



IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

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IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries

Sponsor

Petroleum and Chemical Industry Committee

of the

IEEE Industrial Applications Society

Approved 9 December 2009

IEEE-SA Standards Board

Abstract: This standard is intended to be a basic or primary document that can be utilized and referenced by owners of ac motors and generators (machines) that need refurbishment, repair, and/or rewinding, as well as service or repair facilities. It has been developed for the petroleum, chemical, and process industries, and it may be adapted to other areas of interest. The use of this standard is expected to result in higher quality and more cost effective, timely repairs. A means of evaluating work performed and repair or service facilities is also provided.

Keywords: ac generator, ac machine, ac motor, induction, refurbish, repair, repair facility, rewind, service facility, synchronous

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Introduction

This introduction is not part of IEEE Std 1068-2009, IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries.

This document was originally published in 1990 and was revised in 1996. In keeping with the goals of maintaining progressive standards, in 2002 the Standards Subcommittee of the IEEE Petroleum and Chemical Industry Committee assigned a task force to revise and update this standard. References to other documents have been corrected. The wording in this standard was modified to reflect worldwide standards and to promote uniform application of such devices in petroleum and chemical industry facilities.

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IEEE ~~Recommended Practice~~ Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical ~~Industry~~, and Process Industries

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1. Overview

1.1 Scope

This document ~~recommended practice~~ covers general recommendations for the repair of alternating current (ac) electric motors and includes guidelines for both the user and the repair facility. It is not intended to replace specific instructions contained in the manufacturer’s instruction book or in any contractual agreement between a manufacturer and a purchaser of a given machine.

For the purpose of this document, the term “motor” is used in lieu of, and shall equate to, the terms wound rotor, generator, and machine. These recommendations apply to horizontal and vertical motors, NEMA frame size 140 and above, having a voltage rating of 15 kV or less. These recommendations apply only to the repair of motors and are not intended to cover major modifications

This standard covers reconditioning, repair, and rewind of horizontal and vertical induction motors and of synchronous motors. It applies to all voltages 15 kV and less, and all ratings above 0.75 kW (1 hp).

This standard applies only to the repair of motors, and in cases involving modifications to the basic design, care must be taken so as not to negatively affect the safety and reliability of the motor.

Excluded from the scope of this standard are the following:

- Specific requirements, certification, and inspection required for ~~listed~~-explosion proof ~~and~~, dustignition proof ~~machines~~, flameproof, and like motors having a listing issued by a Nationally Recognized Testing Laboratory (NRTL), for example, Underwriters Laboratories, Inc. (UL), Factory Mutual (FM), and Canadian Standards Association (CSA). For motors in this category, the user shall verify if the repair facility shall be certified by such an agency

– Any specific or additional requirements for hermetic motors, hydrogen-cooled generators,
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submersible motors, or Class 1E nuclear service motors.

- [Direct current \(dc\) motors.](#)

1.2 Purpose

This standard is intended to be [used](#) ~~a basic or primary document that can be utilized~~ and referenced by users of motors that need repair as well as by owners and operators of establishments that offer motor repair services. It has been developed primarily for the needs of the petroleum and chemical industry but can be adapted to other applications [or industries.](#)

The use of this standard by users and repair facilities is expected to result in higher quality, ~~more~~ cost-effective, timely repairs. It also provides a means of evaluating repairs and facilities.

2. Normative references

[The following referenced documents are indispensable for the application of this document \(i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained\). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document \(including any amendments or corrigenda\) applies.](#)

[ANSI/ABMA 20-1996, Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types—Metric Design.](#)^{1,2}

[API 541-2003, Form-Wound Squirrel-Cage Induction Motors — 500 Horsepower and Larger.](#)³

[API 546-1997, Brushless Synchronous Machines—500 KVA and Larger.](#)

[API 547-2005, General-Purpose Form-Wound Squirrel Cage Induction Motors—250 Horsepower and Larger.](#)

[ASTM B117-03, Standard Practice for Operating Salt Spray \(Fog\) Apparatus.](#)⁴

[IEC 60034-8, Rotating Electrical Machines—Part 8: Terminal Markings and Direction of Rotation.](#)⁵

¹ ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

² ABMA publications are available from the American Bearing Manufacturers Association (ABMA), 2025 M Street, NW, Suite 800, Washington, DC 20036 (<http://www.abma-dc.org/>).

³ API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA (<http://www.api.org/>).

⁴ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

⁵ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3 rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States

[IEEE Std 1™-2000 \(Reaff 2005\), IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.](#)^{6,7}

[IEEE Std 43™-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.](#)

[IEEE Std 112™-2004, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.](#) IEEE

[Std 115™-1995, IEEE Guide: Test Procedures for Synchronous Machines.](#)

[IEEE Std 432™-1992 \(withdrawn\), IEEE Guide for Insulation Maintenance for Rotating Electrical](#)

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[Machinery \(5 Hp to less than 10 000 Hp\).⁸](#)

[IEEE Std 510TM-1983 \(withdrawn\), IEEE Recommended Practice for Safety in High-Voltage and High-Power Testing.⁹](#)

[IEEE Std 522TM-2004 \(Reaff 2009\), IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.](#)

