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EASA Standard AR100-2010

RECOMMENDED PRACTICE

FOR THE REPAIR OF ROTATING ELECTRICAL APPARATUS

ELECTRICAL APPARATUS SERVICE ASSOCIATION

Reliable Solutions Today

ELECTRICAL APPARATUS SERVICE ASSOCIATION, INC.
INTERNATIONAL HEADQUARTERS
1331 Baur Blvd., St. Louis, MO 63132 • Phone: 314-993-2220 • Fax: 314-993-1269 • www.easa.com

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Section 1
General

1.1 PURPOSE

The purpose of this document is to establish recommended practices in each step of rotating electrical apparatus rewinding and rebuilding.

1.2 SCOPE

This document describes record keeping, tests, analysis, and general guidelines for the repair of rotating electrical apparatus. It is not intended to take the place of the customer's or the machine manufacturer's specific instructions or specifications.

Excluded from the scope of this document are specific requirements, certification, and inspection required for listed explosion proof, dust-ignition-proof, and other listed machines for hazardous locations; and specific or additional requirements for hermetic motors, hydrogen-cooled machines, submersible motors, traction motors, or Class 1E nuclear service motors.

1.3 IDENTIFICATION

1.3.1 Service Center Labeling

Machines received for repair should have the repair company's name or identifying logo and shop order number permanently embossed or inscribed adjacent to the nameplate on the frame for future reference. This shop order number should be listed on the repair invoice.

1.3.2 Records

A record of each machine received for repair should be established at the time of receipt and kept on file for at least 3 years. The record should include the nameplate data, electrical test data (both before and after repair), mechanical measurements (both before and after repair), original winding data, final winding data, and details of replaced parts. This record should be made available to the customer for review if requested. The primary cause of failure should be determined, if possible, and should be recorded on the apparatus repair record.

1.3.3 Nameplate

An electrical machine should have a permanent nameplate containing the principal information needed to put the machine into service. The original nameplate is preferred. If a machine is redesigned, the original nameplate should remain on the unit and a new nameplate mounted adjacent to it with the word "redesigned" and the new rating and date of redesign shown. The original nameplate may be reversed (blank side out) to prevent misinterpretation, but it should remain with the frame.

1.4 CONDITION ASSESSMENT AND FAILURE INVESTIGATION

The service center should inspect and test the apparatus to confirm its condition and obtain data for any failure investigation. For the latter, data collection should proceed before any work is carried out. Inspect all parts for defects before and after cleaning. Document any evidence of distress, such as physical damage, overheating, tampering, oil levels, electrical tracking, or encounters with animals. If possible, obtain information about operating conditions at the time of failure. Collect and carefully examine any debris from any fault.

1.5 INSPECTION AND CLEANING

1.5.1 Inspection

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 Stds. 432, Sec. 5.)

Bars and end rings for amortisseur and squirrel cage windings should be examined for evidence of defects. Testing may be needed (see Paragraph 4.3.2).

1.5.2 Cleaning

All windings and parts should be cleaned. Dirt, grit, grease, oil, and cleaning agents should be removed. Windings and parts should then be dried.

1.6 TERMINAL LEADS

All apparatus should be equipped with lead wire of rated temperature and voltage insulation and of sufficient current carrying capacity. The temperature rating should be appropriate for the duty and any oven curing process, and allow for the effect of heat transfer to the terminals.

All leads should be suitably marked or colored where necessary to indicate correct connection. Lead markings should conform to original manufacturer markings, NEMA Stds. MG 1 or IEC Stds. 60034-8, whichever is applicable.

Leads and markings should be of sufficient durability to withstand the environment involved and be of sufficient length for ease of connecting to power supply at the terminal box or to terminal blocks. Leads on totally enclosed apparatus should be properly sealed to meet environmental operating conditions.

A print or plate should be furnished, where necessary, indicating correct connections.

1.7 TERMINAL CONNECTORS

The recommended method of attaching terminal connectors (lugs) to lead wire is by crimping or pressure indenting the lug barrel, using a lug sized to suit the particular cable stranding provided, in accordance with recommendations of the lug manufacturer.

Damaged or missing lugs should be repaired or replaced.

