Guidelines for Repair/Replace Decisions and Performance Optimization

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GUIDELINES FOR REPAIR/REPLACE DECISIONS AND PERFORMANCE OPTIMIZATION

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ABSTRACT

For general-purpose motors, there are many cases where replacing a failed motor with a new one of EPACT efficiency levels or better is the best choice. However, in some cases, the motor will fail again unless the root cause of failure is addressed through some modification to the motor or the system.

There are also many cases where repairing the existing motor is the best choice. This is especially true if an upgrade is required to address the cause of failure, or in some cases, where cost, availability or unique performance is an issue. The motor service center is in an excellent position to make these assessments. The purpose of this paper is to explore both choices and present some of the many options available.

Quite often when a motor fails, the procedure is to remove the damaged motor from service and replace it without a thorough evaluation of the "root cause" of the failure. Depending on the motor size and the amount of damage, the old motor may be repaired and placed into spares inventory or even scrapped.

The problem with this approach is that the replacement motor, whether new or rebuilt, may fail again for the same reason. If a root cause failure analysis is conducted, it is often possible to identify and correct the underlying cause. All that may be required is to modify the motor, driven equipment or system to extend the *mean time between failures* (MTBF) significantly.

In most cases, where a standard motor is no longer suitable for the application, the service center is able to make the required modification faster than the motor manufacturer can produce a unique model.

The application checklist in Appendix A can be used to assist in this analysis.

This paper was presented at EASA's Convention in Chicago, Illinois, June 25, 2001.

MOTOR REPAIR BEST PRACTICE GUIDES

The Electrical Apparatus Service Association (EASA) has available the following repair guidelines to assist in providing quality motor repairs.

- ANSI/EASA — AR100-1998, *Recommended Practice for the Repair of Rotating Electrical Apparatus*, Copyright 1998.
- Association of Electrical and Mechanical Trades (AEMT) — *Good Practice Guide: The Repair of Induction Motors, Best Practices to Maintain Energy Efficiency*, Crown Copyright 1998.
- EASA — *A Guide to AC Motor Repair and Replacement*, Copyright 1999.

These documents can be obtained from EASA headquarters in St. Louis to be used as reference documents when selecting or working with a motor repair facility.

Appendix D includes several sample pages from these documents.

INTRODUCTION

The Electrical Apparatus Service Association (EASA) has established Recommended Practices for its 2500 members around the world to assure that the repair process does not degrade the motor performance characteristics. This paper provides the reader with a repair guideline to implement these procedures with their local repair organizations.

Criteria are presented to determine when the repair of the motor is not practical and may lead to reduced efficiency levels. In some cases, it is possible to improve the level of operating efficiency during the repair process.

EASA members rebuild electrical equipment, primarily motors and generators. Many EASA service centers also rebuild peripheral equipment such as pumps and switchgear.

EASA is in the process of conducting a major test program to verify the results of these Recommended Practices. This paper will include an update on this work in progress.

EASA/AEMT MOTOR REWIND STUDY

INTRODUCTION

Previous studies were conducted on motors in the 10 hp range at four-pole speeds, which do not reflect the true degree of difficulty associated with rewinding the typical failed motor. The EASA/AEMT Motor Rewind Study is focusing on motors that are more typically rewound for both the NEMA and IEC designs.

OBJECTIVE OF STUDY

The major objectives of the study include:

- Issue a best practice guide for motor rewinds.
- Determine whether low- and medium-voltage machines respond similarly.
- Investigate the impact of repeated rewinds of the same motor.
- Establish the correlation between the *static core loss test* and the *running core loss test*.
- Evaluate the impact of physical damage to the stator core.

SCOPE OF PRODUCT EVALUATED

There will be at least 27 motors used in the study, most of which will be in the 50 to 200 hp range. Both 50 and 60 Hertz will be included, as well as low- and medium-voltage, IEC and NEMA frames, ODP and TEFC enclosures and two- and four-pole speeds.

PARTICIPATING MANUFACTURERS AND INSTITUTIONS

At least seven different motor manufacturers have committed to provide motors, technical data and assistance for the study. The Dowding and Mills facility in Birmingham, UK will facilitate all motor modifications and repairs that are part of the study. The University of Nottingham will perform the basic load testing on their dynamometers in Nottingham. There may be additional tests performed at Dowding and Mills.

ROUND ROBIN TESTING AND TEST PROTOCOL

One motor will be selected for round robin testing to ensure the accuracy of the Nottingham University facility. These tests will be conducted at the U.S. Electrical Motors Motor Technology Center in St. Louis, Mo. and the Invensys Brook Crompton UK plant. Both IEEE and IEC methods of efficiency testing will be conducted. All testing will include (at no load and full load) a loss segregation method that allows for detailed analysis.

OTHER DELIVERABLES

It is expected that due to the large size of the sample and the data collected additional deliverable might be developed as part of a supplementary document. It may be possible to update an EASA tutorial on other aspects of motor repair that affect overall motor performance and efficiency. Winding configuration, span, slot fill, flux density and mechanical factors will be considered.