[IEEE Std 841TM-2009, IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled \(TEFC\) Squirrel Cage Induction Motors—Up to and Including 370 kW \(500 hp\).](#)

[NEMA MG 1-2006, Motors and Generators.¹⁰](#)

2.1 General

~~Definitions, construction, and test methods not specifically covered in this recommended practice should comply with the following standards insofar as they are applicable. When the following standards are superseded by an approved revision, the revision shall apply.~~

~~IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation (ANSI).²~~

~~IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms~~

~~IEEE Std 112-1991, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators (ANSI). IEEE Std 115-1983 (Reaff 1991), IEEE Guide: Test Procedures for Synchronous Machines (ANSI). IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10 000 hp) (ANSI).~~

~~IEEE Std 841-1994, IEEE Standard for the Petroleum and Chemical Industry- Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors Up to and Including 500 hp (ANSI).~~

~~NEMA MG 1-1993, Motors and Generators.³~~

2.2 Insulation tests

~~Where appropriate to the construction, tests should be made in accordance with the following IEEE test procedures:~~

~~IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).~~

~~IEEE Std 117-1974 (Reaff 1991), IEEE Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random Wound AC Electric Machinery (ANSI).~~

~~IEEE Std 275-1992, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating Current Electric Machinery Employing Form Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below (ANSI).~~

~~IEEE Std 429-1994, IEEE Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below (ANSI).~~

¹API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

³NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Suite 1017, Rosslyn, VA 22209, USA.

2.3 Other insulation systems

~~For other insulation systems that do not have established test procedures, similar procedures may be used if it is shown that they properly discriminate between service-proven systems known to be different.~~

~~When being evaluated by an established test, a new or modified insulation system should be compared to an insulation system on which there have been two years of service experience. If a comparison is made to a system of the same temperature class, the new system should have equal or longer thermal endurance under the same test conditions; if a comparison is made to a system of a lower temperature class, the new system should have equal or longer thermal endurance at an appropriately higher temperature. When comparing systems of different classes, an appropriate higher temperature should be considered to be 25 °C per class higher than the temperature for the base insulation system class.~~

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be referenced for terms not defined in this clause.¹¹

accepted test: A test on a system or model system that simulates the electrical, thermal, mechanical, and environmental stresses occurring in service.

insulation class: Insulation systems are divided into classes according to the thermal endurance of the system for temperature rating purposes. NEMA classes of insulation systems used in motors include Classes A, B, F, and H. These classes have been established in accordance with IEEE Std 1™-2000.¹² The insulation systems shall be as follows:

- a) NEMA Class A: An insulation system (105 °C temperature limit including a 40 °C ambient or 65 °C rise) that by experience or accepted test can be shown to have suitable thermal endurance

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⁷ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

⁸ IEEE Std 432-1992 has been withdrawn; however, copies can be obtained from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

⁹ IEEE Std 510-1983 has been withdrawn; however, copies can be obtained from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

¹⁰ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

¹¹ *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at <http://shop.ieee.org/>.

¹² Information on references can be found in Clause 2.

when operating at the limiting Class A temperature specified in the temperature rise standard for the machine under consideration.

- b) NEMA Class B: An insulation system (130 °C temperature limit including a 40 °C ambient or 90 °C rise) that by experience or accepted test can be shown to have suitable thermal endurance when operating at the limiting Class B temperature specified in the temperature rise standard for the machine under consideration.

- c) NEMA Class F: An insulation system (155 °C temperature limit including a 40 °C ambient or 115 °C rise) that by experience or accepted test can be shown to have suitable thermal endurance when operating at the limiting Class F temperature specified in the temperature rise standard for the machine under consideration.

- d) NEMA Class H: An insulation system (180 °C temperature limit including a 40 °C ambient or 140 °C rise) that by experience or accepted test can be shown to have suitable thermal endurance when operating at the limiting Class H temperature specified in the temperature rise standard for the machine under consideration.

insulation system: An assembly of insulating materials in association with the conductors and the supporting structural parts. All the components described as follows that are associated with the stationary winding constitute one insulation system, and all the components that are associated with the rotating winding constitute another insulation system:

- a) Coil insulation with its accessories: All the insulating materials that envelop and separate the current-carrying conductors and their component turns and strands, and form the insulation between them and the machine structure; includes wire coatings, varnish, encapsulants, slot insulation, slot fillers, tapes, phase insulation, pole-body insulation, and retaining ring insulation when present
- b) Connection and winding support insulation: All the insulation materials that envelop the connections that carry current from coil to coil, and from stationary or rotating coil terminals to the points of external circuit attachment; and the insulation of any metallic supports for the winding
- c) Associated structural parts (insulation system): Items such as slot wedges, space blocks, and ties that are used to position the coil ends and connections; any nonmetallic supports for the winding; and field-coil flanges

motor: A rotating machine that converts electrical power into mechanical power.

record: Process whereby a physical condition is permanently documented by means of a photograph, sketch, drawing, diagram, writing or printing, rubbing, and similar means. Record also extends to charts, tables, output(s) from instrument(s) or sensor(s) (e.g., magnetic tape), processed electronic signal(s), computerized data files, and the like.

repair: Includes incoming inspection and test, damage appraisal, cleaning, replacement or restoration of damaged part(s) or both, assembly, postrepair inspection and test, and refinishing. Damage resulting from a motor failure varies widely as do the associated repair costs. Evaluation processes that consider various levels of repair are better enabled to yield accurate assessments. For example:

- Level 1 — Basic reconditioning. Includes replacing of antifriction bearings or inspection and verification of hydrodynamic 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 and rewinding the stator (replacing windings and insulation).
- Level 4—Includes rewinding of 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.