1.8 TERMINAL BOXES

Terminal boxes should accommodate the connections without crowding. Missing terminal boxes should be replaced, and damaged terminal boxes should be repaired or replaced. See NEMA Stds. MG 1, 4.19 for guidance on replacement terminal boxes. Gaskets and seals should be replaced where necessary.

1.9 COOLING SYSTEM

The fans and cooling ducts should be clean and operational. Cover plates and air baffles should be in place. Damaged or missing parts of the cooling system should be repaired or replaced.

1.10 EXTERIOR FINISH

Apparatus should be externally cleaned and painted. Shaft extensions should be treated to prevent corrosion.

1.11 PACKAGING AND TRANSPORTATION

After completion of the repair and testing, the machine should be packed in a manner suitable for the form of transport to be used. Packing and transport should be as arranged with the customer. Blocking of the shaft is recommended, depending on the type of machine, mode of transport and the distance to be traveled. Where blocking is used, it should be clearly identified. Oil-lubricated machines should be shipped without oil, and the need for lubricant clearly identified.

Section 2
Mechanical Repair

2.1 SHAFTS

Shafts should be checked for wear, cracks, scoring and straightness. Shaft extension dimensions should be checked.

2.1.1 Diameter Tolerances

- NEMA frame size machines: See Table 2-1.
- IEC frame size machines: See Table 2-2.

2.1.2 Permissible Runout

- NEMA frame size machines: See Table 2-3.
- IEC frame size machines: See Table 2-4.

2.1.3 Keyseat (Keyway) Width Tolerances

- NEMA frame size machines: See Table 2-5.
- IEC frame size machines: See Table 2-6.

Keyseats should be true and accommodate keys to a tap fit.

2.2 BEARINGS

Bearings should be inspected for fretting, fluting, frosting, scoring or other damage.

2.2.1 Ball or Roller Bearings

Bearing housing and shaft bearing fits should be measured and compared to design specifications (Reference: ANSI/ABMA Stds. 7 as a guide). Any fits that are not within tolerance should be restored. See Tables 2-13 and 2-14. Replacement bearings should be equivalent to the original manufacturer's specifications.

2.2.2 Sleeve Bearings

When sleeve bearings are remanufactured or replaced by new bearings, the fit in the housing and the diametral clearance should be set to original equipment manufacturer's specifications if available. See Section 9 of the EASA Technical Manual for guidance on diametral clearances for oil-lubricated horizontally-mounted sleeve bearings. Measure the new bearing dimensions.

Sleeve bearings should be uniform in diameter, of proper fit in the housing, smooth internally, and suitably grooved for adequate distribution of lubricant. Note: Not all sleeve bearing bores are cylindrical.

2.2.2.1 Sleeve Bearing End-Thrust

Bearings of horizontal machines should be positioned on the shaft to eliminate end-thrust against either bearing.

2.2.2.2 Oil Rings

Oil rings should be true and rotate freely. Retainers, when provided, should be inspected and replaced if necessary.

2.2.2.3 Seals

Seal clearance should be set to original equipment manufacturer's specifications if available. Otherwise, the values in Table 2-7 are provided as a guide. Measure the final seal dimensions.

2.3 LUBRICATION

2.3.1 Grease

Grease passages and pipes should be clean. Grease inlets should be equipped with fittings. Lubricant should be compatible with the customer's lubricant. Open bearings should be filled with grease during assembly.

In the absence of the machine manufacturer's lubrication instructions, the grease reservoir should be filled to approximately 1/3 capacity.

2.3.2 Oil

Lubricant, including oil for test operation, should be compatible with the customer's lubricant . There should be a means to indicate proper oil level, such as an oil sight gauge. Evidence of oil leaks should be investigated and the cause corrected.

2.4 FRAME AND BEARING HOUSINGS

2.4.1 General

Frame and bearing housings should be examined for defects. Cracks and breaks should be repaired and fits restored to manufacturer's specifications.

2.4.2 Mounting Surface Tolerances, Eccentricity and Face Runout

- NEMA Type C face-mounting motors and Type D flange-mounting motors: See Table 2-8.
- NEMA Type P flange-mounting motors: See Table 2-9.
- IEC flange-mounted machines: See Table 2-10 and Table 2-11.

2.5 LAMINATIONS

Examine stator and rotor laminations for evidence of hot spots or damaged or missing components.

