Electrical Equipment Co

Motor Repair Services Program —
Safety, Quality and Standards

About EECO

Electrical Equipment Co

Electrical Equipment Company (EECO) provides both Industrial Motor Services and Electrical Supply Solutions for a customer base that ranges from the heavy industries of metals, mining, shipbuilding and forest products to precision manufacturers of food and consumer products, pharmaceuticals, semiconductors and automated machinery. EECO serves a large portion of the Southeast with 3 repair facilities and 13 supply locations in Virginia, North Carolina, South Carolina, and Georgia.

EECO was founded in 1926 largely to serve the Motor Repair needs of the Pulp and Paper industry in central North Carolina. The company is privately held and governed by a board of directors consisting of actual owners and several consultants with specific expertise. Ownership has remained within the same small group of families and associated board members since inception.

We have been a member of EASA since it was founded several decades ago. Our employees have served various roles as committee members, chapter officers, and international officers.

Our Evolution

- Mid 1940's-Electrical Supplies added.
- 1984 – Automation products added, serving industry and OEM's.
- 1997 – Procurement and Inventory Management Solutions Group
- 2008 – Motor repair business is formally recognized as Industrial Motor Services, a division of Electrical Equipment Company.

Today

- $110 million in sales
- 13 supply locations
- 3 repair facilities
- 251,000 sq. ft. warehouse space
- Over $11 million of inventory

Quality Management

Our quality program provides feedback to everyone on our team, challenging us to prove ourselves to each other and certifying bodies. **Our goal is to provide accurate repair services in accordance with defined standards, while ensuring the safety of everyone involved.**

Our program is designed around areas of Specification Management, Knowledge Management, Evaluation, and Safety.

Specification Management

We begin with EASA AR-100, which references specifications defined by IEEE, NEMA, ABMA, ANSI, and ISO. A biography of these can be found on page 41. One copy of each required specification is stored in our electronic library, which serves terminals throughout each of our facilities. In this manner we can easily keep all specifications current, as hard copies are not relied on. Any special customer requirements become part of this library. Procedures are developed from these specifications, and each procedure will reference the specification for which it is designed.

Work in process is recorded in our proprietary software, written on a Microsoft SQL platform. All specifications, including customer specifications, are only a click away while working on a job. The software was custom designed for motor repair by our repair technicians. As major tasks are completed, Quality Steps provide a checklist for the task, referencing procedure and specification, and must be asserted before the task can be marked complete. Customer specific requirements are also enforced by quality steps, are automatically driven by account number, and highlighted in green to be clearly visible to technicians. Our software not only captures the record but the operating technician as well, providing the necessary history for use in audits. Finally, all quality steps are included on our standard repair report.

Additional detail on procedures, methods, and equipment can be found as specified below:

Quality Management - Knowledge Management

Procedures and specifications are integrated into our job management system through our electronic quality manual, which provides instant access while working within a job record. All standards, procedures, and defined process are stored on a Microsoft SharePoint internal website. The body of knowledge required to perform quality repairs is organized in this electronic library of technical references, articles, manuals, and drawings. This library features all required forms, training, employee handbooks, or other data required to work with our team. Remote access is provided ensuring that employees can access required information while traveling or at home.

We are committed to training and have dedicated one official position to the training of our personnel and evaluation of our practices. Our training material was developed specifically to support our work procedures and required specifications. Classroom sessions and self led training are provided, and tests are implemented online. Lab exercises are performed in the shop on actual work intervals under supervision of instructors. Transcripts for each technician are maintained by an online University service, which is provided by BlueVolt.

Training topics include but are not limited to:

EASA Repair Fundamentals

a. Motors and Applications
b. Testing and inspection procedures
c. Disassembly
d. Rotors
e. Shafts
f. Bearings
g. Shaft openings, seals, and fits
h. Accessories
i. Terminal boxes
j. Motor dynamics
k. Vibration and geometry
l. Shaft currents
m. Line connections

Apparatus and Application Specific Training

a. Explosion Proof motors
b. Synchronous operation and repair
c. DC operation and repair
d. Sleeve bearings
e. Ball bearings
f. Vertical mount bearings
g. Thermal expansion

Specific Methods

a. Abrasive blasting
b. Cleanliness and contamination control
c. Brazing, soldering, and welding
4. EASA AR-100 Specification
5. Failure analysis by FMEA Root Cause Methodology

External Training is also provided through local universities, equipment manufacturers, and other related agencies such as EASA.