NOTE—There may be cases where multiple levels apply to the same motor.¹³

repair facility: The entity contracted to make repairs, which includes the “on site” repair(s) made by employees of that entity in addition to repair(s) made at a service center operated by or under the supervision of that entity.

total indicated runout (TIR): The difference between highest and lowest reading of a dial gauge touching a shaft (mechanical runout) or a properly adjusted noncontacting proximity probe sensing the shaft surface (electrical runout) at a designated location on a shaft as it is slowly rotated through a complete revolution. The readings shall be taken with the shaft in its bearings, on V blocks or in centers, and may be corrected depending on the method used.

~~**3.2 experience:** Successful operation for a long time under actual operating conditions of machines designed with temperature rise at or near the temperature rating limit.~~

~~**3.3 insulation system:** An assembly of insulating materials in association with the conductors and the supporting structural parts. All of the components described below that are associated with the stationary winding constitute one insulation system, and all of the components that are associated with the rotating winding constitute another insulation system.~~

~~— *Coil insulation with its accessories.* All of the insulating materials that envelop and separate the current-carrying conductors and their component turns and strands, and form the insulation between them and the machine structure; includes wire coatings, varnish, encapsulants, slot insulation, slot fillers, tapes, phase insulation, pole-body insulation, and retaining ring insulation when present.~~

~~— *Connection and winding support insulation.* All of the insulation materials that envelop the connections that carry current from coil to coil, and from stationary or rotating coil terminals to the points of external circuit attachment; and the insulation of any metallic supports for the winding.~~

~~— *Associated structural parts (insulation system).* Items such as slot wedges, space blocks, and ties that are used to position the coil ends and connections; any nonmetallic supports for the winding; and field-coil flanges.~~

~~— *Insulation class.* Divided into classes according to the thermal endurance of the system for temperature rating purposes. NEMA classes of insulation systems used in motors include Classes A, B, F, and H. These classes have been established in accordance with IEEE Std 1-1986. Other classes of insulation are constantly being developed for such use.~~

~~Insulation systems shall be classified as follows:~~

~~— *NEMA Class A.* An insulation system (105 °C temperature limit including a 40 °C ambient or 65 °C rise) that by experience or accepted test can be shown to have suitable thermal endurance~~

~~**3.7 repair facility:** The entity contracted to make repairs; includes the “on site” repair(s) made by employees of that entity in addition to repair(s) made at a shop operated by or under the supervision of that entity~~

~~**3.8 user:** The owner of the motor or an authorized agent of the owner~~

4. Responsibilities ~~Prerepair activity and responsibility~~

Items to be considered and documented throughout the various stages of refurbishment and repair vary in number depending on the level of repair to be undertaken. The definition of issues and their resolution ranges from simple to complex, where complicated problems may require several iterative investigations and solutions. This begins at the user’s facility prior to removal of the motor and then continues through prerepair appraisal, dismantling, component evaluation, refurbishment or repair, and final testing at the repair facility. Some users may continue recording and evaluation during the re-installation and startup process. The items, steps, or processes noted within this document are not listed in any specific order and may be modified, added, or deleted as necessary; performed in a different order; or conducted simultaneously.

Photographs are part of the appraisal process and inspection report and may be necessary for reassembly or failure analysis. Photographs are useful for clarifying conditions that cannot be described adequately; documenting location, orientation, or special markings; or identifying the extent of visible damage. Examples include conduit locations, cable routing, fan orientation, stator coil damage, broken rotor bars, and so on. The use of digital photography is encouraged.

In the absence of clear photographs, any drawings, sketches, diagrams, or descriptions should allow no uncertainty as to the location of the conditions described. If references are made to “clock position” or to ends of the motor (e.g., “inboard” or “outboard”), some explanatory note or sketch should make clear the location being described. The terms “drive end” and “opposite drive end” are recommended for horizontal shaft motors, and “top” and “bottom” are recommended for vertical shaft units.

¹³ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

~~Several items should be considered and documented prior to repairs. Indeed, some prequalification activities should be finished prior to failure or shipment to a repair facility. Some these activities are the responsibility of the user, while others are assigned to the repair facility.~~

4.1 User responsibility

To ensure that the repair operation is of high quality and is cost effective, the user should make advance preparation and prequalification of the repair facility. These steps should be finished prior to motor failure or shipment of the unit.

4.1.1 Records

~~Obviously, the more information the owner can furnish to the repair shop, the better the repair will be. For example, at times the nameplate will not be readily readable after several years in service, and pertinent data must be obtained largely by measurements. It would be ideal if the owner would~~ The user should keep a record of the nameplate and other motor information in a file along with any data such as baseline, operational performance, failure history, bearing replacement, and other problems and repairs. When furnished to the repair facility, these records are critical to the diagnosis, evaluation, and repair process. For example, at times, the nameplate will not be legible after several years in service.

