% less torque. The line current also may increase (10% or more), as well as the motor's operating temperature.



**A motor's operating temperature at full load may be higher on unbalanced voltage than on balanced voltage. Efficiency and winding life may also decrease, even if the motor has been derated.**

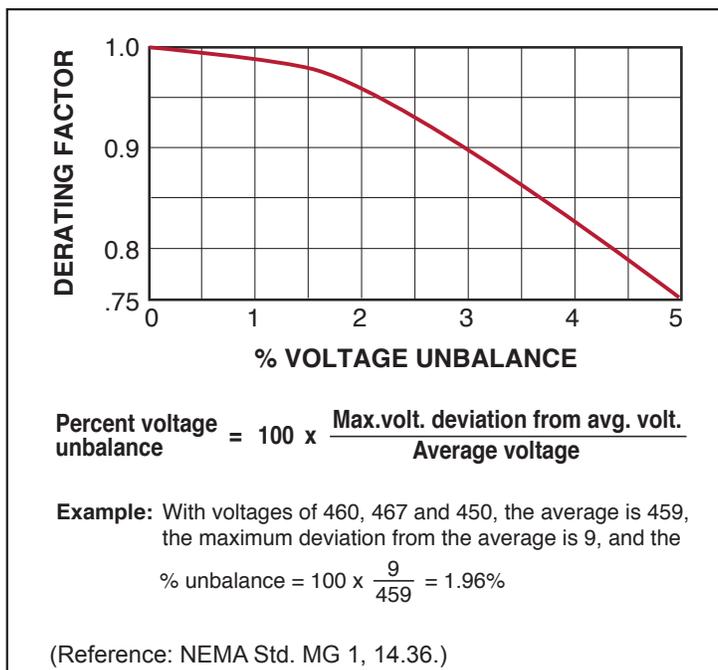
Some manufacturers show several different voltages on the nameplate, such as the common 208-230/460 rating. Since NEMA's  $\pm 10\%$  tolerance for a 230-volt rating would extend down to 207 volts ( $230 \times .90 = 207$ ), that appears safe. The problem is that the actual voltage from a 208-volt source could dip well below 207 volts.

In addition, ordering a motor rated 480 volts for use on a 480-volt circuit, while allowable, isn't recommended. To account for voltage drop in the circuit, the standard motor rating is 460 volts.

# Getting The Most From Your Electric Motors

Phase voltage unbalance (i.e., a different voltage on each phase) is often overlooked, but NEMA Std. MG 1 calls for reducing the horsepower rating if it exceeds 1%. At the maximum allowable unbalance of 5%, horsepower must be reduced 25% (Figure B2). Don't confuse voltage unbalance with voltage variation. Because of the additional losses associated with it, voltage unbalance also reduces motor efficiency.

- **Code letter for locked rotor kVA (CODE).** NEMA Std. MG 1, 10.37.2 defines locked rotor kVA per hp with a series of code letters (A to V). Generally, the farther the code letter is from A, the higher the inrush current per hp. A replacement motor with a "higher" code letter may require different upstream electrical equipment, such as a larger motor starter.



**Figure B2. Derating curve for voltage unbalance.**



**Similar nameplate letter designations also represent other motor characteristics. Read the nameplate carefully to avoid misinterpreting code, design and insulation class.**

- **Design letter (DES, NEMA DESIGN, DESIGN).** NEMA Std. MG 1, 1.19 defines four motor designs (A, B, C and D) in terms of torque and current characteristics (see Tables B2 and B3 and Figure B3). Most motors are Design B because of their comparatively high efficiency and torque characteristics. Design A motors may be more efficient but are used infrequently because their relatively high starting current can cause nuisance tripping of motor protection circuitry. Design A motors may also require larger than standard-size starters.