Quality Management - Evaluation

Evaluation of performance, and the feedback generated, is considered critical to success. Internal audits are conducted on monthly and bi-monthly frequencies as a primary means of evaluation. A calibration program is also employed on intervals required by the equipment manufacturer, EASA, or governing standard. Finally, we seek the guidance of certifying bodies, such as Advanced Energy, to provide an outside audit of our program.

Quality Management - Safety

All employees are introduced to our OSHA PPE and Hazardous Communication Program. Testing is conducted in the same manner as technical training. New employees are paired with a mentor until basic skills develop. A formal PPE assessment provides specific guidelines for standard PPE equipment and is specific to work process and equipment. The PPE program provides a list of approved vendors and devices of PPE equipment. Our PPE and hazard communication programs have been examined by the NC Department of Labor.

Formally administered safety training topics include:

Personal Safety and Health

a. PPE Devices and Use
b. Eye and Face Supplemental
c. Blood borne pathogens
d. Hazardous Communication
e. Respiratory Protection

Environment and Awareness

a. Fire extinguisher use and safety
b. Electrical Safety
c. Lock Out-Tag Out
d. Customer Site Safety

Work Process Safety

a. Grinding and cutting
b. Jacks and pullers
c. Slings, Chains, and Lifting
d. Welding
e. Vehicle loading, tie down, and transportation
f. Liquid nitrogen

A dress code is observed and uniforms are provided to employees. Minimum observed PPE equipment includes:

1. Safety footwear
2. Safety glasses

Additional devices required depending on work process or equipment use include gloves (3 types), face shields, dust mask, respirator, ear plugs, and other specific devices.

Warranty

A stainless steel tag is provided on each repair, denoting the warranty number, beginning date, bearings, and lubrication provided. Decals are used on smaller motors. We track warranty claims and awards, reviewing the data for potential changes in process, procedure, and/or training. Our performance metric is that warranties are no greater than .5% of sales.

Excerpt. See complete warranty for additional terms.

Complete Mechanical Recondition & Electrical Rewind of Electric Motors.

Upon completion, EECO warrants that the Apparatus has been dismantled, inspected, parts cleaned, all mechanical tolerances brought back to manufacturer's tolerances (if known) or EASA Recommended Practice, all windings replaced with new windings composed of new insulation and wire, dynamically balanced rotating components, assembled, to include the replacement of rolling element bearings with new, lubricated, tested and painted. EECO warrants its materials and workmanship of the electrical rewind portion of the job for a period of two years from date of completion and warrants its materials and workmanship for the mechanical recondition portion of the job for one year from date of completion.

Mechanical Recondition of Electric Motors.

Upon completion, EECO warrants that the Apparatus has been dismantled, inspected, parts cleaned, all mechanical tolerances brought back to manufacturer's tolerances (if known) or EASA Recommended Practice, windings dried and varnish treated as required, dynamically balanced rotating components, assembled, to include the replacement of rolling element bearings with new, lubricated, tested and painted. EECO warrants the materials and workmanship for a period of one year from date of completion.

Other Repairs and Service.

For all other repairs and service of Apparatus, EECO warrants materials used in the repair and service and workmanship for work carried out by EECO for a period of ninety (90) days from date of completion.

Evaluation

Audit & Certification

Each of our facilities is audited on monthly or bi-monthly periods. Audits are conducted on random samplings of work in process as well as recorded data of completed work.

Audits focus in areas of:

- Safety
- Compliance to Procedure
- Maintenance
- Record Keeping
- Training
- Turnaround
- Due Date Performance
- Pricing

Certifications

Each of our facilities is qualified to perform UL repairs. Certification numbers are:

- Richmond E68680
- Raleigh E59844
- Augusta E184676

We are conscious of the need to preserve energy efficiency levels and made the commitment to maintain a proof of efficiency verification program. Our choice has been Advanced Energy, whose lab is located on the NC State University Campus in Raleigh, NC. In 2010 we achieved certification for our Richmond facility. At the time of print our Augusta and Raleigh facilities are in process of certification.