4.1.2 Repair facility prequalification

The user should ~~take the time to~~ prequalify several local repair facilities according to the type of repairs that may be required. The following are ~~possible check items~~ suggested guidelines for particular areas of repair:

- a) *Crane equipment capacity.* The capacity and condition of lifting equipment should be adequate to handle large motors safely and smoothly. Lifting equipment should be adequate for the largest motor for which that facility is being prequalified.
- b) *Cleanliness.* Facilities should be clean and orderly, and tools and equipment should be in good repair. Winding areas and bearing installation areas, containers, and equipment used to apply the insulation system should ~~be checked~~ have special emphasis.
- c) *Insulation requirements.* The facility should have the necessary equipment to install and test adequately the integrity of the insulation system.
- d) *Offsite supply and repair.* Where components, such as coils, shafts, bearings, and brackets, are supplied or repaired at a different location, care shall be taken in handling, packing, and transporting those parts.
- e) *Instrumentation.* The ~~shop should~~ repair facility shall have adequate instrumentation and measurement equipment ~~that is calibrated yearly~~ to perform properly all tests. ~~Records are necessary on all testing, and that equipment should be calibrated at least annually. Calibration shall be documented and traceable to a recognized national standard.~~ Backup instruments are recommended for data verification. ~~Pricing structure. Agreement on costs, inspection, rewinding, or reconditioning motors should be established in advance.~~
- f) *Removal of windings.* Facilities for removing windings safely and without damaging motor laminations shall be available. ~~Warranty. All warranty items and conditions should be in writing and clearly understood by both parties before repairs are begun.~~
- g) *Rotor balancing.* Rotor balancing and vibration analysis equipment shall be available for the largest motor and speed for which that facility is being prequalified.
- h) *Quality assurance program* The repair facility shall have a formal quality control/quality assurance (QC/QA) program in place. ~~. Does the shop have a formal Quality Assurance (QA) program in place and does the program, if any, meet with your company standards for QA?~~
- i) *Machining.* The repair facility shall have sufficient machinery (lathes, mills, etc.) capable of properly handling the size and weight of the various motor components requiring repair or refurbishment. Included are the necessary tools, fixtures, cutting elements, and other

quality repair.

- j) Cleaning. The repair facility shall have the equipment and training necessary for the various types of mechanical and electrical component cleaning required in the repair process. It is also the responsibility of this facility to ensure that cleaned components are suitable for human handling and do not pose present or future environmental risk.
- k) Test stand. The repair facility should be evaluated on the capabilities of its test stand(s) with respect to the sizes and ranges of the motor(s) for repair or refurbishment, such as kW (hp), voltage, starting capability, rpm and speed range, mounting position, motor physical size and weight, oil or water cooling capacity, air ventilation capability, load or heat run test capabilities, excitation panels, and adjustable frequency drive systems.
- l) Standards and references. The repair facility should possess and have readily available at site the current version of standards and reference documents relating to the materials, components, assemblies, and completed motor with respect to the testing, performance, and evaluation criteria thereof.
- m) Evaluation form. A typical repair facility evaluation form is included as Annex B.

4.1.3 Diagnostics in user's plant

While a motor is operating in the user's plant, certain tests and measurements can be performed that will assist with determination of the problem and possible future repair facility work. These include the following:

- a) Measurement of current and voltage on all phases, with attention to unbalances.
- b) Temperatures such as frame, bearing housing, stator, and bearing. Include the method of measurement.
- c) Vibration spectrum.
- d) Other operational behaviors including noise, slip, event cyclical occurrence.
- e) Current signature analysis.
- f) Data such as insulation resistance records, partial discharge records, lubricant analysis, maintenance history, or other information that may be available.
- g) Application details such as type of driven equipment, load characteristics, loading and duty cycle, method of coupling, starting requirements, starting method, total number of starts, starting frequency, direction of rotation, installation arrangement, and any unusual conditions or requirements.
- h) Environmental description including ambient temperature range, precipitation, and exposure to contaminants (liquids, solids, or gases).
- i) A typical motor application, environment, and condition form is included in Annex C.

4.1.4 Intended work scope and information

The user shall provide the repair facility with the intended work scope, nameplate information, operational and failure history, previous repair records, and user data sheets when available. The motor repair order may also contain special instructions or deviations from this standard. A typical motor repair order is in Annex D.

4.2 Repair facility responsibility

Incoming After preliminary inspection ~~Prior to unloading~~ and evaluation of the motor, the shipment ~~should be inspected with~~ repair facility shall provide a response to the ~~shipper representative for obvious~~ damage that may have occurred during shipment user's motor repair order. Unless otherwise specified, repair work shall not proceed until the full scope and definition of the work to be performed is agreed on.

Following initial user approval of the work scope, any additional repairs or modifications shall be approved by the user. The repair facility shall provide the user with a proposal for any additional cost and the revised completion date before extra work is performed. Situations may occur where there are schedule constraints on urgent repairs, and extra work becomes necessary when it is not possible to contact the user. In these cases, with prior user approval to maintain the work schedule, the repair facility may proceed with the extra work and make all efforts to inform the user at the first opportunity.