SCHEDULE

The motors are all now at the University of Nottingham

FIGURE 1: REPAIR OR REPLACE OPTIONS

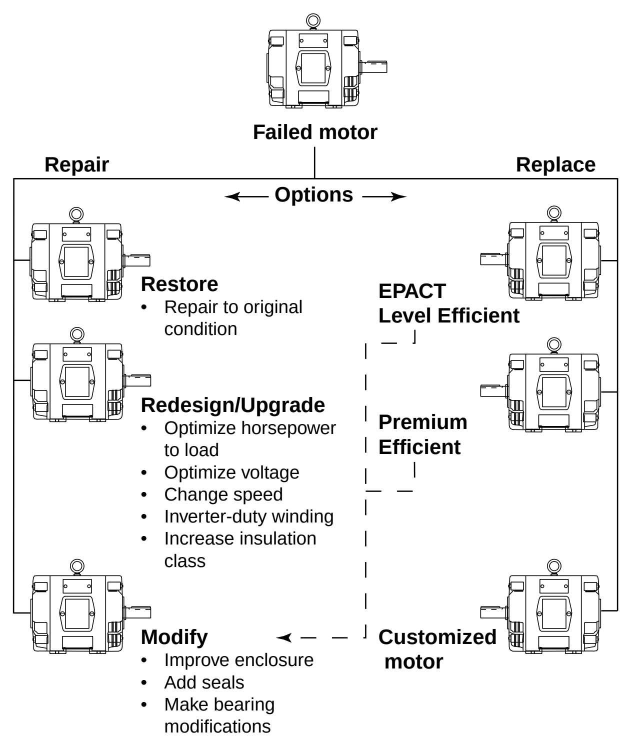
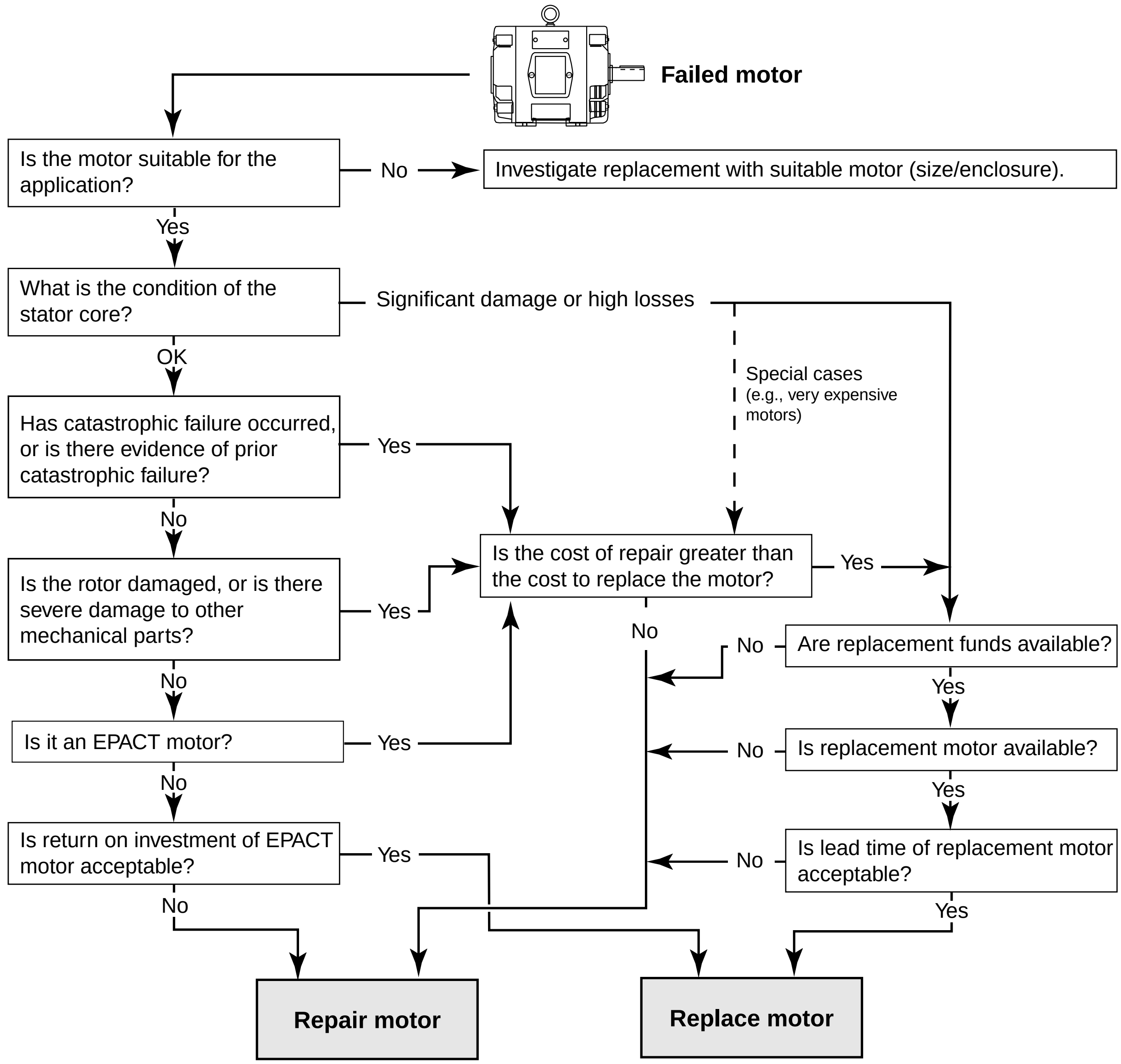


FIGURE 2: REPAIR OR REPLACE DECISION PROCESS



- Additional considerations include increased reliability, life expectancy and benefits of additional features, upgrades or modifications.

and testing is under way. It is expected that this evaluation will be complete by the end of 2001. The co-chairmen are David Walters and Austin Bonnett. The technical group will review progress monthly and have already held one meeting in Birmingham.

REPAIR-REPLACE DECISION MODEL

In the past, the decision whether to repair or replace an electric motor has been one of economics. Replacement of an older electric motor with a more efficient model often makes sense for a motor operating continuously. However, in most cases the decision is more complex (Figures 1 and 2). A motor operating infrequently, a motor with special mounting or design features, an EPACT motor or a motor larger than those covered by EPACT are all examples where the repair option may be the better choice.

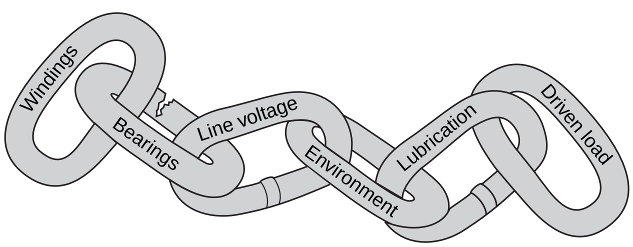
When comparing the cost to replace or repair an electric motor, the equation should include not only operating cost and payback period, but also downtime and associated factors such as capital depreciation, lost opportunities and customer good will. A replacement EPACT motor that fails within a year or two may have a significantly higher cost than a repair that optimizes the motor for its unique application.

Annual energy savings of several hundred dollars are quickly wiped out by unscheduled downtime when a motor fails unexpectedly.

Much of today's literature emphasizes efficiency and the cost of energy as stand-alone factors in the repair-replace decision matrix. Frequently, the cost of the motor – or its repair – is a small fraction of the total cost of downtime *when lost production is factored in.*

Considerations (other than efficiency and simple payback) include reliability, performance and anticipated motor life as well as availability of a replacement. Of these, the most critical may be reliability. A motor *customized* to its application will offer the greatest chance of long life. (See Appendix C for a list of repair options.) "Zero downtime" is a noble goal, one that requires commitment and planning.

NEMA MG 1-1998 defines Unusual Service Conditions (Appendix B). Most readers will recognize many of these as the norm for real-life motor applications. By itself, this fact may be justification for repair and customization of a failed electric motor.



It makes economic sense to identify the weak link in any process, and to detect imminent failure before it occurs. When the weak link is strengthened, the entire process becomes stronger. A motor subject to accidental washdown should be of a suitable enclosure, and can be modified to further protect the motor from this hazard. Likewise, since more than 50% of electric motor failures start as bearing failures, bearing temperature detectors or vibration probes are logical options in many cases, as shown in Figure 3.

