APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Efficiency Opportunities through Motor Maintenance

Summary

The electricity consumed by a motor in one year costs more than the motor itself, by as much as 10 times. Multiplying this cost by the life of the motor puts the necessity of maintaining optimum motor performance in true perspective.

Motor maintenance is more than making sure the motor itself is operating correctly. It also involves ensuring that power supplied to the motor is within acceptable tolerances, that the motor's output power is efficiently transmitted to the load and that the load itself is properly maintained so as not to make the motor work harder than necessary.

Record-keeping is an essential part of motor maintenance. Comparing results of recent tests to historical records, maintenance staff can much more readily spot degraded performance and potential breakdowns and take steps to adjust the system and avoid costly unscheduled downtime.

Motor maintenance programs must be customized. Hot, dirty, humid conditions require more frequent checks of performance and attention to maintaining the physical condition of the motor. It may also be necessary to isolate motors from extreme conditions or to blow conditioned air over them for cooling purposes.

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How Motor Maintenance Saves Energy

Motors eventually become less efficient through wear, breakdown of lubricants and falling out of alignment. Scheduled maintenance is the best way to keep the whole system operating within acceptable tolerances. Properly applied, maintenance will also provide valuable information on potential motor failure so that unscheduled downtime can be minimized. Potential sources of efficiency loss are shown in Figure 1.

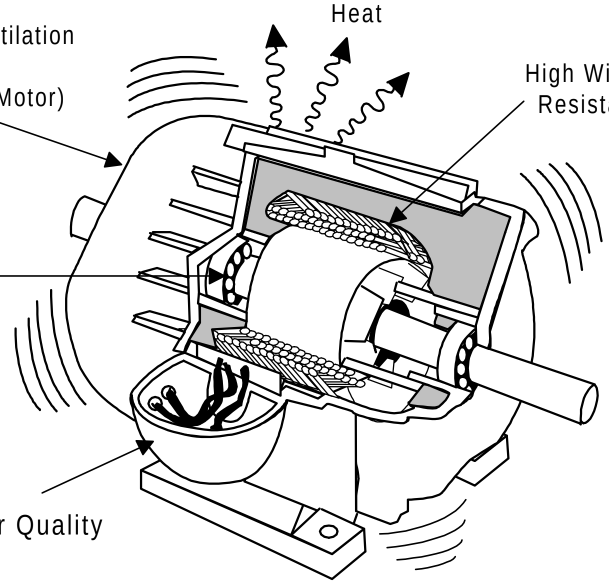

Figure 1: Sources of Potential Motor Efficiency Losses that can be Avoided with Proper Maintenance *(Reprinted with permission. Copyright 1992 by Dranetz Technologies, Inc. All rights reserved.)*

Motor Maintenance Energy-Saving Strategies

The greatest enemies of efficient motor operation are improper installation or adjustments, low-quality electrical power, adverse environmental conditions (*e.g.*, dust, dirt, moisture, extreme temperature) and wear. The general guidelines in this section address these issues. For more detailed information, see Reference 2.

Motor Maintenance Logs

A motor maintenance program is of most value when it is consistently applied. The system should remind staff when it is time to perform specific maintenance functions on individual motors; provide a means of recording the functions performed; and act as an historical record to track the performance of individual motors.

Each motor should have a maintenance form, recording the load served (*e.g.* supply fan #1 or boiler feedwater pump #3) and the motor's make, model, serial number and ratings. Specifications for ancillary equipment (*e.g.*, drive belts, pulleys) should be recorded for quick reference. Space should be provided for recording observations of unusual motor performance.

Computerized maintenance programs are available that will notify plant personnel of upcoming motor maintenance. These programs also provide a convenient repository for information on all motors (plus other systems that require maintenance) and analysis tools for determining how effectively maintenance is being carried out.

Proper Lubrication

Proper lubrication is essential to long operating life for motors and all mechanical equipment. It must be done periodically and consistently—it is too late when the motor audibly communicates its needs. Many times service personnel try to quiet a noisy motor by pumping lubricant into the bearing. This may work for a short while but the life of a noisy bearing is limited and over-lubrication (as described below) may result.