2.5.1 Rotors

The rotor laminations should be of proper fit on the shaft, sleeve or spider on which the lamination stack is assembled. The outer diameter of the rotor laminations should be true and concentric with the bearing journals. Inspect stator and rotor for evidence of stator-rotor contact and visual evidence of post-manufacture machining of the outer diameter of the rotor.

Cores should be examined for evidence of shorting or lamination hot spots. Testing may be needed (see

Paragraph 4.2.7).

2.5.2 Stators

The stator laminations should not be loose in the frame. The bore of the stator laminations should be true and concentric with the rabbet (spigot) diameter of the frame.

2.6 BALANCING

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 enable the machine to meet final vibration limits as defined in Paragraph 4.5.6.

Note: Locate balance weights so that they do not interfere with other components.

2.7 SLIP RINGS

The slip rings should be turned to concentricity with the shaft bearing seats.

The surface of the finished rings should be smooth and polished.

Slip rings should have sufficient stock to ensure proper brush performance. Manufacturer's limits should apply.

2.8 COMMUTATORS

2.8.1 Machining

The commutator should be turned to concentricity with the shaft bearing seats.

The surface of the machined commutator should be smooth and burnished. No flat spots or high, low or loose segments should exist.

Commutators should have sufficient stock to ensure proper brush performance. Manufacturer's limits should apply.

2.8.2 Undercutting

The mica should be undercut, or left flush, as required by the application. When undercut, the mica should be removed along the sides of the bar for at least the complete length up to the riser or dust groove and to a depth of approximately the width of the slot. Undercut areas should be free of foreign material and high mica.

Beveling may be required for those commutators that have rough segment edges resulting from work-hardening of the copper during the undercutting process.

2.9 BRUSHHOLDERS

Brushholders should be clean and free of any debris, oil, or dirt. Movable brushholder parts should be free working. The brush fit in the brushholder box should be inspected for excessive clearance, and worn brushholders should be replaced. Clearances should be as specified in Table 2-12.

Brush stud insulation should be free of cracks and should not be charred or have missing components.

In the final assembly of the machine, brushholders should be adjusted for clearance to the commutator or slip rings of 0.060 inch (1.5 mm) to 0.125 inch (3mm), depending on the size of the unit. Manufacturer's specifications should apply.

For commutator machines, it should be verified that the brushholders align the brushes with the commutator bars and maintain equal circumferential spacing between brushes.

Spring pressure should be measured and adjusted to a range recommended by the original equipment manufacturer or the brush manufacturer for the specific application and brush type. For commutator machines, brush springs should provide the required brush pressure for successful commutation.

Brushholders and jumpers should be high-potential tested to the machine frame at the test voltage specified for the corresponding winding circuit (see Subsection 4.4).

2.10 BRUSHES

Brush shunts should be tight in the brush and connections to the holder should be clean and tight and clear of other items.

The face of the brush should be seated, or contoured, to make full contact with the commutator surface or slip rings. The brush fit in the brushholder box should be inspected for side clearance (see Table 2-12) and for excessively worn brushes. Brushes worn beyond useful length should be replaced.

Brushes in the same circuit of a machine should be of the same grade unless otherwise specified by the original equipment manufacturer. For DC machines, brushes should be the size and grade to give successful commutation in normal service.-

2.11 BRUSH SETTING FOR DC MACHINES

In the final assembly, the brush rigging should be positioned so that the brushes are set for brush neutral, with brush position clearly marked. Accepted methods of determining this position vary widely, and no single standard procedure applies.

Note: In an assembled DC machine, each brush must contact at least two commutator bars at a time. Then, the brush short-circuits the armature coil connected to these bars. The brushes are considered to be set for brush neutral when the armature coils shorted by the brushes are midway between main poles.

2.12 AIR GAP OF DC MACHINES

In a DC machine, the main pole and the interpole air gap should be uniform (within plus or minus 5% of the average), or to original manufacturer's specifications. Note: Some manufacturers intentionally vary the air gap of the interpoles to obtain satisfactory commutation.

2.13 ACCESSORIES

2.13.1 Capacitors

Capacitors should be tested for rated capacitance and subjected to a high-potential test (see Paragraph 4.4). Capacitors should be replaced if damaged.

2.13.2 Starting Components and Switches

Short circuit devices, centrifugal mechanisms, switches, and starting relays should be verified for electrical and mechanical operation at correct speed and voltage. These items should be replaced if damaged.