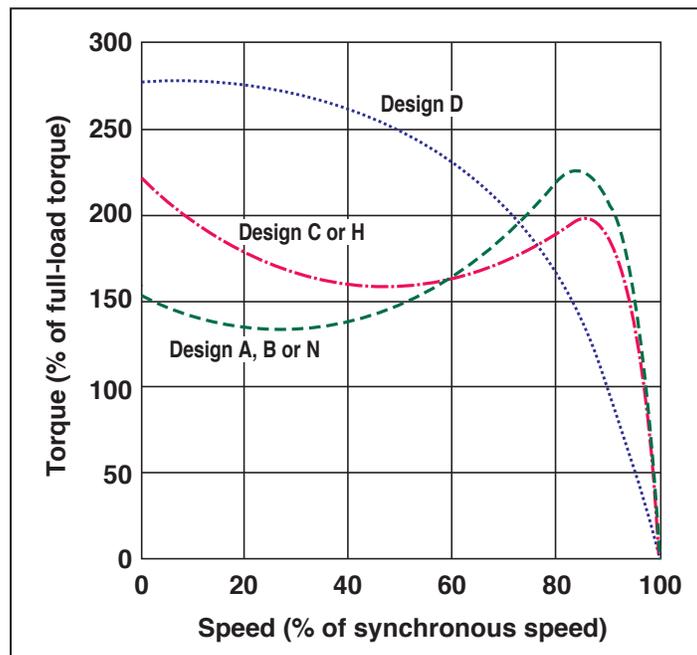
**Table B2. NEMA design versus torque and current characteristics.**

NEMA design	A	B	C	D
Locked rotor current	High	Medium	Medium	Medium
Locked rotor torque	Medium	Medium	High	Very high
Maximum torque	High	Medium	High	Very high

# Getting The Most From Your Electric Motors

**Table B3. Typical applications for various designs.**

NEMA designs	Applications
A and B	Fans, blowers, centrifugal pumps, unloaded compressors, and loads where starting torque requirements are relatively low.
Design C	Conveyors, crushers, reciprocating pumps and compressors, where starting under load is required.
Design D	High peak loads that require large speed variation such as punch presses; also hoists and elevators.



**Figure B3. Speed/torque curves for NEMA design motors.**

- **Nominal efficiency (NOM EFF).** Efficiency is defined as output power divided by input power, expressed as a percentage:

$$(\text{Output/Input}) \times 100$$

NEMA requires nameplate efficiency to be a “nominal” value based on the average of a large group of motors of the same design. The actual efficiency of any one motor must be within a tolerance band based on a  $\pm 20\%$  variation in motor losses. The nominal efficiency is often used to calculate energy consumption. Nominal efficiency must be included on polyphase induction motor nameplates when required by NEMA Std. MG1, 12.59.

- **Service factor (SF).** The service factor is only required on a nameplate if it is higher than 1.0. Industry standard service factors include 1.0 for totally-enclosed motors and 1.15 for open motors.

# Getting The Most From Your Electric Motors

Totally-enclosed, fan-cooled motors with a 1.15 service factor are also widely available, and values of 1.25, 1.4 and higher exist.

At nameplate voltage and frequency, the allowable overload for a motor with a nameplate service factor equals the rated load multiplied by that service factor. Such operation, however, will adversely affect efficiency, power factor, and temperature rise.

- **Thermally protected (THERMALLY PROTECTED).** The words “THERMALLY PROTECTED” are required if the motor provides all the protection described in NEMA Std. MG1, 12.57 (see NEMA Std. MG1, 1.72 and 1.73).
- **Overttemperature protections (OVERTEMP PROT. \_\_).** For motors rated above 1 hp equipped with over-temperature devices or systems. A number from NEMA Std. MG 1, 12.58 must be inserted in the blank to identify the protection type.

## Other terms

Other terms that may appear on NEMA nameplates include:

- **Power factor (PF or P.F.) and correction capacitors (MAX KVAR or MAX CORR KVAR).** Power factor is the ratio of active power (watts) to apparent power (volt-amperes) for the motor at full load. If power factor is shown on the nameplate, NEMA recommends (not requires) expressing it as a percentage.

The nameplate may also list the maximum size of the power-factor correction capacitor with a notation like MAX CORR KVAR, followed by a numeric value in kilovars. Using a capacitor value greater than indicated may result in higher voltages that could damage the motor or other components.

- **Bearings (SHAFT END BRG, DE BRG, OPP END BRG, ODE BRG).** Some motor manufacturers supply bearing data on nameplates, which usually includes both the shaft- or drive-end bearing and the opposite-drive-end bearing. Although designations vary by manufacturer, rolling-element bearing types and sizes are commonly indicated by an “ABMA number” from the American Bearing Manufacturers standards.
- **Serial number (SERIAL NO or SER. NO.).** Nameplates typically include the motor manufacturer’s brand name and a serial number or other unique number that can be used to trace the motor through manufacturing.