Too much lubrication can be just as harmful as too little. Excess oil or grease tends to accumulate: ***Windings***[1] become coated and this film collects even more dirt, moisture and, if ***brushes*** are involved, carbon dust. Oil and grease on the stationary switch contacts may cause them to overheat, arc or burn, and even to weld themselves closed. Lubricants harm many internal motor parts. If the manufacturer has lubricant recommendations they should be followed, especially in severe duty applications.

[1] Bold-Italic words are defined in the section titled Definition of Key Terms.

Shaft Alignment

Larger motors are usually coupled to their loads and proper shaft alignment is important to adequate bearing life. In belt-driven applications, belts must be perpendicular to the shaft axes or they will wear and bearing life will be shortened. Alignments made under one set of circumstances can change due to temperature, loading, foundation movement and rotational speeds.

Motor output power is transferred to the load by belts, chains, gears or direct couplings. Belt drives depend on pulleys, or sheaves, mounted on the shafts of the motor and the load. A continuous belt wraps around the sheaves and, as the motor sheave turns, power is transmitted to the load. Chain drives work in a similar manner, but the belt is replaced by a chain and sheaves are replaced with cogged sprocket wheels, similar to a bicycle chain and sprocket. Gear drives can be used to greatly increase or decrease the rotational speed of the load and to reverse its direction, depending on the sizes, number and arrangement of gears used. Direct couplings make a semi-permanent connection between motor and load shafts that are aligned end-to-end and may be categorized as rigid, flexible or fluid. For a more extensive discussion of motor drive systems please see Reference 5.

In direct-coupled drives, proper alignment exists when a straight line through the motor shaft axis extends through the axis of the driven equipment shaft. Flexible couplings can, to some extent, make up for improper alignment.

An exaggeration of a typical direct-coupling misalignment situation is shown in Figure 2 which contains both radial and angular errors. The object is to make distances A1 and A2 between the coupling faces equal, and to reduce distance R between the coupling rims to zero.

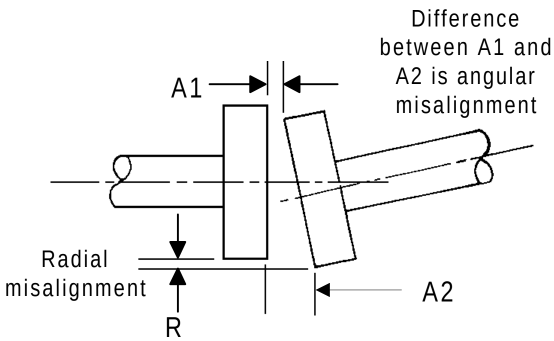

Figure 2: Typical misalignment of motor coupling *(Source: Fuchs)**

Belts and Pulleys

Pulleys also need to be precisely aligned for optimum performance. They must also be properly spaced for belts to have the right tension. Figure 3 illustrates both parallel and angular misalignment; either will result in unnecessary friction between belt and pulley.

Belt tension is achieved by moving the pulleys. If they are too far apart, undue stress is placed on the bearings of the pulley shaft, shortening their life. If too close together, the belt will slip on the pulleys, losing efficiency and wearing excessively.

Belts and pulleys must be kept clean. Dirt, oil or grease on either can lead to shortened belt life and inefficient transfer of power. If needed, belts should be cleaned with a rag dampened with a light, non-volatile solvent. Belts should not be soaked or brushed with solvent and they should not be sanded or scraped.