2.13.3 Terminal Boards

Terminal boards should be replaced if damaged, with components of the same ampacity and temperature rating of the original components.

2.13.4 Space Heaters

Space heaters should be tested for rated current or power and subjected to a high-potential test (see Paragraph 4.4). They should be replaced if damaged.

2.13.5 Temperature Sensors

Bearing and winding sensors or protectors should be identical with or equivalent to the original devices in electrical and thermal characteristics.

Table 2-1. SHAFT EXTENSION DIAMETER TOLERANCES

NEMA MACHINES

DIMENSIONS IN INCHES			DIMENSIONS IN MILLIMETERS		
Shaft Diameter	Tolerance		Shaft Diameter	Tolerance	
0.1875 to 1.5000, incl.	+0.000	-0.0005	4.76 to 38.1, incl.	+0.000	-0.013
Over 1.5000 to 6.500, incl.	+0.000	-0.001	Over 38.1 to 165.1, incl.	+0.000	-0.025

Reference: NEMA Stds. MG 1, 4.9.1. Dimensions shown in millimeters are rounded off.

Table 2-2. SHAFT EXTENSION DIAMETER TOLERANCES

IEC MACHINES

DIMENSIONS IN MILLIMETERS					DIMENSIONS IN INCHES			
Tolerance Designation	Nominal Shaft Diameter Over	Nominal Shaft Diameter Up To	Tolerance		Shaft Diameter Over	Shaft Diameter Up To	Tolerance	
j6*	6	10	+0.007	-0.002	0.236	0.394	+0.0003	-0.0001
j6*	10	18	+0.008	-0.003	0.394	0.709	+0.0003	-0.0001
j6*	18	30	+0.009	-0.004	0.709	1.181	+0.0004	-0.0002
k6	30	50	+0.018	+0.002	1.181	1.969	+0.0007	+0.0001
m6	50	80	+0.030	+0.011	1.969	3.150	+0.0012	+0.0004
m6	80	120	+0.035	+0.013	3.150	4.724	+0.0014	+0.0005
m6	120	180	+0.040	+0.015	4.724	7.087	+0.0016	+0.0006
m6	180	250	+0.046	+0.017	7.087	9.843	+0.0018	+0.0007
m6	250	315	+0.052	+0.020	9.843	12.402	+0.0020	+0.0008
m6	315	400	+0.057	+0.021	12.402	15.748	+0.0022	+0.0008
m6	400	500	+0.063	+0.023	15.748	19.685	+0.0025	+0.0009
m6	500	630	+0.070	+0.026	19.685	24.803	+0.0028	+0.0010

*In some countries the k6 tolerance is used instead of j6.

Reference: IEC Stds. 60072-1, C.1.4. Dimensions shown in millimeters are rounded off.

Table 2-3. PERMISSIBLE SHAFT EXTENSION RUNOUT

NEMA MACHINES

DIMENSIONS IN INCHES		DIMENSIONS IN MILLIMETERS	
Shaft Diameter	Shaft Runout*	Shaft Diameter	Shaft Runout*
0.1875 to 1.625 incl.	0.002	4.76 to 41.3, incl.	0.051
Over 1.625 to 6.500, incl.	0.003	Over 41.3 to 165.1, incl	0.076

*Maximum permissible change in indicator reading when measured at the end of the shaft extension.

Note: The permissible shaft runout tolerance has not been established where the shaft extension length exceeds the NEMA standard. However, runouts for shafts longer than standard are usually greater than those indicated above.

Reference: NEMA Stds. MG 1, 4.9.7. Dimensions shown in millimeters are rounded off.

Table 2-4. PERMISSIBLE SHAFT EXTENSION RUNOUT

IEC MACHINES

DIMENSIONS IN MILLIMETERS			DIMENSIONS IN INCHES		
Nominal Shaft Diameter		Shaft Runout*	Shaft Diameter		Shaft Runout*
Over	Up To		Over	Up To	
6	10	0.030	0.236	0.394	0.001
10	18	0.035	0.394	0.709	0.001
18	30	0.040	0.709	1.181	0.002
30	50	0.050	1.181	1.969	0.002
50	80	0.060	1.969	3.150	0.002
80	120	0.070	3.150	4.724	0.003
120	180	0.080	4.724	7.087	0.003
180	250	0.090	7.087	9.843	0.004
250	315	0.100	9.843	12.402	0.004
315	400	0.110	12.402	15.748	0.004
400	500	0.125	15.748	19.685	0.005
500	630	0.140	19.685	24.803	0.006

This table applies to rigid foot-mounted and flange-mounted machines.
*Maximum permissible change in indicator reading when measured midway along the shaft extension length.