Disposition of all salvageable and nonsalvageable material or equipment shall be determined between the repair facility user at time of delivery of the motor.

A thorough appraisal of the motor's condition, as received, is essential for the following purposes:

- To determine what specific repairs are needed. The motor may have been sent to the repair center with limited external evidence as to the nature and location of trouble. The problem may be correctable in several ways.
- To find unsuspected trouble, perhaps unrelated to the obvious defect.
- To diagnose causes and effects to help prevent recurrence

A detailed damage appraisal of motor components is divided into two categories: mechanical and electrical.

~~a) A receiving report should be filled out and include broken or missing parts and/or any unusual problem(s)~~

~~b) For conditions that cannot be adequately described, pictures should be taken for clarity.~~

~~e) Record all motor nameplate information available. The following data should be obtained:~~

- ~~1) Type of apparatus~~
- ~~2) Manufacturer~~
- ~~3) Style~~
- ~~4) Serial number~~
- ~~5) HP/kVA/kW/power factor~~
- ~~6) r/min~~
- ~~7) Phase~~
- ~~8) Frequency~~
- ~~9) Volts~~
- ~~10) Full load amps~~
- ~~11) Temperature rise/insulation class/ambient base~~
- ~~12) Type of bearing and manufacturer~~

4.2.2 Incoming tests

~~Prior to incoming running, perform the following and record information where appropriate:~~

~~a) Verify that there is no shaft or bearing damage.~~

~~b) Verify that bearings are lubricated.~~

~~c) Insulation resistance tests should be performed. See 4.3.1 items i) through l) for minimum insulation resistance values, temperature compensation requirements, and test voltages. See Annex A for a motor data insulation resistance record form.~~

~~d) Hipot to ground in accordance with IEEE Std 432-1992 as appropriate to the winding being tested.~~

~~e) Other tests required before energizing the motor are as follows:~~

~~1) Continuity of field coils and stator windings.~~

~~2) Condition and installation of brushes.~~

~~3) Single phase, low voltage (approximately 10-20% of rated voltage) test on ac squirrel cage rotor to find defective rotor bars. Maximum accepted line current variation < 3%, as the shaft is~~

~~rotated with full load current applied.~~

- ~~4) — Core loss test.~~
- ~~5) — Polarization index (where appropriate).~~
- ~~6) — Surge test (where appropriate).~~

~~If conditions permit, the motor should be run at reduced voltage initially (25–50% of rated voltage). If the test is successful, complete the data sheets in Annexes A and B, and then run the motor at full voltage, if possible.~~

4.2.3 Disassembly procedures and instructions

- ~~a) — Before any disassembly is begun, parts should be marked (i.e., brackets, frame, covers, and brush holders).~~
- ~~b) — Brackets and bearings should be identified as pairs.~~
- ~~c) — Frame mounted devices should be identified and recorded.~~
- ~~d) — Wiring should be recorded, sketched, and marked before disconnecting.~~
- ~~e) — Before removing the coupling or other shaft mounted components, measure and record their position with respect to the end of the shaft (flush, past flush, or from flush). Critical components may need to be match marked for reassembly.~~
- ~~f) — Check fan blades for damage and cracks using a penetrating dye system.~~
- ~~g) — As parts are removed, record all noted damage or special markings.~~
- ~~h) — Check shaft extension runout compliance with original motor specifications. If other information is not available, use the following:
 - ~~1) — AC motor runout = 0.001 in total indicator reading~~
 - ~~2) — DC motor runout = 0.002 in total indicator reading~~~~
- ~~i) — Visually check for evidence of rubbing at outside diameters (fan, shrouds, end rings, armature laminations, etc.).~~
- ~~j) — If possible, check for tightness of the core on its shaft. Visually inspect for signs of axial and radial movement.~~
- ~~k) — Visually check rotating components for excessive heating and other abnormalities.~~

4.2.3.1 DC machines

~~Check condition of commutator, core laminations, windings, connections, bands, keyway, support rings, wedges, ties, threaded fits, etc.~~

4.2.3.2 AC machines

~~Inspect condition of bar joints, end rings, windings, slip rings, key ways, threaded fits, synchronous pole pieces, etc.~~

- ~~a) — Measure and record dimensions of the following:
 - ~~1) — Shaft extension~~
 - ~~2) — Journal and bearing fits~~
 - ~~3) — Shaft extension runout~~
 - ~~4) — Shaft seal fits~~
 - ~~5) — Commutator/collector ring diameter~~~~

- ~~6) Commutator riser and brush surface length~~
- ~~b) Visually inspect the condition of nonrotating components (brackets, baffles, shrouds, brush holders, brushes, gasket, spacers, shims, threaded fits, machine fits, etc.).~~
- ~~c) Measure and record bracket fits for housings, cartridges, and bearings.~~
- ~~d) Visually inspect the condition of ball or roller bearing housing or cartridges (wear, grooving, seal fits, fretting, grease fitting, insulation, oil gages, etc.).~~
- ~~e) Visually inspect the condition of sleeve bearings while still in brackets (wear, oil grooves, oil rings, seals, dowels, parts, etc.).~~
- ~~f) Visually inspect field frame poles, iron, mounting blocks, welds, machined fits, brush rigging, space heaters, etc.~~