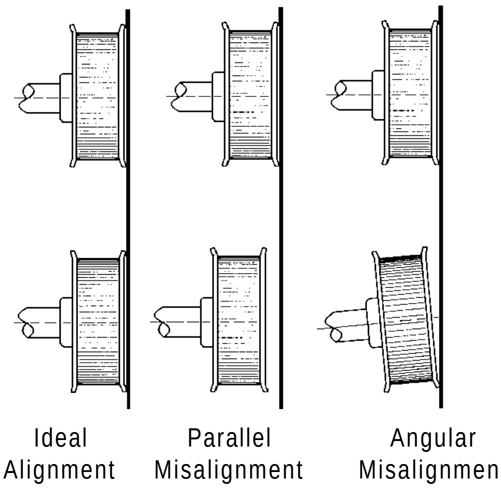

Figure 3: Typical misalignments of sheaves *(Source: Fuchs)**

Bearing Maintenance

All bearings require maintenance to perform properly and achieve their service lives. Bearings can be classified as sleeve or anti-friction types. In sleeve bearings the shaft rides in a thin film of lubricant between the shaft and the bearing. Antifriction bearings have ball or roller bearings that spin between the shaft and the bearing housing. There is considerable overlapping in the use of both types in electric motors. Proper maintenance consists simply of keeping the bearing clean, lubricated and loaded not in excess of its rating.

Commutator Maintenance

The ***commutator*** is a vital part of every DC motor. Fortunately, commutators tend to show signs of distress in advance of serious trouble. Periodic inspection is a valuable preventive maintenance tool. Please see Reference 2 for a detailed discussion of what to look for when performing commutator inspections.

Brushes must maintain good physical and electrical contact with the commutator surface. If surface irregularities or rotational speed cause the brushes to lose contact, arcing, burning and flat spots can occur. In extreme cases the leading edges of brushes may be shattered.

Besides mechanical surface considerations, the proper surface film must be developed and maintained. This film is the result of electrochemical deposition of carbon, graphite, copper oxide and water vapor on the commutator surface. Brush and commutator wear will be accelerated if this film is damaged mechanically, electrically, or chemically, or is contaminated by dirt. A smooth, even, glossy copper, brown, or chocolate color is normal. Sometimes a color pattern may be evident between bars; as long as the pattern is repeated around the entire commutator there is no cause for concern.

Regular inspection will reveal developing problems. If problems are noted, the commutator should be removed and turned on a lathe to remove any flat spots and ensure concentricity. Brushes should also be replaced during reassembly.

Power Quality

Power quality can have a large impact on motor performance. Motors are designed with the assumption that electric power will be provided within certain tolerances. It is easy to assume that because motors are operating the power is within acceptable tolerances, but this is not always true. Power quality can be degraded as it is supplied from the utility or at the facility; in either case it is necessary to identify the cause and correct it. Important power quality issues are discussed below.

Single-Phasing

This occurs when one leg of the three-phase supply system opens. It could be caused by a utility failure, a broken circuit in the plant, a bad contact in the motor starter or a single blown fuse.

Three-phase motors subjected to single-phasing while carrying a substantial load will continue the attempt to drive their loads, while drawing elevated currents on the remaining two lines. Unless removed from service, they will experience winding damage: Inspection will show a repeated pattern of burning in the end-turn region; windings connected to the phase that was de-energized will appear undamaged. Ampere readings taken on each leg will show two legs at high current levels will carry no current.

Unbalanced Voltage Operation

This condition is recognized in the industry standards. All polyphase motors can operate successfully when the unbalance at the motor terminals does not exceed 1 percent. Voltages preferably should be evenly balanced as closely as can be read on a voltmeter. In actual practice, there is always some degree of unbalance. For example, you might obtain three line-to-line voltage readings of 233, 230 and 228 volts. The formula for calculating percent unbalance is:

$$\%\_unbalance = 100 \times \frac{max\_deviation\_from\_avg\_voltage}{avg\_voltage}$$

It is not recommended that motors be operated with an unbalance condition of more than 5 percent, which carries a recommended motor derating to 75 percent of rated horsepower according to NEMA Standard MG1-14.34. Corrective action should be considered when voltage unbalance exceeds 1 percent. Heat generated by a 2 percent unbalance may reduce insulation life 8 times.

Measurement of the three line-to-line voltages at the service entrance will indicate if voltage unbalance originates with the utility. Usually the problem is internal and caused by an unequal distribution of single-phase loads between the phases. Correction requires redistributing the single-phase loads between phases to produce a balanced supply to all motors affected.