Reference: IEC Stds. 60072-1, C.1.6.
Dimensions shown in inches are rounded off.

Table 2-5. SHAFT EXTENSION KEYSEAT WIDTH TOLERANCES

NEMA MACHINES

DIMENSIONS IN INCHES			DIMENSIONS IN MILLIMETERS		
Width of Keyseat	Tolerance		Width of Keyseat	Tolerance	
0.188 to 0.750, incl.	+0.002	-0.000	4.78 to 19.1, incl.	+0.051	-0.000
Over 0.750 to 1.500, incl.	+0.003	-0.000	Over 19.1 to 38.1, incl.	+0.076	-0.000

Reference: NEMA Stds. MG 1, 4.9.2.
Dimensions shown in millimeters are rounded off.

Table 2-6. SHAFT EXTENSION KEYSEAT (KEYWAY) WIDTH TOLERANCES

IEC MACHINES

DIMENSIONS IN MILLIMETERS				DIMENSIONS IN INCHES			
Nominal Width of Keyseat (Keyway)		Tolerance*		Width of Keyseat (Keyway)		Tolerance*	
Over	Up To			Over	Up To		
2 up to	3	-0.004	-0.029	0.078	0.118	-0.0002	-0.0011
3	6	0	-0.030	0.118	0.236	0	-0.0012
6	10	0	-0.036	0.236	0.394	0	-0.0014
10	18	0	-0.043	0.394	0.709	0	-0.0017
18	30	0	-0.052	0.709	1.181	0	-0.0020
30	50	0	-0.062	1.181	1.969	0	-0.0024
50	80	0	-0.074	1.969	3.150	0	-0.0029
80	100	0	-0.087	3.150	3.937	0	-0.0034

*Normal keys, Tolerance N9.

Reference: IEC Stds. 60072-1, C.1.5.
Dimensions shown in inches are rounded off.

Table 2-7. LABYRINTH SEAL DIAMETRAL CLEARANCE GUIDE

DIMENSIONS IN INCHES					
Shaft Diameter* 3000 to 3600 rpm		Diametral Clearance**	Shaft Diameter* 1800 rpm or lower		Diametral Clearance**
From	Up To	(+.002”/-.000”)	From	Up To	(+.002”/-.000”)
3.000	3.500	0.009	3.000	3.500	0.012
3.500	4.000	0.010	3.500	4.000	0.014
4.000	4.500	0.012	4.000	4.500	0.016
4.500	5.000	0.014	4.500	5.000	0.018
5.000	5.500	0.015	5.000	5.500	0.020
5.500	6.000	0.017	5.500	6.000	0.022
6.000	6.500	0.018	6.000	6.500	0.024
6.500	7.000	0.020	6.500	7.000	0.026
7.000	7.500	0.021	7.000	7.500	0.028

DIMENSIONS IN MILLIMETERS					
Shaft Diameter* 3000 to 3600 rpm		Diametral Clearance**	Shaft Diameter* 1800 rpm or lower		Diametral Clearance**
From	Up To	(+.050mm/-.000mm)	From	Up To	(+.050mm/-.000mm)
76	89	.230	76	89	.305
89	102	.255	89	102	.355
102	114	.305	102	114	.405
114	127	.355	114	127	.455
127	140	.380	127	140	.510
140	152	.430	140	152	.560
152	165	.455	152	165	.610
165	178	.510	165	178	.660
178	191	.535	178	191	.710

Speeds given are synchronous speeds corresponding to the applicable line frequency and winding poles. Dimensions shown in millimeters are rounded off. The above table is to be used for horizontal machines with bronze/brass labyrinth seals, absent specific clearance recommendations from the manufacturer. Galling materials, such as cast-iron, may require greater clearance. Vertical machines may require less clearance. Labyrinth seal clearance must always be greater than the bearing clearance. A general rule of thumb suggests labyrinth seal clearance should be 0.002” - 0.004” (.050 - .100 mm) greater than the sleeve bearing clearance.