4.2.4 Removal of field coils-synchronous rotors

- ~~a) A diagram showing field pole location orientation and wiring connections should be made before attempting to remove poles.~~
- ~~b) Field poles should be marked according to frame and or rotor location.~~
- ~~c) The axial position for rotating field poles should be measured and recorded before removal to ensure that they are reinstalled at correct electrical center.~~

4.2.5 Removal of field poles on dc machines

- ~~a) A wiring diagram of field pole connections should be made facing connection end. Show main poles and interpoles with relation to some permanent frame mounted device such as conduit box, etc. Clearly identify connecting leads from interpole to brush holders in order to ensure correct commutating polarity when reconnecting.~~
- ~~b) Follow standard practice of identifying shunt pole leads with F1-F2, series pole leads with S1-S2, and interpole/armature leads with A1-A2.~~

4.2.6 Rotors/rotating poles inspection

- ~~a) Prior to disconnecting the wiring, make an accurate drawing showing the location of all poles, wiring, fan blades, and associated hardware. Shaft keyway can be used as a reference indicating relationship of collector rings, brush exciter, leads, and wiring cleats.~~
- ~~b) Each pole piece should be match marked with respect to the rotor spider to ensure that they are reassembled in the same location and in the same orientation. General practice is to number the poles in a clockwise sequence while facing the collector ring or exciter end.~~
- ~~c) Measure and record the axial location of the pole pieces with respect to the rotor core and shaft. (Generally, this is best accomplished by identifying Pole #1, placing a center punch mark at its mid-point, and measuring the distance from the center punch mark to the shaft reference. Then using this dimension and shaft reference, place a center punch mark on each of the remaining poles. Locating the poles in this manner will allow the rotor to be returned to its correct magnetic center. An alternate method is to measure the distance between each pole piece dovetail and its outside rotor slot edge.)~~
- ~~d) When inspecting collector rings, if the rings must be removed in order to dismantle the poles, all orientations for the rings should be recorded on a drawing.~~
- ~~e) When inspecting squirrel cage rotor bars (synchronous and induction), rotor bars and their connecting end rings should be inspected for cracks, arcing in slots, and for cage migration. All cracks and evidence of arcing should be recorded and, if possible, pictures should be taken showing the location of damaged bars. A drawing should be made showing the defective bar location, and all connecting parts between poles and end rings should be identified and recorded on the drawing.~~

- a) ~~Motor parts should be inspected for presence of cracks, signs of wear, or rubbing.~~
- b) ~~The keyway should be inspected for wear.~~
- c) ~~Ball, roller, and sleeve bearing tolerances, including bearing cap clearance, should meet the motor manufacturer's or bearing manufacturer's specifications.~~
- d) ~~Dimensions of bracket fits for housing, cartridge, and bearings should be measured and recorded.~~

4.3 Damage appraisal

~~This appraisal should include a complete review of the following conditions of each part of the motor:~~

- ~~— General cleanliness~~
 - ~~— Cracked or broken welds or castings~~
 - ~~— Missing hardware~~
- ~~— Wear or rub marks, including fretting~~
- ~~— Discoloration, charring, or other evidence of overheating~~
- ~~— Looseness at mating fits~~
- ~~— Corrosion, moisture, or oil inside the machine~~
- ~~— Mounting feet flatness (motor frame feet are to be flat within 0.005 in when placed on a flat reference surface)~~

~~Photographs of any abnormal conditions found are strongly recommended as part of the appraisal process and inspection report. In the absence of clear photographs, any drawings, diagrams, or descriptions should allow no uncertainty as to the location of the conditions described. If references are made to "clock position" or to ends of the machine (e.g., "inboard" or "outboard"), some explanatory note or sketch should make clear the location being described. The terms "drive end" and "opposite drive end" are recommended for horizontal shaft machines; "top" and "bottom" for vertical shaft units.~~

~~Damage appraisal of motor components is divided into two categories, electrical and mechanical (see 4.3.1 and 4.3.2).~~

4.3.1 Electrical

~~The stator winding comes first. Look for the following:~~

- a) ~~Slot wedges ("top sticks") that are loose, damaged, or have shifted in position.~~
- b) ~~Ties or lashings that are loose or broken.~~
- c) ~~Dirt, oil, or moisture deposited on coil surfaces.~~
- d) ~~Coil damage. Besides obvious burning, tracking, or charring, look for loose or cracked tape, coils that have moved within the slot, deposits of dirt or chemicals, and insulation pitted or worn away by airborne abrasive particles. If severe arcing or burning has taken place, inspect the entire unit interior carefully for globules or fragments of molten copper that may have been projected from the failed winding. Windings of motors rated 5 kV and above that have slot partial discharges will evidence white or grey powder on the surface.~~
- e) ~~On lead cables or straps, look for cracked, overheated, or frayed insulation; and loose or burned terminal lugs.~~
- f) ~~When a winding shows clear evidence of destructive arcing or overheating, observe and record carefully the location and nature of the damage. If all coils appear equally overheated, ventilation failure, undervoltage, stalling, or prolonged overload are likely causes. If coils within one phase are largely undamaged, the likely causes are single-phase operation or serious voltage unbalance. If only certain~~