Voltage and Frequency

Permissible limits for voltage and frequency are also defined by NEMA. Both ac and dc motors will operate satisfactorily over a range of ±10 percent of rated voltage and universal motors over a range of ±6 percent of rated voltage. The standards also permit a frequency variation of ±5 percent of rated frequency. A combined variation in both voltage and frequency of 10 percent (sum of absolute values) is permitted, provided the frequency variation is not more than 5 percent and the voltage variation for universal motors does not exceed 6 percent (except for fan motors).

The turning force produced by a motor (*i.e.*, its torque) is proportional to the square of the applied voltage. For example, if the voltage applied to a motor is 80 percent of the motor's design voltage, it will only produce approximately 64 percent of it rated torque. High efficiency motors are less affected than standard motors.

Motor Circuit Analysis

An advance in motor testing has evolved as a powerful tool for assessing and maintaining motors and the electric circuits that feed them. The technology, generally called motor circuit analysis (MCA), measures the absolute and relative resistance, inductance, and capacitance of motor circuits and windings. An historical record of such testing lets the operator assess the integrity and failure risk of individual motors. Consistently applied, MCA can help avoid motor failures, enable proactive maintenance or replacement, and improve the energy efficiency of motor systems in general.

What makes MCA unique is the grouping and automation of powerful testing methods it includes. Because all test data are acquired by a common system and the various tests are nearly simultaneous, MCA offers much better assessments of motor integrity.

MCA is still an evolving technology, but at least five manufacturers offer MCA equipment and testing services. Several dozen industrial companies are using the technology and report encouraging results in reduced downtime, increased production, and improved energy efficiency.

More traditional analytic methods involve measurements of winding resistance. Insulation electrically isolates the windings from the grounded frame, one conductor from another and one phase from another. They are subject to electrical, mechanical and thermal stresses and the effects of external contamination and moisture. The service life of a motor will largely depend on the level of care given its insulation. The maintenance program to be followed depends on the operator's experience and philosophy. The records of tests performed on a motor can be extremely useful in evaluating its present insulation condition.

Motor windings are factory-tested, but in spite of this testing, motors have a higher failure rate immediately after installation. Once the “infant mortality” phase has passed the failure rate will be lower until the effects of service and aging begin to take hold.

In the field, low-voltage tests are generally used to determine insulation condition. This may be the only test required or it may be the necessary initial test prior to high-voltage testing. This testing is referred to as “megger” testing after the piece of equipment used. Acceptable values of insulation resistance must not be less than 1 megohm per kV of motor rating (rounded up) plus 1 megohm when testing is performed at 104°F. For example, a 600 volt motor is rated at 0.6 kV, so minimum insulation resistance would be 0.6 + 1 megohms rounded up to 2 megohms. Insulation resistance doubles for each 18°F reduction in temperature (above the dew point) and corrections should be applied to tests made at other than 104°F winding temperatures. If the 600 volt motor was tested at 86°F, the minimum resistance would be 2 x 1.6, or 3.2 megohms, rounded up to 4 megohms and tests performed at 68°F would require a minimum resistance of 2 x 3.2, or 6.4 megohms rounded up to 7 megohms.

Larger motors have more insulation surface, thus lower insulation resistance. Motors as large as the 680 frame size should have insulation resistances above 50 megohms if clean and dry and the insulation is not deteriorated. Small motors with healthy insulation may register close to infinity on the megger scale.

Keeping records of past measurements is very important. Consider, for example, two motors both testing at 18 megohms. Motor A has an historical insulation resistance level of 120 megohms; clearly its insulative value has significantly deteriorated and thorough cleaning and/or drying is called for before placing it in service. Motor B, on the other hand, has an historical figure of 20 megohms and can be placed in service with little cause for concern.

Dielectric absorption tests provide additional valuable information, especially for higher voltage motors with form-wound coils. This method requires the determination of insulation resistance after one minute and again after 10 minutes of megger voltage application. The 10-minute value divided by the one-minute value is called the polarization index. The recommended minimum value for ac and dc motors is 1.5 for Class A insulation and 2.0 for Classes B and F insulation.