With today's rapidly changing technology, the motor manufacturer is hard-pressed to incorporate emerging technology within a 2- to 3-year period. One advantage the service center has is its ability to deal with each unique motor and apply new technology *as it develops* to address specific concerns about that particular motor's application and environment.

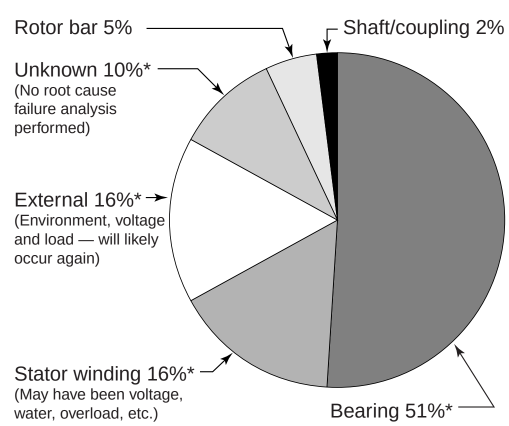
This means the end user can take advantage of unique technology that meets their unique needs.

TABLE 1: LEVELS OF REPAIR

Level 1	Basic reconditioning. Includes replacing bearings, cleaning all parts and replacing lubricant. Also adds seals and other accessories as agreed with customer.
Level 2	Includes Level 1 with the addition of varnish treatment of stator windings, repair of worn bearing fits and straightening of bent shafts.
Level 3	Includes Level 1 as well as rewinding the stator (replacing windings and insulation).
Level 4	Includes rewinding of the stator plus major lamination repair or rotor rebar. May include replacement of the stator laminations or restacking of laminations. Shaft replacement would normally fall into this category. In short, Level 4 involves major repairs that are costly enough to justify examining the option of replacement.
Level 5	Motors that would normally be replaced except for special circumstances faced by the customer (i.e., no spare or unacceptable lead time for a replacement). Level 5 includes misapplied motors, inadequate enclosures and pre U-frame motors. A motor that should be replaced, if not for the owners' inability to operate without it.

As these five levels imply, the damage resulting from a motor failure varies widely as do the associated repair costs. An evaluation process that fails to consider the various levels of "repair" is too simplistic to yield an accurate assessment.

FIGURE 3: FAILURES BY COMPONENTS



* *For each component shown, appropriate measures to either prevent or predict the failure could greatly reduce three-quarters of motor failures.*

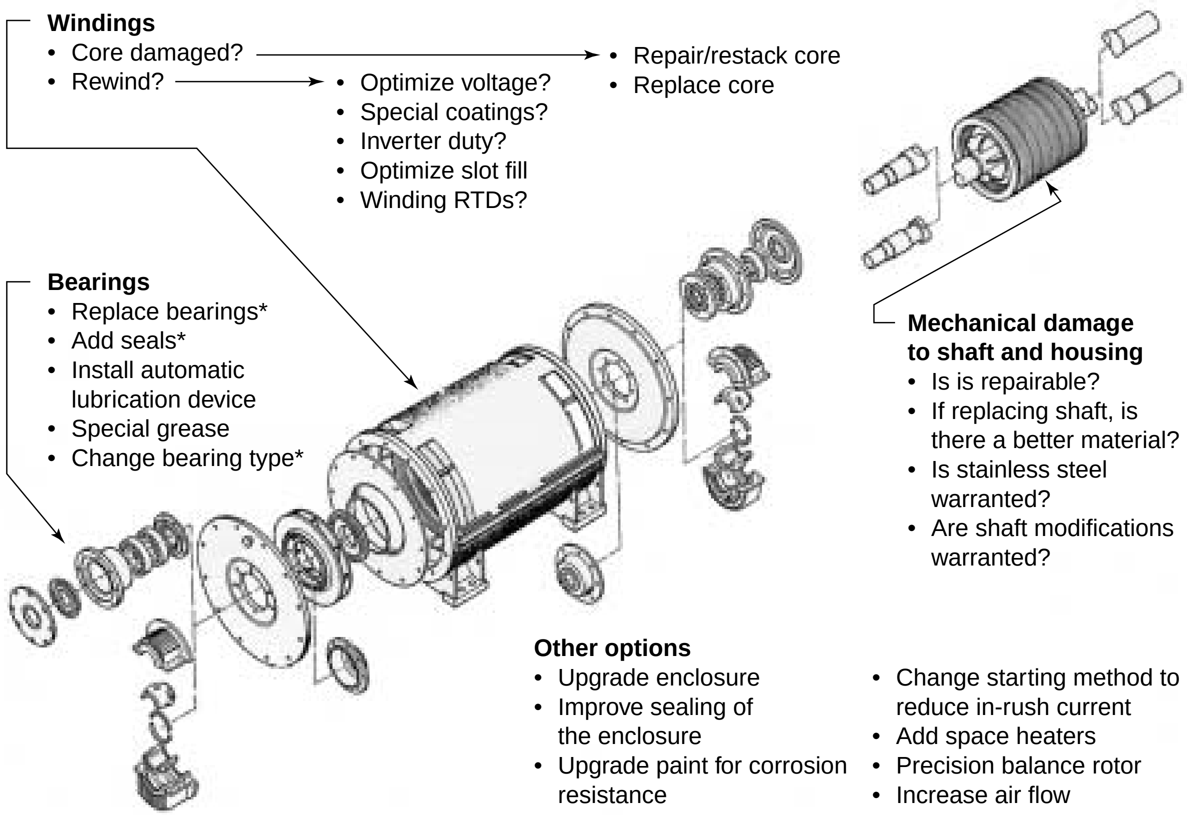
Reference: IEEE Petro-Chemical paper PCIC-94-01

Whether the concern is winding temperature, vibration or bearing temperature, specific accessories can be incorporated into the repair process to enhance motor life and permit the end-user to monitor the critical feature.

Consider winding temperature alone: There are 4 different RTD resistances, 14 different thermocouples and numerous thermistors and bimetallic switches in common use. Clearly, a stock motor cannot cover all these options. These features are a special order from motor manufacturers and usually require long lead times. The service center is able to tailor the motor repair to match the monitoring equipment used by the user, incorporating special features without impacting the repair turnaround.