~~coils adjacent to line leads have been damaged, especially with relatively little heating, the likely cause is a transient surge voltage on the feeder circuit. These and many other failure modes, with the probable contributing factors, are reviewed in the bibliography (Clause 8).~~

~~g) Be alert also for evidence of insulation damage caused by flying objects such as broken fan blades within the motor. The impact will typically gouge down to bare copper without any burning unless adjacent turns become short-circuited and failure progresses.~~

~~h) Pay close attention, whether or not winding damage is apparent, to all stator ventilating passages. These can be blocked by varnish or contaminants even when a winding looks fairly clean on the surface.~~

~~i) If no stator winding damage is apparent, test the insulation resistance for windings using a megohmmeter in accordance with IEEE Std 43-1974. Record the value of insulation resistance (IR) between the winding (all leads connected together) and the stator core. Test voltage, applied for 1 min, should be as follows:~~

Rated motor voltage	Megohmmeter test voltage, dc
240-2400	500
3000-4800	2500
5200-13 800	2500 or 5000

~~j) If the measured insulation resistance corrected to a reference of 40 °C is not at least equal to 1 MΩ per 1000 V of motor nameplate rating plus 1 MΩ, the winding should be thoroughly dried and the test then repeated. Drying-out temperature of the winding should not exceed 80 °C as measured by thermometer.~~

~~k) To correct IR readings to the reference temperature, use the formula found in IEEE Std 43-1974.~~

$$R_e = K_t \times R_t$$

~~where~~

~~R_e = Insulation resistance (in megohms) corrected to 40 °C~~

~~R_t = Measured insulation resistance (in megohms) at temperature t~~

~~K_t = Insulation resistance temperature coefficient at temperature t~~

~~Obtain K from figure 1 in IEEE Std 43-1974.~~

~~l) Windings in apparently good condition should receive a dc overpotential (hipot) test for 1 min at a voltage T calculated as follows:~~

$$T = 0.65 (2E_m + 1000 \text{ V})(1.7) \text{ Volts}$$

~~where~~

~~E_m = Rated motor nameplate voltage~~

~~m) If these tests are not passed, the repair center should discuss the results with the owner to arrive at a decision to rewind or to attempt further reconditioning and retesting (e.g., by reimpregnating the winding).~~

~~n) Inspect the stator core structure itself carefully for evidence of severe corrosion, local overheating of laminations, loose or broken slot teeth, loose or shifted vent spacers, or rub marks from contact by the rotor or material caught in the air gap. A core loss test should be performed to evaluate the condition of the laminations.~~

~~o) The rotor is the second major electrical component to be appraised. Cleanliness, laminations, vent~~

spacers, slot tooth condition, and rub marks are checked as in the stator. Rotor laminations should be checked for “coning” (separation of laminations, causing the length of the rotor to be greater at the outer diameter than it is at the shaft).

- p) ~~A squirrel-cage rotor will be the type most often encountered. It may use a cage bar and end ring structure that is cast in place using aluminum alloy, a fabricated aluminum bar or ring assembly, or a fabricated copper alloy cage. Whichever the type, using a dental mirror if necessary, inspect all accessible surfaces of bars and end rings, looking for “blued” (overheated) areas, cracks, missing pieces, bar movement in the slots, porous or deteriorated brazed or welded joints, and bars that have “lifted” outwards in the slots under centrifugal force. Record the location and nature of all defects found.~~
- q) ~~When overheated or melted bars are present, the most severe damage will typically be at the ends of the rotor, outside the core stack, when starting duty is the source of trouble. If running overload or blocked ventilation is the problem, rotor damage is more likely to be within the core stack itself.~~
- r) ~~Look for evidence of arcing or burning along the edges of bars adjacent to slots. This generally indicates bar looseness.~~
- s) ~~One or more cracked or broken cage bars normally dictates replacement of the entire cage. If the rotor cage requires replacement, aluminum or aluminum alloy cages should be of low copper content (0.2% or less). Copper or copper alloy cages should use metal joining material that is phosphorus free. If bars are loose but undamaged, swaging (with a properly radiused tool) of the bars near each end of the core stack and at one or more locations along the stack length may expand the bar material sufficiently to tighten the fit. However, this will not work if the bars are of the T-shape (narrow top, wide bottom) designed for a loose fit of the upper portion. Varnish treatment of a rotor containing a loose cage, even if vacuum pressure impregnation is used, will not permanently lock loose bars in position and should not be used to repair a loose cage. Unless the bars can be mechanically tightened, they should be replaced.~~
- t) ~~The entire rotor should be tested in one of two ways to locate broken cage bars that are not otherwise apparent. If the stator and bearings are in usable condition, a single phase test may be performed [applying typically 10% rated voltage to only two leads of the stator winding, turn the rotor slowly by hand and observe for current variations indicating the possible presence of cage defects; see 4.2.2 item e) 3)]. Otherwise, the removed rotor can be similarly tested on a “growler.” Neither test, unfortunately, is either infallible or procedurally standardized. A typical difficulty is that the halves of a broken bar may separate only when the rotor is hot, the gap closing again when the rotor cools off. Oven-heating the rotor for a short time prior to a growler test may be helpful.~~
- u) ~~Examine steel retention caps or “shrink rings” (usually attached to the ends of high speed rotor cages to restrain centrifugal expansion) for signs of distortion, looseness, or fretting. End rings themselves in such rotors may sometimes fail by being expanded outward into a somewhat conical shape by high centrifugal forces a condition that must be corrected by replacement rather than remachining.~~