These tests are considered more meaningful than one-minute megger tests. Low values generally indicate moist or contaminated windings which require drying out or cleaning. The motor can be disassembled and the windings cleaned with an approved solvent compatible with the insulation system. Dirt can be flushed from windings and cooling passages with water, but careful drying will have to be performed. Windings are normally dried either in baking ovens at 175 - 195°F, by blowing warm, dry air over them, or by passing current through them to generate internal heat. This process can take several days and periodic testing should be performed to track progress. For more information on insulation testing and maintenance, refer to IEEE Standards 43 and 432.

Applicability

Motor maintenance is applicable to all motors without exception. Because the cost of energy to operate a motor over its life far exceeds its original cost, it makes sense to minimize energy costs by maintaining motor systems at close to optimum efficiency. Table 1 provides general guidelines on the frequency of inspections and testing.

Field Observations to Identify Motor Inefficiencies

This section discusses field observations and checks to ensure that motor maintenance practices are sufficient for efficient system operation.

Related to Applicability

- **The environment** in which motors operate is the most obvious indicator of the level of maintenance required. Dirty, dusty, humid or hot environments indicate the need for more frequent maintenance.

- **Motor temperature** has traditionally been used as a rough indication of motor efficiency—inefficient motors have greater losses manifested as heat, which leads to a hotter motor. This test

Activity	Environment		
	Clean, Dry	**Moderate**	**Dirty, Wet**
General Inspection Environment - Cleanliness - Lubrication - Belts - Couplings	6-12 Months	3-6 Months	1-3 Months
Testing Electrical Integrity - Volts/Amps - Temperature - Vibration	12-18 Months	8-12 Months	3-8 Months
Lubrication Oil Grease	6 mos. 12 mos.	3 mos. 6-12 mos.	Monthly 3-6 mos.
Bench Inspection: Disassemble - Inspect - Repair - Reassemble - Check	6-12 Months	3-6 Months	1-3 Months
Motors with brushes, slip rings or commutators: Check brushholders, commutators, rings and brushes	6-12 Months	3-6 Months	1-3 Months

*Table 1: Approximate frequency of motor O&M procedures (Source: Fuchs)**

is not as reliable as it once was due to better insulation performance. Table 2 gives maximum temperature and ranges of operating temperatures for existing winding insulation classes. Note that these are winding temperatures; the motor housing temperature will be lower. It is best to use a contact thermometer on the motor housing and record the readings for ongoing maintenance procedures.

- **Excessive vibration** indicates that some part of the motor system is out of balance and needs attention**.** The imbalance may be in the alignment of the drive, it may originate with the load, or it may be due to worn or out-of-balance motor parts.

- **Excessive noise** is another indication of a problem with the system. These problems can arise from worn parts (*e.g.*, bearings), broken parts within the motor, squealing of loose belts, chatter from misaligned drives and a number of other sources.

Insulation Class	Maximum Winding Temperature	Winding Temperature Rise Above Ambient
A	220°F	140°F to 160°F
B	265°F	175°F to 195°F
F	310°F	220°F to 240°F
H	355°F	255°F to 275°F

Table 2: Approximate motor winding maximum operating temperature and temperature rise (Source: Fuchs)*

- **Starting and stopping** a motor stresses all its parts, and this can degrade performance. The more frequently it is stopped and started, the more frequent maintenance should be.

Related to Energy Savings

- **Motors hot to the touch** are usually dissipating energy as heat. An efficiently operating motor converts at least some of this wasted energy directly from electric to mechanical energy (*i.e.*, to turn the motor shaft). Thermographs can be very helpful in identifying trouble spots.

- **Loud or vibrating motors or loads** indicate a problem that should be resolved. Energy losses associated with noises and vibrations may not be great, but may indicate problems such as worn bearings, improper belt tension or broken parts, any of which will have some impact on energy performance.

- **A buildup of dirt, dust, grease or other contaminants** indicates the motor is probably not getting adequate cooling, which will result in inefficient operation.

Related to Implementation Cost

- **The cost of an effective electric motor O&M program** will be influenced by the number of motors and their sizes.

