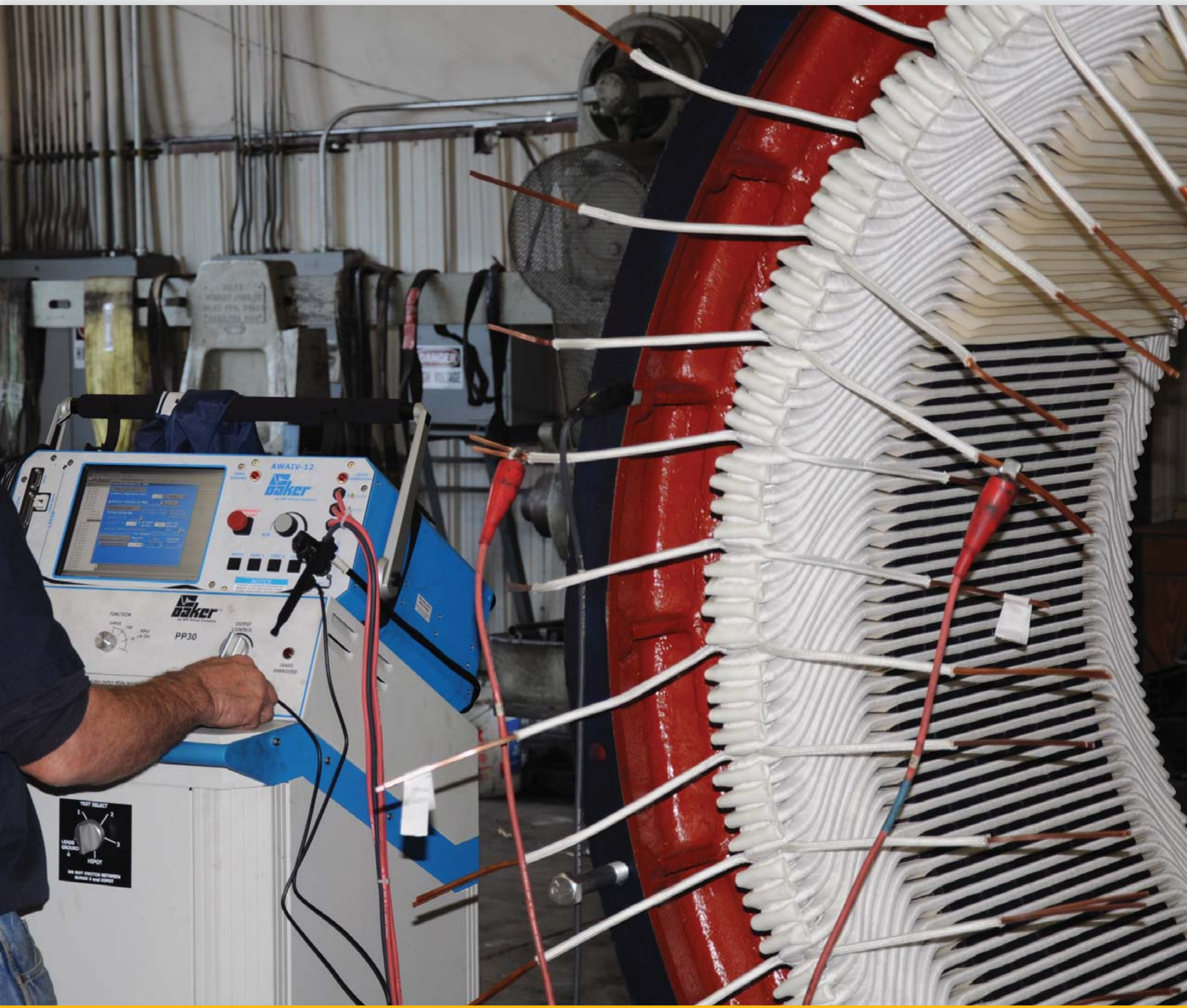
EECO

Electrical Equipment Co

Low and Medium Voltage Motor Testing and Common Standards



TEST DEFINITIONS

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Electrical Test Definition

Insulation Resistance tests (IR) are conducted as specified by IEEE Stds. 43, Sec. 5.4 and 12.2. Test voltage is applied for one minute. Rated voltages are applied as defined in IEEE Stds. 43, Table 1. Readings are recorded in Meg-ohms and corrected to 40^{0}C. (Note: our software performs this correction by simply entering ambient temperature). Applied voltages are specified as follows:

IEEE 43, Table 1 — Guidelines for dc voltages to be applied during insulation resistance test

Winding rated voltage (V)	Insulation resistance test direct voltage (V)
<1000	500
1000–2500	500–1,000
2501–5000	1000–2,500
5001–12 000	2500–5,000
>12 000	5000–10,000

IEEE 43, Table 3 — Recommended minimum insulation resistance values at 40 °C (all values in

Minimum Insulation Resistance	Test Specimen
IR1 min = kV + 1	For most windings made before about 1970, all field windings, and others not described below
IR1 min = 100	For most dc armature and ac windings built after about 1970 (form wound coils)
IR1 min = 5	For most machines with random-wound stator coils and form wound coils rated below 1 kV

NOTES
1—IR1 min is the recommended minimum insulation resistance, in meg-ohms, at 40 °C of the entire machine winding
2—kV is the rated machine terminal to terminal voltage, in rms kV

Note: Bearing insulation is tested in similar manner with a 500V meg-ohmmeter. Insulation resistance should be 1 meg-ohm or greater (EASA AR-100).

Turn to Turn Short Testing (Surge Testing)

Surge testing serves to identify a shorted conductor turn (on the same phase) and can occur during coil manufacturing, the winding process, or applied as condition assessment to an operating motor. As in the case of overvoltage testing, lower levels are applied after consecutive tests or to machines in use.

The 2e+1000 equation applied to overvoltage testing is often referenced for surge testing. This is an incorrect assumption, as the two tests are very different in both intent and function. IEEE 522 clearly defines a method to determine voltage levels based on the intent and function of the test. The formula suggested by IEEE is (√2/√3)*VL)*3.5) as referenced in section 522-6.2, where additional consideration is given to rise time. Resulting test levels are:

Surge Testing Level Definition

New Winding	Reconditioned Winding	Dry Taped, Un-Insulated Coils	Resin Rich, Uncured Coils
$(\sqrt{2}/\sqrt{3})*V_L)*3.5)$	75% of the new value	60% of the new value	40% of the new value

Corresponding Surge Testing Levels (in volts)

Winding Rated Voltage	New Winding	Reconditioned Winding	Dry Taped, Un-Insulated Coils	Resin Rich, Uncured Coils
230	657	493	394	350
460	1315	986	789	536
2300	6573	4930	3944	2629
4160	11888	8916	7133	4755

Surge comparison tests are taken during inspection of a motor as well as part of acceptance testing. Individual coils are tested first by the coil manufacturer (prior to shipment) and secondly during the rewind process. During rewind, they are tested after series connections are made but before insulating and making group connections (an option noted in IEEE 522).

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Overvoltage or High-Potential (Hi-Pot) Tests

After visual inspection and proof testing, overvoltage tests are performed on windings and certain accessories of electrical machines at a specified voltage. Component devices and their circuits, such as space heaters and temperature sensing devices in contact with the winding and connected other than in the line circuit, are connected to the frame or core during machine winding high-potential tests. IR test are repeated after Hi-Pot testing.

Caution must be taken when conducting the test as it stresses the insulation system and can be destructive. NEMA MG 1 refers to IEEE 112 when specifying overvoltage, which sets the voltage for new windings at two times the rated line voltage plus 1000 volts for test using alternating voltage (AC). IEEE 4, Standard Techniques for High Voltage Testing is referenced as a guide. Both Direct Voltages and Alternating Voltages can be applied to conduct the test, each having advantages and disadvantages. Alternating voltages stress the system in ways that direct cannot, and vice versa. Direct voltage tends to be less destructive and has therefore become our standard. The DC testing procedure is specified by IEEE 95, and appropriate levels are specified in IEEE 95, EASA AR-1000, NEMA MG1, IEEE 432 and IEEE 112. Applied voltage levels are typically defined in AC volts and the resulting DC test voltage is specified as 1.7 times the AC voltage.