Calibration

Our calibration program is employed on intervals required by the equipment manufacturer, EASA, and governing standards. Each instrument and transducer is calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or equivalent standards laboratories (References: ANSI/NCSL Z540-1-1994 and ISO 10012).

A list of calibrated equipment and respective providers can be provided at each facility. Calibration services providers are required to meet the requirements of ISO 17025, "General Requirements for the Competence of Testing and Calibration Laboratories", and are subject to change. Application specific calibrations of note include:

1. CSI vibration equipment is calibrated by CSI as part of a regular maintenance program, and is NIST traceable.
2. Balancing machines, even those considered to be self calibrating through operation, are calibrated with calibrated rotors. Each machine is also tested and certified to ISO standards.

Standard Inspection
Prior to Quote or Estimate of Repairs

Inspection is a critical portion of the job, and defines the entire scope of work. Motors are disassembled, cleaned, and exposed to numerous tests and measurements. Motors are visually inspected and 3 photos are captured of the exterior. A failure assessment is conducted and suggested causes, including photos, are recorded. Electrical testing begins after a physical assessment of condition for suitability to test run. Windings are tested to ensure that there are no grounds, short circuits, open circuits, incorrect connections or high resistance connections.

Standard Inspection - Standard Electrical Testing Prior to Quote

1. Insulation Resistance, corrected to 40ºC (per IEEE-43)
2. Initial Test Run (If possible)
3. Winding Resistance and Inductance (Per IEEE 1415)
4. Dielectric absorption test followed by a polarization index (if DA is questionable)
5. Step Voltage Test or DC Hi-pot, condition permitting (NEMA MG1 and IEEE 95)
6. Single phase rotor tests. (Per EASA AR100)
7. Inter-laminar Insulation or Core Loss tests (Per IEEE 432 and EASA Tech Note 17) are performed on windings subject for rewind (unless otherwise specified by customer) before and after burnout and stripping.

Note: DA and PI testing are conducted in graphical format to identify problems that could otherwise escape standard test.

Standard Inspection - Application Specific Testing Prior to Quote

Stator and Wound Rotor Windings
a. Insulation Resistance
b. Winding Resistance
c. Surge Comparison

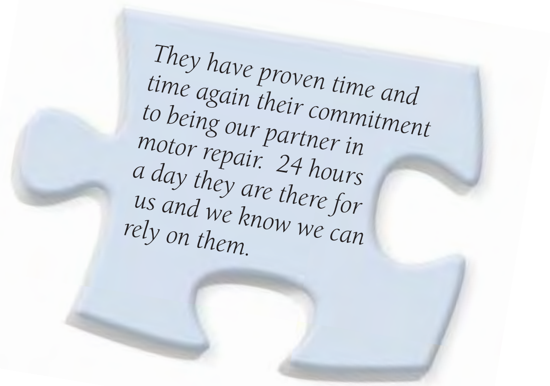
Squirrel Cage (Rotor) Windings
a. Single phase test if winding is acceptable or:
b. Growler test

Armature Windings
a. Insulation Resistance
b. Bar-to-bar resistance via specific tester or low resistance bridge

Shunt, Series, Inter-pole, Compensating Windings, and Synchronous Rotor Windings
a. Insulation resistance
b. Winding resistance
c. Voltage Drop

	Permissible Variance	
	AC	DC
Synchronous Rotor Fields	5%	2%
DC Motor shunt fields, series fields, interpoles and compensating fields	10%	5%

d. Single phase surge test



Mechanical Inspection

Motor components are inspected beginning with guidelines specified in EASA AR-100 1.5.1:
"Inspect all parts for wear and damage before and after cleaning. Insulation should be examined for evidence of degradation or damage, such as:

1. Puffiness, cracking, separation or discoloration as indication of thermal aging.
2. Contamination of coil and connection surfaces.
3. Abrasion or other mechanical stresses.
4. Evidence of partial discharges (corona).
5. Loose wedges, fillers, ties, banding, or surge rings.
6. Fretting at supports, bracing or crossings (an indication of looseness or movement). (Reference: IEEE 432, Sec. 5.) Bars and end rings for amortisseur and squirrel cage windings should be examined for evidence of defects" *EASA AR-100 2010.*

Bearing seats, passage, and shafts are inspected with calibrated micrometers and bore gauges. All fits are measured at up to nine points standard, depending on housing depth or journal width. Measurements are made in a linear fashion across the surface and each rotated by 60^0. Shafts are checked for wear, cracks, scoring and straightness. Shaft extension dimensions are checked to standard dimensions. Shaft extension fits are inspected as determined by EASA AR-100.