4.3.2 Mechanical

The mechanical condition appraisal should give particular attention to the following:

- a) ~~*Antifriction bearings.* Condition of lubricant; dirt, rust, or moisture; fretting corrosion; thermal discoloration; pitting or spalling of balls, rollers, or races; broken or missing retainers.~~
- b) ~~*Sleeve bearings.* Scoring or wiping of babbitt; integrity of any insulation furnished to block passage of bearing current (50 MΩ minimum IR is recommended; no temperature correction is needed; use megohmmeter with less than 50 V output); oil leakage; oil ring wear. Check forced oil lubrication systems for blockage inside piping; presence of proper metering orifices in the system; proper pump operation.~~
- e) ~~*Shafts.* Straightness (NEMA MG 1 1993, Section 1, Part 4); cracks, corrosion; scoring or galling.~~
- d) ~~*Seals.* Rubbing or wear; leakage; glazing or hardening of felt or elastomeric materials.~~

- e) ~~Gaskets. Hardened, broken, or shifted parts; missing gaskets; evidence of lubricant or contaminant leakage past a gasket.~~
- f) ~~Fasteners and dowels. Loose, missing, or broken parts.~~
- g) ~~Frame or housing. Corrosion; structural weld integrity; blocked drains, breathers, or ventilating air passages.~~
- h) ~~Condition of accessories. Space heaters, thermostats, etc.~~
- i) ~~Bearing replacement versus reuse. Many users and repair facilities consider it good practice to replace antifriction bearings on any unit sent in for overhaul regardless of what other repair work is done. When large and expensive components are involved, such as spherical roller thrust bearings, financial constraints dictate keeping existing bearings in service if at all possible. That requires careful appraisal of bearing condition. To do that, the repair facility should use illustrated guidelines published by most bearing manufacturers and readily available through suppliers of power transmission equipment. The symptoms of shaft current flow, improper thrust loading, fatigue, lubrication failure, or other defects are well defined in such literature.~~

5. Preliminary assessment

5.1 Initial receipt

Prior to unloading the motor, the shipment shall be inspected with the shipper representative for obvious damage that may have occurred during shipment. The repair facility shall file appropriate damage reports and inform the user. A receiving report shall be filled out and include broken or missing parts and/or any unusual problem(s). Prior to evaluation, and at appropriate times during later work, clean the motor and components to the extent required to perform subsequent work.

Record all nameplate information available. The following data should be obtained:

- a) Type of apparatus, such as: horizontal, vertical, partial motor, engine type, hermetic, cryogenic, submersible, etc.
- b) Manufacturer
- c) Style, model, type
- d) Serial number
- e) Rated output, as appropriate
 - 1) Horsepower (hp)
 - 2) Kilovolt ampere (kVA)
 - 3) Kilowatt (kW)
- f) Power Factor (for synchronous motors or generators)
- g) Rated speed
 - 1) Revolutions per minute (rpm)
 - 2) Number of poles, if available
- h) Input power; include information for primary and any secondary or field windings as necessary
 - 1) Voltage(s)
 - 2) Phase and phase sequence (where applicable)
 - 3) Frequency
 - 4) Amperage(s)
 - 5) Locked rotor amps or code letter

- 6) Winding connection, starting method
- i) Insulation information
 - 1) Insulation class
 - 2) Temperature rise
 - 3) Ambient temperature design base
- j) Bearing information
 - 1) Type
 - 2) Manufacturer, as available
 - 3) Identification or markings as available
 - 4) Type of lubricant used
- k) Service Factor and service duty limits, if any
- l) Enclosure type and hazardous (classified) area designation (if any)
- m) Information available from additional nameplates, for example:
 - 1) Space heaters (quantity, voltage, and wattage)
 - 2) Auxiliary devices
 - i) Temperature detectors
 - ii) Vibration detectors
 - iii) Surge capacitors, lightning arresters
 - iv) Current transformers (CTs)
 - v) Air filters and differential pressure switches
 - 3) Direction of rotation
 - 4) Motor identification tags
- n) Other information as available from the user
 - 1) Vibration reports, signatures, etc.
 - 2) Motor current signature data

5.2 Incoming tests

To determine whether the motor can be run or whether additional work is justified, an initial evaluation is required. Locate or obtain the motor repair order from the user and review it before proceeding with work on the motor. Perform and record the results of the following inspections, tests, and examinations prior to electrical or mechanical connection, and before any running or attempted operation of the motor:

- a) Frame: readily visible damage
- b) Shaft
 - 1) Unrestricted rotation
 - 2) End play or end float (axial movement of shaft)
 - 3) Readily visible shaft distortion
- c) Bearing(s)
 - 1) Adequate lubrication (grease, oil, and oil mist)
 - 2) Readily visible damage
- d) Check type of coupling and condition. Notify end-user promptly if damage exists as the mating half is likely to be in the same condition.