Vibration monitoring is available as a continuous, online system. Accelerometers are but one item that can be retrofitted to improve the user's ability to predict equipment failure. Non-contact shaft probes, accelerometers intended for continuous monitoring and periodic data collection, accelerometers integral to a sophisticated continuous monitoring system; all are available

FIGURE 4 : POSSIBLE MOTOR UPGRADES AND MODIFICATIONS



Special considerations

Corrosion
- Special paints
- Varnish treatment
- Stainless steel shaft

Inverters
- Spike-resistant wire
- Higher corona-inception voltage
- Upgrade winding bracing

Abrasion
- Special energy-absorbing coatings
- Improve wedging
- Upgrade enclosure and add filters

Moisture
- Special coatings
- Shaft seals
- Seal leads
- Gaskets
- Seal brackets
- Space heaters

Heat
- Add RTDs
- Improve fan design
- Heat exchanger
- Upgrade insulation class

Severe starts
- Better shaft material
- Stronger shaft design
- Additional winding bracing
- Change starting method

** Adding seals or changing bearing types may affect efficiency.*

Illustration courtesy of Siemens AG

technology today. Once a user makes the financial commitment to a particular system, it is rarely practical to abandon it in favor of another emerging technology. That makes the service center a partner in maintaining the system(s) selected by each end user.

With most companies returning to their "core business," and outsourcing maintenance, the competent service center is best qualified to assess the cause of each motor failure and develop a plan to reduce the possibility of a repeat failure. The service center warranty ensures the repairer has a vested interest in identifying the root cause of the motor failure, and performing a quality repair.

EXAMPLES OF UPGRADES AND MODIFICATIONS

Once a cause of failure is determined, the service center can work with the equipment owner to identify specific remedies to extend MTBF. The following are but a few examples of frequent problems — and solutions — service centers encounter.

VOLTAGE OPTIMIZATION

A municipal pump station is located at the end of the power transmission line. Motor failures are common, and winding temperatures are higher than identical motors operating at the water treatment plant in town. Repeated measurements have confirmed chronic low voltage.

When a winding failure is the result of low applied voltage, the replacement motor — regardless of efficiency — will be subject to the same low line voltage. The solution, then, is to redesign the motor to optimize performance at the actual applied voltage. It is common to apply a 230 volt motor to a 200 or 208 volt application. Compounding the problem, the utility supplying 208 volts is allowed to deviate and may supply even lower voltage.

TABLE 2: EFFICIENCY AND WINDING TEMPERATURE

Volts	208	230
Efficiency (%)	80.6	84.4
Power factor (%)	85.0	82.7
Full load current (amps)	30.5	26.9
Inrush current (amps)	129	148
Temperature rise (° C)	91	72
Slip (%)	5.9	4.1
Design B, 4-pole, tri-voltage motor (208-230/460)		

Table 2 illustrates the effect on efficiency and winding temperature.

Low voltages are especially common in rural areas, where the motor may be operating at a considerable distance from the nearest substation. Irrigation pumps and municipal pump stations are two examples.

While many manufacturers can deliver a motor to optimize non-standard line voltage, typical manufacturer lead times of five to eight weeks may be prohibitive. The service center can accomplish the same voltage optimization during a motor repair.

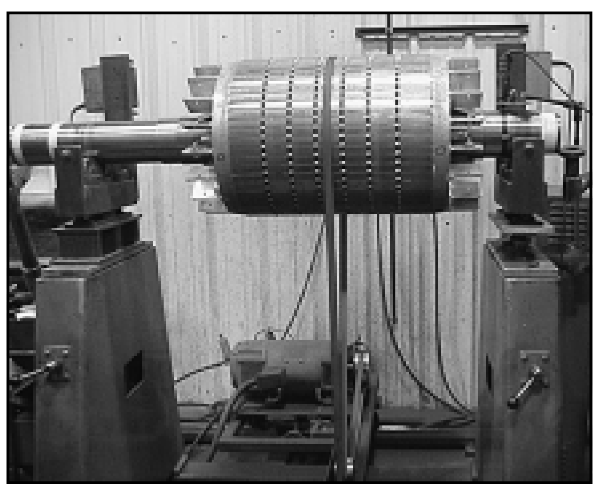
An added benefit: It is common practice for manufacturers to produce motors with up to 12 leads, so that the motor may be used on multiple voltages, often as a part-winding start or wye-start, delta-run. This means the electrician may deal with 9 to 12 leads in the junction box, increasing the chances of a ground failure from abraded leads. When an electric motor is repaired, the service center has the option of installing only the number of leads required. With only 3 or 6 leads, there is more room in the junction box and less chance of lead damage or misconnection during installation.

Note: Tri-voltage motors represent a compromise between the possible applied voltages. This improves potential availability, to the detriment of efficiency at certain applied voltages.

VIBRATION MONITORING AND IMPROVEMENT

A Blanchard grinder begins to vibrate, and pieces of valuable precision plate are scrapped before the cause is identified.

FIGURE 5: ROTOR BALANCING



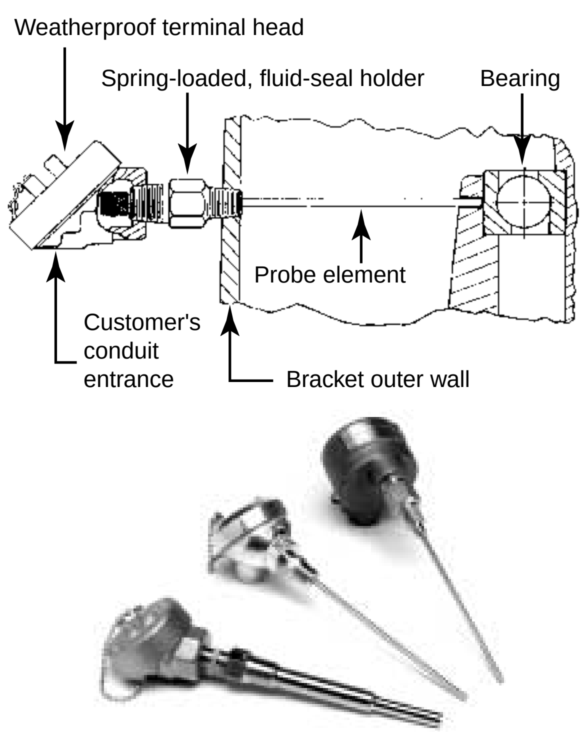
Rotor being dynamically balanced in a service center.

Vibration sensors are vital when the application is a precision grinder or similar vibration-sensitive equipment. Installation of vibration probes can be accomplished by the service center with minimal intrusion into the motor. Accelerometers can be installed on the frame or in the junction box, while non-contact shaft probes may be preferred for sleeve bearing machines. A finishing grinder in a machine shop must hold close tolerances to minimize scrap. Vibration from a defective bearing can be expensive.
Another good candidate for vibration sensors is a pump motor operating in a remote location. Continuous monitoring by instrument is infinitely better than a weekly visit by a plant operator.