Fits and dimensional tolerances are observed as specified by the OEM (if accessible), or as referenced by EASA (ABMA). In certain conditions the SKF General Catalog may be referenced.

Mechanical Fits Reference

Bearing housing and shaft bearing fits are measured and compared to design specifications referencing OEM specifications if available or customer specifications if provided. Otherwise, ANSI/ABMA 7 is referred to as a guide. Any fits that are not within tolerance are corrected. Reference Tables 2-13 and 2-14 of EASA AR 100.

Precision, multi-point fits are taken with bore gauges

Standard Repair Operations

Though not an exhaustive specification, additional detail on select repair operations is provided below.

Balancing

All rotors are balanced in two planes to meet the criteria of not less than ISO 1940 G2.5. Two pole motors are balanced to ISO 1940 G1.0. Rotors are supported at the bearing position. Ref EASA AR 100 "Dynamic balancing of the rotating element should be to the level specified by the customer. In the absence of a requested level, dynamic balancing to balance quality grade G2.5 (ISO 1940/1) should en-able the machine to meet final vibration limits as defined in paragraph 4.5.6". Rotor weight is captured on calibrated scales during handling.

Bearing Installation

Replacement bearings are provided and will match the customer specification or OEM requirements (if not specified by customers). As found and as repaired bearing data, including manufacturer, is provided on standard documentation. Installation is performed in a clean environment separated from grinding, machining, and other operations creating potential contaminants. Bearings are installed with professional grade equipment under defined procedure. Bearing heaters include temperature gauges, automatic shut-off, and degaussing. Maximum allowed residual magnetism is 2.6 Gauss measured at the bearing after heating.

Lubrication

Poly-urea based grease (Exxon Mobil, Polyrex EM) is provided unless otherwise required by customer or application specifications. Grease piping and nipples are typically replaced as standard. Grease nipples are removed when sealed bearings are installed and added when non-shielded bearings are installed. Lubricants are stamped on job number plate or on applied decal.

Stocked lubricants include:

Oils (as shown or equivalent)

a. Turbine Oils
   i. ISO VG 32 - Exxon Mobil DTE Light 24
   ii. ISO VG 68 - Exxon Mobil DTE Hvy-Med 26
   iii. ISO VG 100 - Exxon Mobil DTE Heavy
b. Gear oil - LE, 80W-90
c. Others as specified by customer or special applications

Greases (as shown or equivalent)

a. Polyeurea, Exxon Mobil Polyrex EM
b. Lithium Complex - Exxon Mobil, SHC - 100 Synthetic
c. Shaker Service - Optimol, PD-2, Lithium
d. Others as specified by customer or special applications

VIBRATION LEVELS

Ph. 800.993.3326
Web. www.eecoonline.com

Vibration

Unless otherwise required by application or customer specification, motors exceeding 100 HP are subjected to a complete vibration analysis as part of standard pricing. Motors are tested while unbolted on vibration absorbing pads at no load (minimum preload is provided for test of motors with rolling element bearings). Motors are tested at rated voltage and under the following guidelines:

1. Alternating current motors will be tested at rated voltage and frequency.
   a. Single speed motors will be tested at speed.
   b. Multi-speed motors are tested at each rated speeds.
2. Direct current motors are tested at their highest rated speed.
3. All other motors are tested at rated speed.

Motors are tested during no load tests and allowed to run for a minimum of 10 minutes to come to temperature (steady state) and for proper grease distribution within bearings.

Three axis measurements of all bearing locations are recorded using Emerson CSI equipment. Readings are collected at each bearing location on or as near as possible to the bearing (not on fan shroud). Testing pads are the preferred location if provided.