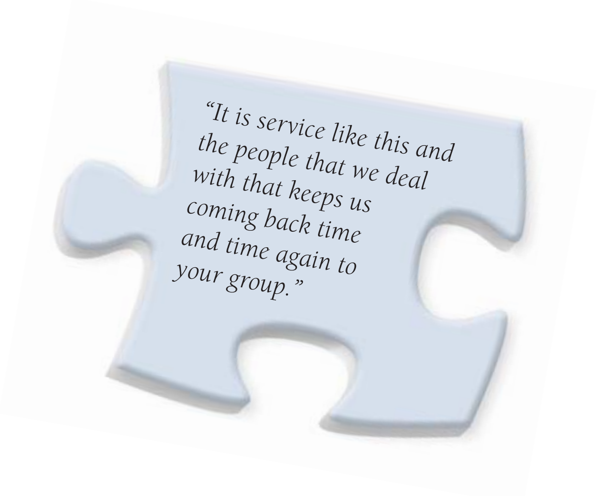
New windings are subjected to higher voltage levels to thoroughly test the new insulation system. The new winding level is 2 times the rated line voltage plus 1000 volts [2e + 1000]. Should an additional test of the winding be required, the applied voltage will be reduced to 80% as specified by NEMA MG1 12.3 (EASA AR-100).

Windings that have not been freshly wound are tested at lower levels. IEEE 432 (Guide for Insulation Maintenance for Machinery 5HP – 10,000 HP) states that "Overvoltage tests may be performed either by alternating or direct voltage methods. The values of test voltages usually are selected as follows:

1. For 60 Hz tests, the overvoltage may be related to the rated machine voltage, and tests in the range of 125 to150% of the line-to-line voltage are normal. Overvoltage tests are typically conducted for 60 s. For test procedures, refer to IEEE Std 4-1978 [1].Equipment for making overvoltage tests at very low frequency (0.1Hz) has become commercially available. Such equipment is typically less in cost and weight and smaller in size than equivalent 60 Hz equipment. For additional information, see IEEE Std 433-1974 [8].
2. For dc tests, the recommended test voltage is a function of the rated machine voltage multiplied by a factor to represent the ratio between direct (test) voltage and alternating (rms) voltage. The recommended value is from 125 to 150% of the rated line-to-line voltage x 1.7".

EASA AR-100 states that overvoltage test for reconditioned windings (ie. clean, dip and bake) is 65% of the new voltage level. This is also referenced in IEEE 95 6.2, which states that the Hi-Pot AC voltage for maintenance testing should be 125-150% of the rated line voltage. This value would be 60-65% of the new winding test value. However, this standard is written for medium voltage motors. Taking 65% of the new winding test level and applying it to a low voltage motor may be excessive. IEEE 432 and 95 clearly states that the test level for reconditioned machines or for field testing should be 125-150% of the rated line voltage (AC, x 1.7 for DC). Our defined test level is 125% of the line rated voltage(s), which at DC would be [e x 1.25 x 1.7] ~ e x 2.2.

Defined Overvoltage Test levels



New Windings
[2e + 1000] x 1.7

Reconditioned Windings
125%e x 1.7 = 2.2e

Field Testing
125%e x 1.7 = 2.2e

Note: EASA AR-100 does not define overvoltage (Hi-Pot) testing for windings that have not been reconditioned. IEEE however does. It should be reiterated that winding must be proof tested per IEEE 43 prior to overvoltage (Hi-Pot) testing.

New Accessories

Surge capacitors, lightning arresters, current transformers, and other devices which have leads connected to the machine terminals are disconnected during the test, with the leads connected together and to the frame or core. Component devices and their circuits, such as space heaters and temperature sensing devices in contact with the winding and connected other than in the line circuit, with leads connected together, are tested by applying a voltage between the circuit and the frame or core. The high-potential test is applied as specified in AR 100, Table 4-4. (Reference: NEMA Stds. MG 1, 3.1.8.)