The service center can install the appropriate vibration sensing accessories on eligible motors in the course of each repair.

Manufacturers' standard motors are balanced to NEMA MG 1-1998, Part 7 specifications while the service center can routinely balance to one-quarter of NEMA or better. While precision manufacturing has a legitimate need for this, many end-users request special balance tolerances because they recognize that there is a reliability factor associated with vibration.

FIGURE 6: BEARING TEMPERATURE DETECTORS



Courtesy of Minco

BEARING TEMPERATURE PROTECTION

The cause of a plant fire is tracked back to a bearing failure. The bearing, unmonitored, failed catastrophically. Vibration damaged the pump seal and the pump leaked, by which time the bearing temperature was high enough to ignite the spewing liquid.

Bearing temperature protective devices (Figure 6) can be installed during routine repairs to provide early warning of increased temperature. Excessive lubrication intervals, high ambient temperature, imminent bearing failure and other general machinery faults may cause an increase in bearing temperature before damage occurs. A bearing RTD is not intended to just protect the bearing, but rather to protect the machinery by alerting personnel when an equipment fault results in an increase in bearing temperature. Depending on the critical nature of the machine, feedback can take the form of a light in the control room, or automatic shutdown of the equipment.

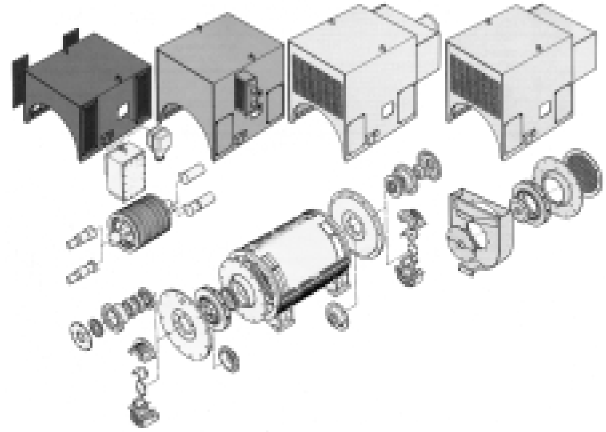
The service center can install the appropriate temperature detectors to interface with instrumentation already in use at the plant.

The cost to fit an electric motor with bearing thermals may be only a few hundred dollars. That cost should be weighed against the possible consequences of failure, *not* against the cost of the motor.

CORROSION RESISTANCE

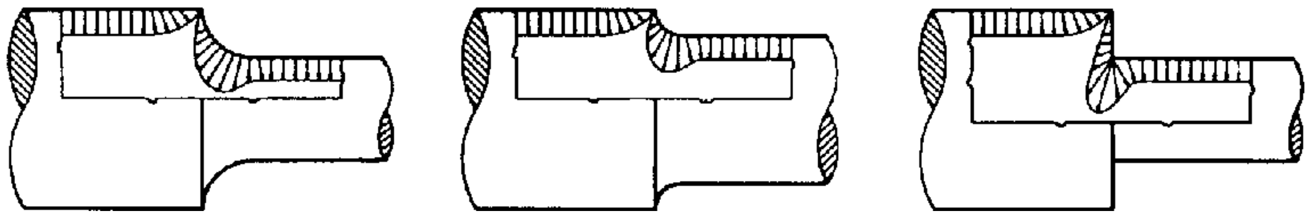
A chemical plant removed a 600 hp motor for routine repairs. The corrosive environment had rusted through the motor frame in numerous places, even the mounting

FIGURE 7: TYPICAL MOTOR ENCLOSURE UPGRADES



Courtesy of Siemens AG

FIGURE 8: STRESS RAISERS



A B C

The lines indicate the path of stresses in the shaft. Where stresses converge, the chance of failure is much higher. The sharp inside corner of shaft C is 40% weaker than it would be with an appropriate radius.

feet. Although running when removed from service, the motor was beyond repair and had to be replaced.

When a motor (new or rebuilt) is placed into a known corrosive atmosphere, the service center can take precautions to greatly improve motor life. At the simplest, corrosion-resistant paint can be used to protect the frame. In extreme cases, the shaft can be chrome plated, or replaced with a stainless steel shaft to better resist corrosive materials. When caustic solutions are evident, aluminum parts may be quickly eroded. Preventive measures may be as simple as dipping the rotor with varnish to protect it. The rotor might even be rebarred using bronze alloy of similar resistivity to avoid changing the torque characteristics (rotor cage resistance should be maintained to avoid changing motor performance). The rotor should also be balanced after work is done to the rotor. A precision balance requires only slightly more time than a "standard" balance.

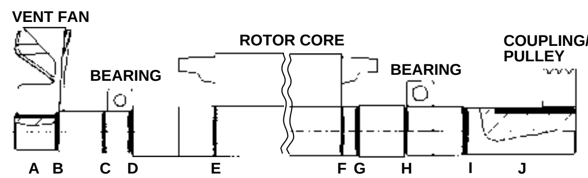
The exploded view of an open motor (Figure 7) illustrates the ease with which various degrees of weather protection can be accomplished by the addition of covers, filters or guards. While an open motor is ill-suited to outdoor operation, the upgraded WPII enclosure was designed for outdoor service.

HIGH-TORQUE APPLICATIONS

An electric motor driving a hammer mill application frequently experiences a broken shaft.

There are several ways to approach this problem depending on the application. One would be to replace the shaft using material with higher tensile strength than the original shafting. The corners should all be radiused to minimize potential stress raisers (Figures 8 and 9). The keyway can be machined in a manner to reduce the stress raisers at the end of the keyway (a sled-type keyway as opposed to a milled keyway.) In extreme cases, the keyway can be milled with a radius bottom and fitted with a

FIGURE 9: STRESS RAISERS



All of the highlighted areas create stress raisers. Points F, H, I and J are usually the most vulnerable because of shaft load at these points. It is hard for a shaft to fracture at points A, B, C, D or E.

custom key. It is not necessary to modify the keyway in the coupling.

Most service centers can machine custom shafts and keyways to address concerns about fatigue-related failures.

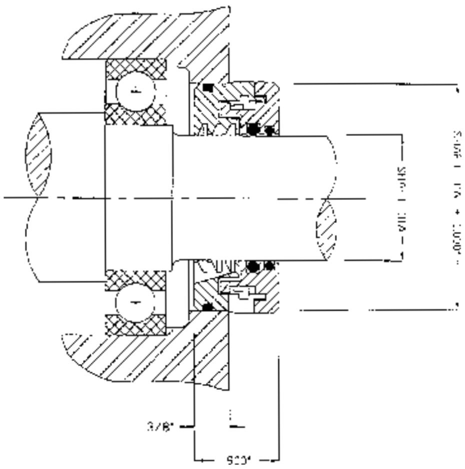
WASH DOWN AND FLOODING

When a power outage occurs, the sump pumps stop and the pit floods. Electric motors must be removed, cleaned and dried before production can be restored.