# Getting The Most From Your Electric Motors

## Appendix C: Motor storage recommendations

### Motor storage basics

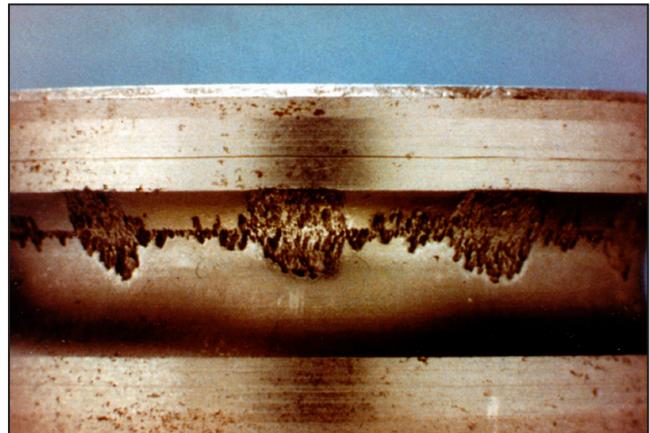
Appropriate storage procedures can protect a motor from environmental damage. Determine which steps to take based on where and how long the motor will be stored.

- **Less than one month.** Protect the motor from the weather and keep the winding temperature 5-10°C (10-20°F) above the ambient (see “Preparations for storage” below).
- **More than one month.** Follow the recommendations in “Preparation for storage” and “Periodic maintenance” on Page 32.

These storage and maintenance intervals aren’t absolute; specific environmental conditions may require different schedules. It’s not always practical to treat smaller motors with the same care as larger or more critical machines.

### Preparation for storage

- **Indoor storage.** If possible, store motors indoors in a clean, dry, heated area.
- **Outdoor storage.** If this is necessary, loosely cover the motor with a tarpaulin that reaches the ground but allows enough air circulation to minimize condensation. Protect the motor from flooding and harmful chemical vapors.
- **Ambient vibration.** Choose a storage area away from ambient vibration sources like heavy construction equipment, production floors, busy roads and rail lines. When a motor isn’t rotating, prolonged exposure to even low-magnitude vibration can damage bearings—e.g., false brinelling (see Figure C1). Lock the shaft to prevent any movement if a motor must be stored in an area with high ambient vibration.
- **Position.** Store horizontal motors horizontally and vertical motors in stable vertical positions.
- **Keep motor windings clean and dry.** The best way to preserve the insulating properties of the windings is to prevent condensation and accumulation of moisture. Unless the storage area is climate controlled, keep the winding temperature 5-10°C (10-20°F) above the ambient by energizing the space heaters (if supplied) or by “trickle heating” one phase of the winding with a low voltage. Another option is to keep the winding warm with an auxiliary heat source by convection or by blowing warm air into the motor.



**Figure C1. The bearing damage shown here corresponds to the spacing of the rolling elements. It started as non-rotating vibration during shipping or storage.**

# Getting The Most From Your Electric Motors

- **Insulation resistance (IR) of the windings.** Measure and record the IR and correct it to a standard temperature before storing the motor, and again just before putting it in service. Address any drop in IR before installing the motor. (See “Insulation resistance (IR) test” on Page 14.)
- **Pests.** Take precautions to keep animals and insects from entering the motor. Rodents, snakes, birds or other small animals can damage the winding insulation, and mud dauber wasps and similar insects can block ventilation or drain openings.
- **Motor surfaces.** Coat all external machined surfaces (especially shaft extensions) with a rust preventive; also coat the bearing journals and other interior surfaces in damp environments. Apply a fungicide to protect the windings in tropical areas. Disassembly may be required to remove the protective coatings before the motor is put in service.
- **Grease-lubricated bearings.** To prevent corrosion and contamination during long-term storage, clean the grease fitting and remove the drain plug before inserting compatible grease. Following relubrication, purge the excess or old grease from the grease chamber by running the motor at least 30 minutes with the drain plug removed.

If the motor has been stored for several years, the grease probably will have hardened, and the drainpipe may be plugged with dried grease. In that case, the motor must be disassembled to remove the old grease and then relubricated before being placed in service.