- **Motors with difficult access** will require more labor effort to maintain.

- **Motors in dusty, dirty or humid environments** may require regular inspections as much as six times as often as motors in clean environments.

- **Loads that tend to vibrate** may require increased attention to alignment and tension.

Estimation of Energy Savings

Energy savings realized from motor maintenance come from maintaining optimum efficiency and are really avoided consumption, as opposed to energy reductions. An accurate estimate of savings would require determining what would be consumed if good maintenance were not practiced. This value is difficult to quantify. The following equations provide a method for determining demand reduction and energy savings.

$$kW_{savings} = 0.746 \times HP \times \sum_{i=1}^{n} \left[LF \times \left(\frac{E_N - E_O}{E_O} \right) \right]_i$$

$$kWh_{savings} = \sum_{i=1}^{n} \left(kW_{savings,i} \times hours_i \right)$$

where:

0.746	=	Conversion from horsepower to kW
HP	=	Motor rated horsepower
LF	=	Load factor
E_N	=	New efficiency obtained by implementing the strategy
E_O	=	Old efficiency prior to implementing the strategy
hours	=	Annual operating hours
i	=	Incremental load factor bin for the motor
n	=	Total number of load factor bins

If the motor experiences a variable load, the range of loads should be divided into bins, or ranges of operation (signified by *i* in the equation above) and calculations made for each of those ranges, then summed. For example, the entire load range may be divided into bins representing decades of fractional load factors (*i.e.*, 0 to 0.10, 0.10+ to 0.20, 0.20+ to 0.30, *etc.*) and representative values of load factor, efficiencies and hours would be inserted in the equation for each bin. Note that for motors under steady load, this equation is simplified as there is then only one operating range for the motor.

In actual application, it is often necessary to estimate the hours of operation in each load factor operating range. Similarly, efficiencies for each range may have to be obtained from plots or charts of typical motor data.

According to EPRI, “The efficiencies of mechanical equipment in general can be increased typically 10 to 15 percent by proper maintenance.” This reduction in energy consumption is difficult to quantify as it is an avoided, rather than a reduced, consumption. The only way to determine savings would be to establish a baseline condition by stopping maintenance functions, which is clearly unacceptable.

Factors Affecting Motor Maintenance Cost

Motor maintenance costs will be influenced by ongoing costs such as: testing, inspecting, cleaning and drying; parts for repairs; consumables (*e.g.*, lubricants, belts, *etc.*); and labor. Costs will be increased directly as the frequency of maintenance activities is increased. In addition, one-time costs may be incurred from time to time to correct problems associated with power supplied to the motors.

The level of testing performed on motors determines the cost of such testing. These tests can be as simple as having maintenance personnel take voltage and current draw measurements, or as sophisticated as comprehensive motor circuit analysis tests. Actual costs for testing and repairs should be obtained from providers of these services.

If the motor is in a particularly dirty or hot location, it will require as much as six times as much attention. It is essential that motors be selected based on the environment in which they will be operating. It may also be desirable to isolate the motor from the environment with barriers or filters and cooling air in order for the motor to operate within design limits.

Laws, Codes, and Regulations

The *National Electrical Code* (NEC) and Underwriter's Laboratories (UL) standards provide minimum requirements for the safe installation of electrical equipment. In addition, NEMA provides standards relating to motor ratings and procedures to be followed in rebuilding and repairing motors to ensure adequate performance and safety.

Definitions of Key Terms

- **Brushes:** Stationary carbon blocks connected to the power supply of a dc motor. Electric current passes through the brushes to the commutator.

- **Commutators:** Sliding electrical contacts between the rotating armature and the stationary brushes connected to the external power supply in dc motors. The action of the electrical current on the commutator provides the force to turn the motor.

- **Rotor:** The center part of a motor, which in most designs is attached to the output shaft and rotates.

- **Stator:** The fixed outer portion of a motor that surrounds the spinning rotor.

- **Windings:** In motor stators, the winding is a number of turns of insulated wire, usually copper, wrapped around a core of steel laminations.

References to More Information

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