Accidental wash down and flooding cause many electric motor failures. To increase reliability, special seals are installed on the shaft openings to exclude water from the bearings (Figure 10). Special water-resistant grease can be used to pack the bearings, to further resist washing of lubricants. Sealed bearings may be preferred when the installation precludes regular maintenance.

The service center can seal T-leads using special potting compounds to prevent water from entering through the lead opening. End brackets can be sealed with silicone during the assembly process. These are inexpensive steps, but are very effective for a motor subject to flooding or inadvertent wash down. Examples of

FIGURE 10: NON-CONTACT BEARING ISOLATOR



The standard-design non-contact bearing isolator consists of two parts: **The stator**, which is press-fitted into a bearing housing and is designed to retain lubricant in the housing, and **the rotor**, which in combination with the stator, is designed to keep contamination out of the bearing housing.

Courtesy of Inpro/Seals Company

candidates for this sort of modification include motors operating below grade in pump rooms, as well as cooling tower motors.

PROTECTION FROM ABRASIVE DUST

An electric motor operates downwind of a rock quarry and abrasive dust sandblasts the windings.

Unprotected windings do not last very long in this type of environment. The service center can topcoat the windings with a special material that absorbs impact energy, thus protecting the windings. Filters can be added to exclude the dust from the motor enclosure, or additional covers can be installed to upgrade the enclosure.

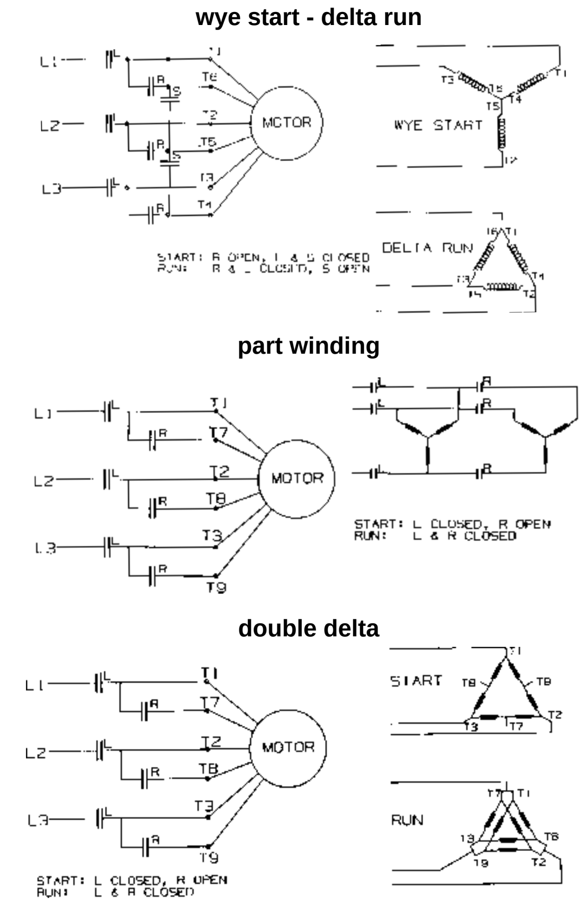
Motors operating in rock quarries, cement mills or power plants benefit from this treatment. Motors operating near agricultural fields may also benefit. These treatments can also be applied to new motors before they are placed into service.

RECONNECTION

To reduce starting torque, a wye-start/delta-run connection can be used. In some cases a motor can be reconnected, while in other cases a rewind is required. Other starting options include a VFD or a solid-state soft-starter.

There will always be applications where reduced starting current will be required. In most cases a Design A

FIGURE 11: ALTERNATIVE METHODS OF CONNECTION



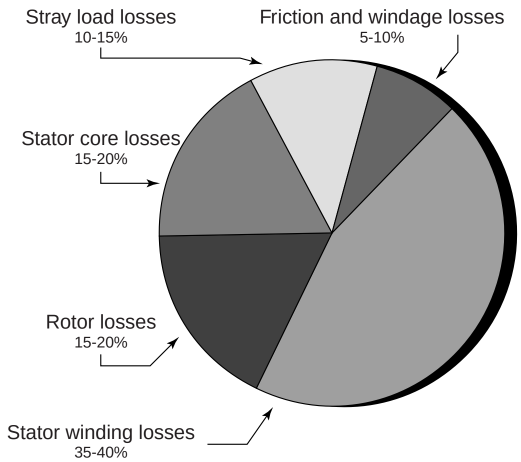
motor will still be justified, when coupled with an appropriate starter sized for the current. Typical paybacks when comparing energy savings against capital investment range between 1 and 3 years, based on the cost of energy and hours of running time. Wye-delta starting reduces inrush current to 37% and provides one-third the torque. Part-winding start methods reduce inrush current to one-half to two-thirds while supplying one-half the starting torque.

The service center can often reconnect an existing winding to reduce starting current and torque. (See Figure 11.)

ENERGY EFFICIENCY IMPROVEMENT

There are occasions when rewinding a motor where the opportunity may exist to enhance the motor performance and reliability by modifying the winding configuration and copper content. For many designs, the copper loss (I^2R) is the largest loss component (Figure 12). In some cases, this loss can be reduced by converting from a concentric, machine-wound configuration to a traditional, hand-inserted lap winding. In many cases, the copper

FIGURE 12: TYPICAL DISTRIBUTION OF LOSSES



The laminated core, stator windings and rotor account for as much as 80% of the total losses for the typical electric motor. While losses are generally associated with lost efficiency, they represent energy converted to heat.

NEMA Standards MG 10-1994, Table 2-2 (National Electrical Manufacturers Association, Rosslyn, VA, 1994).

TABLE 4: ENERGY EFFICIENCY IMPROVEMENT

	Horsepower	Winding type	Space factor (%)*	Nameplate NNE (%)	Full-load efficiency (%)
Original pre-EPACT	25	Machine	43.0	88.5	88.7
Rewound pre-EPACT	25	Lap	62.0	90.2	90.8
EPACT reference	25			91.7	
Original pre-EPACT	50	Machine	46.0	91.7	91.6
Rewound pre-EPACT	50	Lap	60.0	92.4	92.6
EPACT reference	50			93.0	

Typical 4-pole, open dripproof, general purpose, T-frame motors of pre-energy efficient design.

$$\text{*Percent space factor} = \frac{\text{Total number of wires per slot} \times \frac{3.14\,D^2}{4} \text{ of wire}}{\text{Total slot area} - \text{area of insulation}} \times 100$$

D = wire diameter

content (slot fill) can also be increased. Figure 13 shows the contrast between a relatively low slot fill (40 to 50% where the wire is $PD^2/_4$) and one of a much higher percent slot fill (60 to 64%).