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Controlled Overvoltage or Step Voltage Testing

A controlled overvoltage test is typically more desirable than the standard overvoltage (Hi-Pot) test. This is particularly true when testing reconditioned or windings in service. The test begins at a lower voltage, either zero or the appropriate PI voltage levels, and is increased in steps until the actual hi-pot test voltage is achieved. According to IEEE 95:

> "A controlled overvoltage test (sometimes referred to as either a dc leakage or absorption test) is a high direct-voltage test in which the applied voltage is changed in a controlled manner. The voltage may be manually increased in a series of steps or automatically ramped up to the maximum test level.
>
> During controlled overvoltage tests, the measured current versus applied voltage is monitored as the test progresses. Abnormalities or deviations in the current response may indicate insulation problems. When performed under suitable conditions, the test provides information regarding the present condition of the stator winding insulation. The test may also serve as a proof test; if the insulation system withstands the maximum prescribed test voltage, it may be deemed suitable for operation until the next scheduled maintenance outage.
>
> In some cases, a controlled overvoltage test may offer the possibility of detecting an impending insulation problem and thereby allow the test to be halted prior to damaging insulation breakdown. However, because unexpected insulation failure can occur during the test, it is important to be aware of the possible need to make repairs before the machine can be returned to service."

Polarization Index

A PI test is conducted in similar fashion to an insulation resistance test. In this case, the DC test voltage is applied to the circuit for 10 minutes. The resistance value at 10 minutes is divided by the value recorded at one minute, producing the index value. (P.I.) test are useful for trending over time. The graphical PI curve may be of interest as a diagnostic tool, though the PI in itself is not used as an acceptance test. PI test are performed for ten minutes on motors greater than 200 HP as standard. Per EASA AR 100, the recommended minimum value of polarization index for windings rated Class B and higher is 2.0 (References: IEEE 43, Sec. 9.2; and IEEE 432, App. A2). If the one minute insulation resistance is above 5000 meg-ohms, the calculated polarization index (P.I.) may not be meaningful. In such cases, the P.I. may be disregarded as a measure of winding condition (Reference: IEEE 43, Sec. 5.4 and 12.2).

Core Loss – Inter-laminar Insulation Test

Defects in laminated cores can be detected by core tests (Reference: IEEE 432, Sec. 9.1, App. A4). Core loss testing is performed on all stators scheduled for rewind as defined by EASA AR-100 and Tech Note 17. We employ commercial core test machines which provide guides for testing. Hot spots in excess of the average core temperature develop within 10 minutes and typically within 20 minutes at the back iron. Thermal imaging cameras are used to identify hot spots, and those exceeding 10^{0}C above the average must be cleared regardless of overall test results. Overall test results are compared to an EASA provided database, where core loss should be one to six watts per pound depending on lamination material and grade. Tests are conducted before and after the burnout process, comparing the results to ensure they are not only acceptable, but that core loss did not increase more than EASA provided standards (typically 20% maximum). (EASA/AEMT Rewind Study, 2003; EASA Core Iron Study, 1984). Test reports for both before and after tests are scanned and stored electronically with the job record, and include the following data at minimum:

1. Job and Nameplate Data
2. Core physical dimensions (diameter, length, back iron, slot depth, tooth width, # of teeth, approx weight)
3. Test parameters (voltage, power, and current)
4. Test results (core loss in watts-lb, power factor, flux density, and reluctance)

No-Load Test

Current, applied voltages, and frequency (AC) are recorded during no load testing. Applied voltages are as follows:

1. AC motors are made at rated voltage and rated frequency.
2. Shunt-wound and compound-wound DC motors are run with rated voltage applied to the armature, and rated current applied to the shunt field.
3. Series-wound motors are separately excited when tested due to danger of runaway. DC generators are driven at rated speed with rated current applied to the shunt field.

Load Testing

Tests with load may be made as arranged with the customer or as necessary to check the operating characteristics of the machine (References: IEEE Stds. 112 and 115 and NEMA Stds. MG-1). All DC motors are load tested as standard.