*The shaft diameter is the diameter at the seal fit; and “up to” means “up to but not including.”

**The diametral clearance is the clearance for the applicable range of shaft diameter.

Table 2-8. MOUNTING SURFACE TOLERANCES, ECCENTRICITY AND FACE RUNOUT

NEMA TYPE C FACE-MOUNTING MOTORS AND TYPE D FLANGE-MOUNTING MOTORS

DIMENSIONS IN INCHES				DIMENSIONS IN MILLIMETERS			
Rabbet Diameter	Tolerance on Diameter		Eccentricity & Face Runout*	Rabbet Diameter	Tolerance on Diameter		Eccentricity & Face Runout*
Less than 12	+0.000	-0.003	0.004	Less than 304.8	+0.000	-0.076	0.102
12 to 24	+0.000	-0.005	0.007	304.8 to 609.6	+0.000	-0.127	0.178
Over 24 to 40	+0.000	-0.007	0.009	Over 609.6 to 1016	+0.000	-0.178	0.229

*Maximum permissible change in indicator reading.
Reference: NEMA Stds. MG 1, 4.12, Table 4-5.
Dimensions shown in millimeters are rounded off.

Table 2-9. MOUNTING SURFACE TOLERANCES, ECCENTRICITY AND FACE RUNOUT

NEMA TYPE P FLANGE-MOUNTING MOTORS

DIMENSIONS IN INCHES				DIMENSIONS IN MILLIMETERS			
Rabbet Diameter	Tolerance on Diameter		Eccentricity & Face Runout*	Rabbet Diameter	Tolerance on Diameter		Eccentricity & Face Runout*
Less than 12	+0.003	-0.000	0.004	Less than 304.8	+0.076	-0.000	0.102
12 to 24	+0.005	-0.000	0.007	304.8 to 609.6	+0.127	-0.000	0.178
Over 24 to 40	+0.007	-0.000	0.009	Over 609.6 to 1016	+0.178	-0.000	0.229
Over 40 to 60	+0.010	-0.000	0.012	Over 1016 to 1524	+0.254	-0.000	0.305

*Maximum permissible change in indicator reading.
Reference: NEMA Stds. MG 1, 4.13, Table 4-6.
Dimensions shown in millimeters are rounded off.

Table 2-10. MOUNTING RABBET (SPIGOT) DIAMETER TOLERANCES

IEC FLANGE-MOUNTED MACHINES

DIMENSIONS IN MILLIMETERS					DIMENSIONS IN INCHES			
Tolerance Designation	Nominal Rabbet (Spigot) Diameter		Tolerance		Rabbet (Spigot) Diameter		Tolerance	
	Over	Up To			Over	Up To		
j6	30	50	+0.011	-0.005	1.181	1.969	+0.0004	-0.0002
j6	50	80	+0.012	-0.007	1.969	3.150	+0.0005	-0.0003
j6	80	120	+0.013	-0.009	3.150	4.724	+0.0005	-0.0004
j6	120	180	+0.014	-0.011	4.724	7.087	+0.0006	-0.0004
j6	180	250	+0.016	-0.013	7.087	9.843	+0.0006	-0.0005
h6	250	315	0	-0.032	9.843	12.402	0	-0.0013
h6	315	400	0	-0.036	12.402	15.748	0	-0.0014
h6	400	500	0	-0.040	15.748	19.685	0	-0.0016
h6	500	630	0	-0.044	19.685	24.803	0	-0.0017
h6	630	800	0	-0.050	24.803	31.496	0	-0.0020
h6	800	1000	0	-0.056	31.496	39.370	0	-0.0022
h6	1000	1250	0	-0.066	39.370	49.213	0	-0.0026
h6	1250	1600	0	-0.078	49.231	62.992	0	-0.0031
h6	1600	2000	0	-0.092	62.992	78.740	0	-0.0036
h6	2000	2200	0	-0.110	78.740	86.614	0	-0.0043

Note: This table applies to machines with FF, FT and FI mounting flanges.
Reference: IEC Stds. 60072-1, C.1.7.
Dimensions shown in inches are rounded off.