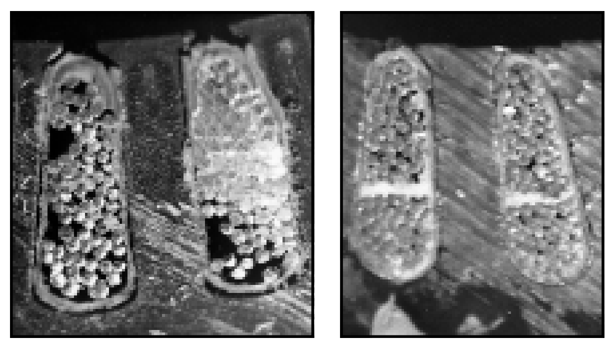
This modification will improve heat transfer, reduce the copper loss and winding temperature and improve motor efficiency. There will be less coil movement, and increased resistance to moisture, due to better varnish retention. Even though these improvements are difficult for the service shop to quantify, they are none the less real and will usually improve motor performance and reliability. With this modification, the motor's service factor will be improved and it will be able to withstand wider variations in voltage, ambient and starting conditions.

Table 4 shows the possible efficiency improvements that can be made for a generation of T frame motors produced during the 1970s and '80s. Not all motors offer this opportunity, but for those that do this option should be considered as a possible product improvement.

CONCLUSION

By incorporating effective technology as it becomes available, it is possible to reduce downtime, improve productivity and operate more efficiently. Reduced costs make an organization more profitable. Savings can be redirected to improve other "weak links." The savvy maintenance professional is always looking for ways to improve processes, and the competent service center is able to assist in this task.

FIGURE 13: EXAMPLES OF SLOT FILL



Low slot fill | Improved slot fill

When evaluating the operating cost of an electric motor, the cost of energy is only one variable (and often not the biggest one) in the equation. The key to maximizing productivity is to eliminate downtime. While zero downtime is not always possible, any significant reduction in downtime improves profitability. When downtime is measured in thousands of dollars per hour, the payback reaped from extending motor life can be enormous.

The economics of the repair or replace decision process are complex. All variables must be considered in order to select the best option.

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- *A Survey of Faults on Induction Motors in Offshore Oil Industry, Petrochemical Industry, Gas Terminals and Oil Refineries*. Olav Vaag Thorsen, Senior Member IEEE and Magnus Dalva, Member IEEE. IEEE Transactions on Industry Applications, Vol. 31, No. 5, Sept./Oct. 1995.

- *Root Cause Failure Analysis for Large AC Induction Motors.* Austin Bonnett, Education and Technology Consultant, Electrical Apparatus Service Association, Inc., St. Louis, MO. Presented at EASA Convention 1999, Toronto, Ontario, Canada.

APPENDIX A • Application Checklist

Voltage

- What is the nominal voltage?
- How much voltage variation is present?
- Is there voltage drop when starting under load?
- Is there nuisance tripping?
- Are there transient peaks?

Environmental factors

- What is the frequency of moisture ingression?
- What is the frequency of condensation?
- What is the ambient temperature range?
- What other contaminants are present?

Load conditions

- Are there load swings? If so, how wide?
- What is the hp required versus rated hp?
- What is the load – pump, fan, compressor, conveyor?

How is the motor mounted / coupled?

- Direct coupled
- Overhung load
- What are the thrust conditions?
- Describe the motor's mounting.

Starting method

- Across-the-line
- Wye start, Delta run
- Part-winding start
- Soft-start

Frequency of starting

- What is the running time between starts?
- How many starts per hour / 8-hours / 24-hours?
- Is it a demand system?
- Is it a constant or variable load?
- Describe the cycling.
- Are there load-shedding opportunities?

Describe unusual service conditions

- See Appendix B, NEMA MG 1-1998, 14.3

Describe the application

- How critical is the operation?
- Is it a dedicated or redundant system?
- What is the availability of spares or backups?
- What are the consequences of shutdown?

History of failures or repairs

- Has the motor been rewound? If so, how many times?
- What is the mean time between failures?

Root cause failure analysis

- What is the cause of failure?
- What can be done to eliminate the cause?
- What is the best method to detect the condition?

Are there similar motors and applications?

APPENDIX B • Unusual Service Factors, NEMA MG 1-1998, 14.3

14.3 UNUSUAL SERVICE CONDITIONS

The manufacturer should be consulted if any unusual service conditions exist which may affect the construction or operation of the motor. Among such conditions are:

a. Exposure to:

1. Combustible, explosive, abrasive, or conducting dusts
2. Lint or very dirty operating conditions where the accumulation of dirt may interfere with normal ventilation
3. Chemical fumes, flammable or explosive gases
4. Nuclear radiation
5. Steam, salt-laden air, or oil vapor
6. Damp or very dry locations, radiant heat, vermin infestation, or atmospheres conducive to the growth of fungus
7. Abnormal shock, vibration, or mechanical loading from external sources
8. Abnormal axial or side thrust imposed on the motor shaft

b. Operation where:

1. There is excessive departure from rated voltage or frequency, or both (see 12.45 for alternating-current motors and 12.68 for direct-current motors)
2. The deviation factor of the alternating-current supply voltage exceeds 10 percent
3. The alternating-current supply voltage is unbalanced by more than 1 percent (see 12.46 and 14.36)
4. The rectifier output supplying a direct-current motor is unbalanced so that the difference between the highest and lowest peak amplitudes of the current pulses over one cycle exceed
   10 percent of the highest pulse amplitude at rated armature current
5. Low noise levels are required
6. The power system is not grounded (see 14.31)

c. Operation at speeds above the highest rated speed

d. Operation in a poorly ventilated room, in a pit, or in an inclined position

e. Operation where subjected to:

1. Torsional impact loads
2. Repetitive abnormal overloads
3. Reversing or electric braking
4. Frequent starting (see 12.55)
5. Out-of-phase bus transfer (see 14.45)
6. Frequent short circuits

f. Operation of machine at standstill with any winding continuously energized or of short-time-rated machine with any winding continuously energized

g. Operation of direct-current machine where the average armature current is less than 50 percent of the rated full-load amperes over a 24-hour period, or continuous operation at armature current less than 50 percent of rated current for more than 4 hours

APPENDIX C • Repair Options

At the time of the motor repair, in addition to the task of restoring the motor to its original condition, it is possible to make modifications and upgrades. During the repair it may become evident that the motor will fail again if returned to its existing environment without modification. It may also be expedient to implement certian "upgrades" to enhance motor performance, reliability and life.