**Don't relubricate bearings with the drain closed or while the motor is running.**

- **Oil-lubricated bearings.** Always drain the oil before moving the motor. After situating the motor in the storage area, fill the reservoir with the correct oil and appropriate rust and corrosion inhibitors. Ideally, the oil should cover the bearings completely without overflowing the stand tube or labyrinth seal. Drain and replace the oil before putting the motor in service.



**Always drain the oil before moving a motor. Otherwise oil may slosh out of the reservoir and contaminate the windings, or even initiate capillary action that can suction oil from the reservoir.**

# Getting The Most From Your Electric Motors

## Periodic maintenance

- **Monthly.** Inspect oil for evidence of moisture, oxidation or contaminants. Replace the oil whenever contaminants are noted, or every 12 months.
- **Every 1 to 3 months.** Rotate the shaft several times to maintain a film of lubricant on bearing races and journals. This also helps protect rolling bearings from damage (e.g., false brinelling) that can occur over time due to even low-magnitude vibration.
- **Every 2 to 3 months.** Measure the insulation resistance (IR) and compare the temperature-corrected results with baseline readings taken before the motor was stored. Address any drop in the insulation resistance before installing the motor. (See “Insulation resistance (IR) test” on Page 14.)
- **Every 3 months.** Inspect grease-lubricated bearings for moisture, oxidation or contaminants by drawing a sample from the drain. If moisture is present, the bearings have probably sustained rust damage and need to be replaced.
- **Every 5 years.** Consider replacing the grease and rolling bearings. By this time the oil and base ingredients of the grease have probably separated, and low-level vibration may have caused false brinelling of the bearing races. Corrosion staining or rust damage may also have occurred if moisture has collected between the balls and races.

# Getting The Most From Your Electric Motors

## Glossary

**Ambient temperature**—The temperature of the surrounding cooling medium; commonly known as room temperature.

**Baseline**—A measurement taken when a motor is in good operating condition that is used as a reference for monitoring and analysis.

**Breakdown torque**—The maximum torque that a motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed; also termed pull-out torque or maximum torque.

**Efficiency**—The ratio between useful work performed and the energy expended in producing it. It is the ratio of output power divided by the input power.

**Full-load speed**—The speed at which any motor produces its rated output.

**Full-load torque**—The torque required to produce rated power at full-load speed.

**General purpose motor**—AC induction motor of 500 horsepower or less, open or enclosed construction, continuous duty, designed in standard ratings with standard characteristics for use under service conditions without restriction to a particular application (see NEMA Std. MG 1, 1.6.1).

**Hertz (Hz)**—The preferred terminology for cycles per second (frequency).

**Horsepower (hp)**—A unit for measuring the power of motors or the rate of doing work. One horsepower equals 33,000 foot-pounds of work per minute (550 ft•lbs per second) or 746 watts. Also, the output rating of motors manufactured on the North American continent.

**Insulation**—Nonconducting materials that separate the current-carrying parts of a motor from each other or from adjacent conducting material at a different potential.

**Kilowatt (kW)**—A unit of electrical power. Also, the output rating of motors manufactured off the North American continent.

**Locked-rotor current**—Steady-state current taken from the line with the rotor at standstill and at a rated voltage and frequency.

**Locked-rotor torque**—The minimum torque that a motor will develop at standstill for all angular positions of the rotor with rated voltage applied at rated frequency.

**NEMA**—National Electrical Manufacturers Association.

**Poles**—The magnetic poles set up inside a motor by the placement and connection of the windings.

**Rated temperature rise**—The permissible rise in temperature above ambient for a motor operating under load.

**Rotor**—The rotating element of any motor or generator.

**Slip**—The difference between synchronous and operating speeds, compared to synchronous speed, expressed as a percentage. Also the difference between synchronous and operating speeds, expressed in rpm.

**Soft foot**—The condition where the mounting feet of a motor and the pads of the base are not all in the same plane.

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**Stator**–The stationary part of a motor; commonly used to describe the stationary part of a motor that contains the power windings.

**Synchronous speed**–The speed of the rotating magnetic field created by the stator winding.

Synchronous speed = (Frequency x 120) / (Number of poles)

**Torque**–The rotating force produced by a motor. The units of torque are expressed as pound-foot or pound-inch (English system), or newton-meter (metric system).

**Trending**–Analysis of the change in measured data over multiple data measurement intervals.

# Getting The Most From Your Electric Motors

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