Table 2-11. MOUNTING SURFACE ECCENTRICITY AND FACE RUNOUT

IEC FLANGE-MOUNTED MACHINES

DIMENSIONS IN MILLIMETERS			DIMENSIONS IN INCHES		
Nominal Rabbet (Spigot) Diameter		Eccentricity & Face Runout*	Rabbet (Spigot) Diameter		Eccentricity & Face Runout*
Over	Up To		Over	Up To	
40 up to	100	0.080	1.575	3.937	0.003
100	230	0.100	3.937	9.055	0.004
230	450	0.125	9.055	17.717	0.005
450	800	0.160	17.717	31.496	0.006
800	1250	0.200	31.496	49.213	0.008
1250	2000	0.250	49.213	78.740	0.010
2000	2240	0.315	78.740	88.189	0.012

Note: This table applies to machines with FF, FT and FI mounting flanges.
*Maximum permissible change in indicator reading.

Reference: IEC Stds. 60072-1, C.7.
Dimensions shown in inches are rounded off.

Table 2-12. BRUSH-TO-BRUSHHOLDER CLEARANCE

DIMENSIONS IN MILLIMETERS			DIMENSIONS IN INCHES		
Nominal Brush Dimensions Width and Thickness	Clearance		Nominal Brush Dimensions Width and Thickness	Clearance	
	Max.	Min.		Max.	Min.
1.6 2 2.5	0.144	0.044	1/16	0.0056	0.00175
3.2	0.158	0.050	1/8	0.0062	0.0020
4 5	0.178	0.050	3/16	0.0070	0.0020
6.3 8 10	0.193	0.055	1/4 5/16 3/8	0.0076	0.0022
12.5 16	0.232	0.072	7/16 1/2 5/8	0.0091	0.0028
20 25	0.254	0.080	3/4 7/8 1	0.0100	0.0032
32 40 50	0.300	0.100	1-1/4 1-1/2	0.0118	0.0039
64 80	0.330	0.110	1-3/4 2	0.0130	0.0043

Reference: IEC Stds. 60136, Table I.
To avoid confusion between dimensions in millimeters and in inches, brushes and brushholders may have markings as follows: metric dimensions ❐; inch dimensions ∆.

NOTE: Replacement of a brush made to inch dimensions with a brush made to millimeter dimensions (or vice versa) might cause problems because of an improper fit in the brushholder.

Table 2-13. RADIAL BALL BEARING FIT TOLERANCES*

	SHAFT FITS (j5 and k5)				HOUSING FITS (H6)					
BASIC NUMBER	TOLERANCE CLASS**	BEARING BORE mm	SHAFT DIAMETER (inches) MAXIMUM	SHAFT DIAMETER (inches) MINIMUM	BEARING OD mm	200 SERIES HOUSING BORE (inches) MINIMUM	200 SERIES HOUSING BORE (inches) MAXIMUM	BEARING OD mm	300 SERIES HOUSING BORE (inches) MINIMUM	300 SERIES HOUSING BORE (inches) MAXIMUM
00	j5	10	0.3939	0.3936	30	1.1811	1.1816	35	1.3780	1.3786
01	j5	12	0.4726	0.4723	32	1.2598	1.2604	37	1.4567	1.4573
02	j5	15	0.5908	0.5905	35	1.3780	1.3786	42	1.6535	1.6541
03	j5	17	0.6695	0.6692	40	1.5748	1.5754	47	1.8504	1.8510
04	k5	20	0.7878	0.7875	47	1.8504	1.8510	52	2.0472	2.0479
05	k5	25	0.9847	0.9844	52	2.0472	2.0479	62	2.4409	2.4416
06	k5	30	1.1815	1.1812	62	2.4409	2.4416	72	2.8346	2.8353
07	k5	35	1.3785	1.3781	72	2.8346	2.8353	80	3.1496	3.1503
08	k5	40	1.5753	1.5749	80	3.1496	3.1503	90	3.5433	3.5442
09	k5	45	1.7722	1.7718	85	3.3465	3.3474	100	3.9370	3.9379
10	k5	50	1.9690	1.9686	90	3.5433	3.5442	110	4.3307	4.3316
11	k5	55	2.1660	2.1655	100	3.9370	3.9379	120	4.7244	4.7253
12	k5	60	2.3628	2.3623	110	4.3307	4.3316	130	5.1181	5.1191
13	k5	65	2.5597	2.5592	120	4.7244	4.7253	140	5.5118	5.5128
14	k5	70	2.7565	2.7560	125	4.9213	4.9223	150	5.9055	5.9065
15	k5	75	2.9534	2.9529	130	5.1181	5.1191	160	6.2992	6.3002
16	k5	80	3.1502	3.1497	140	5.5118	5.5128	170	6.6929	6.6939
17	k5	85	3.3472	3.3466	150	5.9055	5.9065	180	7.0866	7.0876
18	k5	90	3.5440	3.5434	160	6.2992	6.3002	190	7.4803	7.4814
19	k5	95	3.7409	3.7403	170	6.6929	6.6939	200	7.8740	7.8751
20	k5	100	3.9377	3.9371	180	7.0866	7.0876	215	8.4646	8.4657
21	m5	105	4.1350	4.1344	190	7.4803	7.4814	225	8.8583	8.8594
22	m5	110	4.3318	4.3312	200	7.8740	7.8751	240	9.4488	9.4499
24	m5	120	4.7257	4.7250	215	8.4646	8.4657	260	10.2362	10.2375
26	m5	130	5.1194	5.1187	230	9.0551	9.0562	280	11.0236	11.0249
28	m5	140	5.5131	5.5124	250	9.8425	9.8436	300	11.8110	11.8123
30	m5	150	5.9068	5.9061	270	10.6299	10.6312	320	12.5984	12.5998
32	m5	160	6.3005	6.2998	290	11.4173	11.4186	340	13.3858	13.3872
34	m6	170	6.6945	6.6935	310	12.2047	12.2060	360	14.1732	14.1746
36	m6	180	7.0882	7.0872	320	12.5984	12.5998	380	14.9606	14.9620
38	m6	190	7.4821	7.4810	340	13.3858	13.3872	400	15.7480	15.7494
40	m6	200	7.8758	7.8747	360	14.1732	14.1746	420	16.5354	16.5370