Overall acceleration amplitude limit across the operating band should not exceed .5g peak. Vibration velocity line amplitude should not exceed the following limits:

Band	Freq Range (CPM)	Freq Range	Limit (inches/sec peak)	Limit (mm/sec RMS)
1	.3 x RPM .8 x RPM	18 48	.04	.72
2	.8 x RPM 1.2 x RPM	48 72	.075	1.35
3	1.2 x RPM 3.5 x RPM	72 210	.04	.72
4	3.5 x RPM 8.5 x RPM	210 510	.03	.54
5	8.5 x RPM 60K CPM	510 1000	.03	.54
6	60K CPM 120K CPM	1000 2000	.03	.54

Motors less than 100 HP are subjected to overall limit testing as provided by EASA AR-100. Table 4-5 is referenced as provided by section 4.5.6 of AR 100: "Vibration levels for speeds above 1200 rpm are based on the peak velocity of 0.15 inch per second (3.8 mm/s). Vibration levels for speeds below about 1200 rpm are based on the peak velocity equivalent of 0.0025 inch (0.0635 mm) peak-to-peak displacement. For machines with rigid mounting, multiply the limiting values by 0.8".

Rewind Program

Our rewind program is designed to deliver the highest quality coil and insulation systems and is around the following areas:

1. Stator Core Management
2. Coil Design and Construction
3. Insulation System and Curing
4. Quality Testing
5. Process Maintenance

Stator Core Management

The laminations within the stator core are separated by a thin layer of inter-laminar insulation which can be damaged by exposure to high temperatures. Roasting a stator to remove the insulation and facilitate coil removal must be done in a carefully controlled high temperature environment. Since the oven air temperature is only an approximate indication of the core temperature a thermocouple attached to the core is the recommended monitoring point. Core temperatures should not exceed 700°F and should be limited to 680°F. (EASA/AEMT Rewind Study, 2003; EASA Core Iron Study, 1984).

Core loss testing is performed on all stators scheduled for rewind as defined by IEEE 432 and EASA Tech Note 17. After physically checking for hot spots, test results are compared to an EASA provided database. Core loss should be one to six watts per pound depending on lamination material and grade. This is however an inexact science and we therefore test before and after burnout as well, 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). In the event your stator is suspect, we notify you with our recommendations, prior to proceeding. Core loss results are scanned and maintained with electronic documentation of the job.

We process stators in quality ovens with multiple temperature loop controllers. This provides the ability to monitor not only the temperature in the oven, but of the part itself. Using the part feedback loop provides for much tighter control of the actual stator temperature, and helps to avoid potential damage to the stator from overheating. Our ovens also feature a water spray cool down to avoid high temperature fluctuations caused by combustible material burn off. Each oven has continuous monitoring capability with on board chart recorders.

Typical Process Parameters

		References
Maximum Burnout Temperature	680 F	EASA Technical Manual
Typical Burnout Period	6 - 8 hours	Steelman Industries
Core Test	1-6 watts/pound	Lexseco, EASA core database
Comparative Core Loss Test (before and after burnout)	Less than 20% increase	EASA Technical Manual

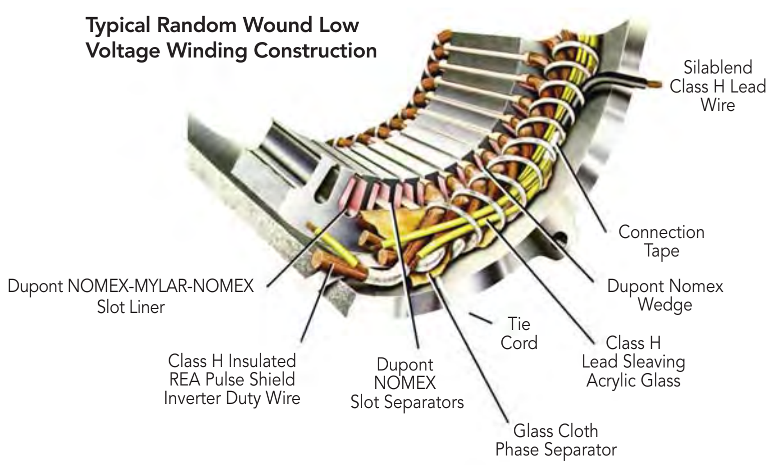
Coil Design and Construction

Coil design and construction begins with good data collection. The stator is inspected to record the design of the winding including number of slots, turns, groups, poles, core dimensions and wire size. This data is evaluated with software provided by EASA to confirm flux density of the stator and compare coil pitch, groupings, and turns to historical motor designs. This helps to ensure the winding we put back in is not only as we found it, but that the original winding was correct. We confirm potential problems with EASA engineers.