Winding Resistance Imbalance

Winding Resistance Imbalance is calculated as the greatest phase to phase difference from the recorded average, measured in ohms. Limits should be as follows:

1. Random wound motors — 1% maximum measured at motor leads
2. Form wound motors — 1% maximum measured at motor leads

Note: % Imbalance = [largest phase to phase delta from the average Ω] / average Ω. Concentric wound motors can be much higher and are treated as an exception.

Applicable Standards

Effective dates of standards are not included in this text as they change over time. It is assumed that the most recent version of the respective standard is observed. This list does not represent every standard required to perform repair services, but is considered a foundation.

ANSI, American National Standards Institute. New York, NY.

1. ANSI/ABMA Standard 7-1995: Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) American Bearing Manufacturers Association, Inc.
2. ANSI S2.41-1985: Mechanical Vibration of Large Rotating Machines with Speed Ranges From 10 to 200 RPS. Measurement and Evaluation of Vibration Severity
3. ANSI/NCSL Z540-1-1994: Calibration–Calibration Laboratories and Measuring and Test Equipment - General Requirements.

EPRI, Electrical Power Research Institute. Charlotte, NC.

1. EPRI 1009700: Guide for Electric Motor Stator Winding Insulation Design, Testing and VPI Resin Treatment
2. EPRI 1000898: Random Wound Motor Failure Investigation
3. EPRI 1009698: Shipping and Storage of Electric Motors

EASA, Electrical Apparatus Service Association. St. Louis, MO.

1. EASA Standard AR-100: Recommended Practice for the Repair of Rotating Electrical Apparatus
2. EASA Technical Manual
3. EASA Motor Repair Fundamentals
4. EASA Root Cause Failure Analysis

IEEE, Institute of Electrical and Electronics Engineers, Inc. New York, NY.

1. IEEE Standard 43: IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.
2. IEEE Standard 95: IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.
3. IEEE Standard 112: IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.
4. IEEE Standard 115: IEEE Guide: Test Procedures for Synchronous Machines.
5. IEEE Standard 432: IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp).
6. IEEE Standard 522: IEEE Guide for Testing Turn-To-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.
7. IEEE Standard 792: IEEE Recommended Practice for the Evaluation of the Impulse Voltage Capability of Insulation Systems for AC Electric Machinery Employing Form-Wound Stator Coils.
8. IEEE Standard 1068: IEEE Recommended Practice for the Repair and Rewinding of Motors for the Petroleum and Chemical Industry.
9. IEEE Standard 1415: IEEE Guide for Induction Machinery Maintenance Testing and Failure Analysis
10. IEEE Standard 113: IEEE Guide Test Procedures for DC Machines
11. IEEE Standard 4: IEEE Standard Techniques for High Voltage Testing
12. IEEE Standard 56: IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10 000 kVA and Larger)
13. IEEE Standard 841: IEEE Standard for Petroleum and Chemical Industry—Up to and Including 370 kW (500 hp)
14. IEEE Paper 0-941783-23-5/0: A Review of VPI Procedures for Form Wound Stators

International Organization for Standardization. Geneva, Switzerland

1. ISO 10012-1: Quality Assurance Requirements for Measuring Equipment.
2. ISO 1940-1: Mechanical Vibration–Balance Quality Requirements of Rigid Rotors.
3. ISO 1940-2: Determination of Permissible Residual Unbalance.
4. ISO 10816-1: Mechanical Vibration–Evaluation of Machine Vibration by Measurements on Non-Rotating Parts–Part 1: General Requirements

Other applicable standards:

NEMA Standards MG 1-2006: Motors and Generators. National Electrical Manufacturers Association.

NFPA Standard 70E-2009: Standard for Electrical Safety in the Workplace. National Fire Protection Association

29CFR1910.331 - .335 OSHA: Electrical Safety-Related Work Practices. Occupational Safety and Health Administration.

ANSI, American National Standards Institute. New York, NY.

EPRI, Electrical Power Research Institute. Charlotte, NC.

EASA, Electrical Apparatus Service Association. St. Louis, MO.

IEEE, Institute of Electrical and Electronics Engineers, Inc. New York, NY.

International Organization for Standardization. Geneva, Switzerland

NEMA Standards MG 1-2006: Motors and Generators. National Electrical Manufacturers Association.

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