The following is a list of possible options that may be considered by the repair facility.

Bearings
- Enclosure — sealed, shielded or open
- Roller or ball (for direct couple or radial load)

External seals
- Non-contact bearing isolator
- Lip seal

Lubrication
- Synthetic grease
- Automatic grease applicators
- Oil-mist systems
- Forced-lube oil systems
- Mineral oil for food service or potable water applications

Severe starting conditions
- Increase rigidity of winding blocking
- Redesign to wye start, delta run to reduce torque and inrush current
- Increase slot fill

Environmental protection
- Abrasion resistance
  - Special coatings
  - Full-length slot wedges for form coil machines
- Corrosion resistance
  - Special epoxy paints
  - Stainless steel shafting
  - Lead potting compound
  - Filters
  - Screens, baffles or covers

Power considerations
- Power factor correction capacitors
- Surge protection or lightning arrestors

Increase motor cooling
- Directional fans
- Special fans to increase air flow
- Heat exchanger
- Auxiliary blower (especially for VFD-fed motors)
- Maximize slot fill

Special accessories
- Winding temperature detectors
- Bearing temperature detectors
- Vibration monitoring: accelerometers or non-contact shaft probes
- Oil chamber heater and thermostat for cold climates

Leads
- Bring out minimum number of leads
- Seal the lead opening against moisture and chemicals
- Increase the lead size
- Other special considerations such as bus bar, special lugs, etc.

Noise reduction
- Add soundproofing material
- Add exterior shrouding
- Utilize special fan configurations
- Special balance requirements

Outlet box
- Size
- Better enclosure for weather protection

Efficiency considerations
- Voltage optimization
- Upgrade insulation class
- Concentric to lap conversion
- Optimize span
- Maximize slot fill (copper and insulation)
- Connection options (wye start, delta run; part-winding start)

Field support
- Startup
- Predictive maintenance
  - Vibration monitoring
  - Current analysis
  - Thermography
  - Tribology

APPENDIX D • Motor Repair Guidelines and Resources

ELECTRICAL APPARATUS SERVICE ASSOCIATION, INC.
INTERNATIONAL HEADQUARTERS

Recognized as an American National Standard (ANSI)

ANSI/EASA AR100-1998

EASA Standard AR100-1998

RECOMMENDED PRACTICE

FOR THE REPAIR OF ROTATING ELECTRICAL APPARATUS

Reliable Solutions Today!

Standards Organizations & Other Resources

The following organizations produce documents and standards, some of which are referenced in the *EASA Recommended Practice for the Repair of Rotating Electrical Apparatus.*

ABMA—American Bearing Manufacturers Association
1200 19th St., NW, Suite 300
Washington, DC 20036
(202) 429-5155
Fax: (202) 223-4579

ANSI—American National Standards Institute
11 West 42nd St., 13th Floor
New York, NY 10036
(212) 642-4900
Fax: (212) 302-1286

IEC—International Electrotechnical Commission *
3 rue de Varembe
CH 1211 Geneva 20, Switzerland

IEEE—Institute of Electrical and Electronics Engineers, Inc.
345 East 47th St.
New York, NY 10017
(212) 705-7900
Fax: (212) 752-4929
For Publications:
445 Hoes Lane
P. O. Box 1331
Piscataway, NJ 08855-1331
(800) 678-4333
Fax: (908) 981-9667

ISO—International Organization of Standardization *
1 rue de Varembe
CH 1211 Geneva 20, Switzerland

MIL-STD—United States Government Printing Office
710 North Capitol St.
Washington, DC 20420
(202) 512-1800
Fax: (202) 512-2250

NEMA—National Electrical Manufacturers Association
1300 N. 17th St., Suite 1847
Rosslyn, VA 22209
(703) 841-3200
For Publications:
(703) 841-3201
Fax: (703) 841-3300

NFPA—National Fire Protection Association
One Batterymarch Park
Quincy, MA 02269
(617) 770-3000
Fax: (617) 770-0700
For Publications:
P. O. Box 9146
Quincy, MA 02269
(800) 344-3555
Fax: (617) 984-7057

NIST—National Institute of Standards and Technology
Route 270
Gaithersburg, MD 20899
(301) 975-2000

UL—Underwriters' Laboratories, Inc.
333 Pfingsten Rd.
Northbrook, IL 60062
(847) 272-8800, Ext. 42612
Fax: (708) 272-8129

* IEC and ISO standards are available through ANSI, which is the American representative to all international standards groups.

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Note: Sections pertaining to the repair of liquid-filled and dry-type distribution transformers were withdrawn from this edition of *EASA Recommended Practice for the Repair of Rotating Electrical Apparatus.*

APPENDIX D • Motor Repair Guidelines and Resources (continued)

Association of Electrical and Mechanical Trades

GOOD PRACTICE GUIDE

THE REPAIR OF
INDUCTION MOTORS
Best Practices
to Maintain Energy Efficiency

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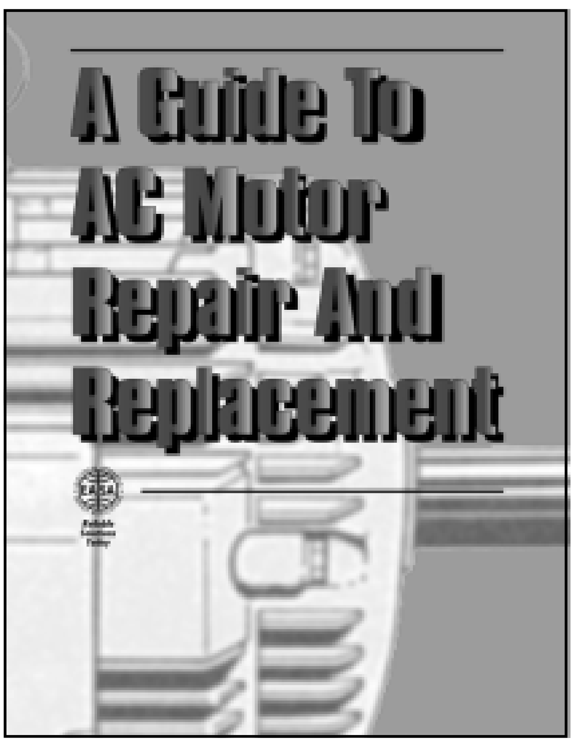

A Guide To AC Motor Repair And Replacement

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