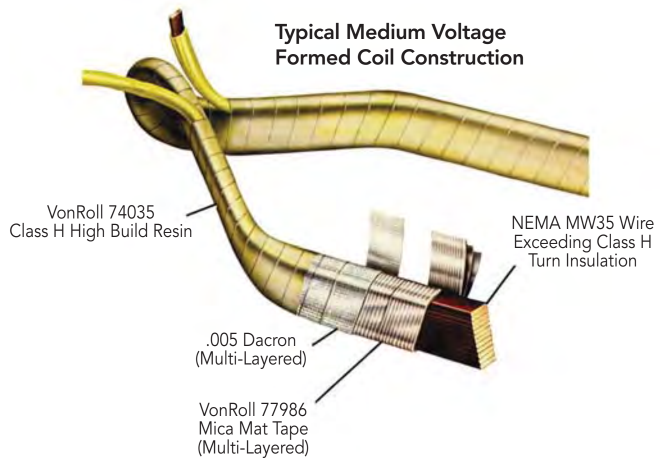
We purchase all formed coils from outside suppliers. The efficiency and economy provided by a dedicated formed coil shop is unmatchable, and our suppliers build and test each coil to our provided standards. Random testing is not acceptable, and each coil must be tested prior to shipment.

All random wound coils are made with invertor duty Rea wire (NEMA MW35 or better). Coils are made on fully automatic, self indexing machines allowing us to save the profile and easily reproduce the coil set again. To ensure we can quickly meet OEM specifications, we stock 32 different invertor duty wire sizes from 8 through 26.

Random Wound Systems



Form Wound Systems



Insulation System and Curing

The ingredients of an effective insulation system must have compatible properties so that they work together to yield the best temperature rating, form factor, dielectric and mechanical strengths possible. Our quality program defines acceptable materials for both random and form wound systems in voltage ranges including 600, 2300, and 4160 volts. The result is a Class H, 180° C winding that you can depend on.

We use only the best of materials, including VonRoll epoxies and tapes, as well as quality DuPont Nomex for wedges and coil separators. Slot liners (random wound) are tri-layer Nomex Mylar Nomex, providing additional strength and resistance to potential imperfections. Glass cloth is used as phase insulation for random windings.

Each of our VPI systems contains VonRoll Permafil® 74035 Epoxy. Permafil has excellent electrical and chemical performance and is used in systems up to 7200 volts. It has years of successful use in the field and is noted for its "high build" properties. Typically one treatment of Permafil provides equal or better build than two treatments of many other epoxies. In a test with a 5810 frame 750 HP machine, one treatment of Permafil provided a total 38 pounds of build, while the competitive comparison yielded only 31.4 pounds. That's an increase of 21% in build on the first application.

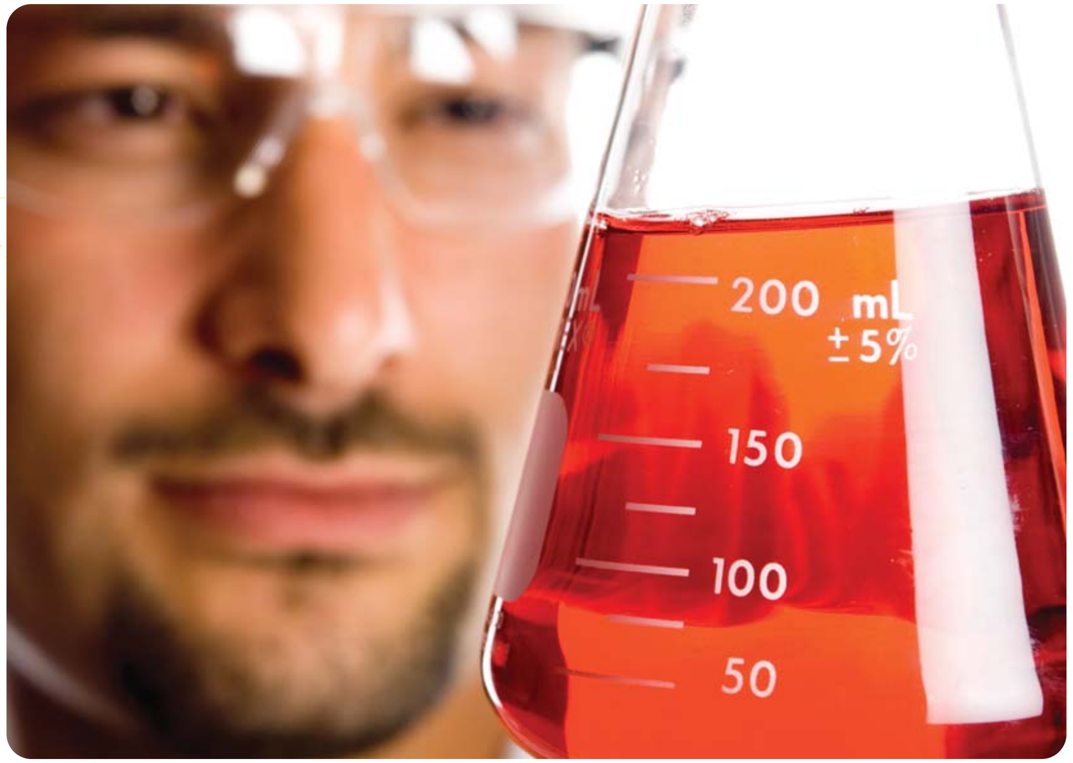
Voltage	Construction	Mil per layer	layers	Volt/ mil	Dielectric	Total
600	1 layer 1/2 lap VRI 77986 or VRI 77877 Mica Mat Tape	6.7	2	450	6030	40KV
	1 layer 1/2 lap ,005 Dacron	5	2	0	0	
	VRI 74035 Resin	5	2	3000	30000	
	Magnet wire (film) NEMA MW35 or better	Min.			5700	
2300	3 layer 1/2 lap VRI 77986 or VRI 77877 Mica Mat Tape	6.7	6	450	18090	50KV
	1 layer 1/2 lap ,005 Dacron	5	2	0	0	
	VRI 74035 Resin	5	2	300	30000	
	Magnet wire (film) NEMA MW35 or better	Min.			5700	
4160	4 layer 1/2 lap VRI 77986 or VRI 77877 Mica Mat Tape	6.7	8	450	24120	60KV
	1 layer 1/2 lap ,005 Dacron	5	2	0	0	
	VRI 74035 Resin	5	2	3000	30000	
	Magnet wire (film) NEMA MW35 or better	Min			5700	

Each form coil system is subjected to a full VPI process (Vacuum Pressure Impregnation) to ensure maximum wet out and penetration of the insulation. Though random wound insulation systems are not designed to absorb epoxy, all random wound stators in excess of 200 HP are VPI processed to ensure minimum voids and the added mechanical strength VPI provides (versus a standard dip and bake process).

Process Maintenance

Ensuring effectiveness of any process including people, equipment, and materials requires ongoing evaluation and maintenance. We maintain our program with several simple tools:

1. Standard materials are defined for compliance to our system. Materials are dated upon receipt as a simple measure to monitor shelf life. Materials are ordered and received by separate personnel to verify compliance.
2. Regular epoxy samples are taken from each tank every 60 days and sent to VonRoll. Each sample is evaluated for viscosity, moisture and impurities. VonRoll technicians then assist with any problems make recommendations for corrective action. Results are stored on our servers as part of our historical records.
3. Coil samples are taken during the VPI process to visually inspect the cross section for effective epoxy penetration.
4. The VPI system is maintained as part of our 60 day inspection, including vacuum pump oil, water filtration, chiller air filtration, and pressure regulation



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°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 $(\sqrt{2}/\sqrt{3})*V_L)*3.5)$ 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).

TEST DEFINITIONS

Ph. 800.993.3326
Web. www.eecoonline.com

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.)

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°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.

STANDARDS

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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.

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.

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