*Shaft rotates–outer ring stationary.

** For hollow shafts, use j6 instead of j5, m5 instead of k5, n6 instead of m5, and p6 instead of m6.

Adapted from ABMA Standard 7, Tables 1, 2, 3 and 4. The above shaft (interference) fits and housing (clearance) fits are practical for most standard electric motor applications. Where wider tolerances (housing fits) are permissible, use tolerance class h7 instead of h6. Some applications such as hollow shaft motors, spindle motors and vibrator motors require a different tolerance class than shown in the table.

Table 2-14. CYLINDRICAL ROLLER BEARING FIT TOLERANCES*

	SHAFT FITS (k5, m5, m6 and n6)				HOUSING FITS (H6)					
BASIC NUMBER	TOLERANCE CLASS	BEARING BORE mm	SHAFT DIAMETER (inches) MAXIMUM	SHAFT DIAMETER (inches) MINIMUM	BEARING OD mm	200 SERIES HOUSING BORE (inches) MINIMUM	200 SERIES HOUSING BORE (inches) MAXIMUM	BEARING OD mm	300 SERIES HOUSING BORE (inches) MINIMUM	300 SERIES HOUSING BORE (inches) MAXIMUM
00	m5	10	0.3942	0.3939	30	1.1811	1.1816	35	1.3780	1.3786
01	m5	12	0.4730	0.4727	32	1.2598	1.2604	37	1.4567	1.4573
02	m5	15	0.5912	0.5909	35	1.3780	1.3786	42	1.6535	1.6541
03	m5	17	0.6699	0.6696	40	1.5748	1.5754	47	1.8504	1.8510
04	m5	20	0.7881	0.7877	47	1.8504	1.8510	52	2.0472	2.0479
05	m5	25	0.9850	0.9846	52	2.0472	2.0479	62	2.4409	2.4416
06	m5	30	1.1818	1.1814	62	2.4409	2.4416	72	2.8346	2.8353
07	m5	35	1.3788	1.3784	72	2.8346	2.8353	80	3.1496	3.1503
08	m5	40	1.5756	1.5752	80	3.1496	3.1503	90	3.5433	3.5442
09	m6	45	1.7727	1.7721	85	3.3465	3.3474	100	3.9370	3.9379
10	m6	50	1.9695	1.9689	90	3.5433	3.5442	110	4.3307	4.3316
11	m6	55	2.1666	2.1658	100	3.9370	3.9379	120	4.7244	4.7253
12	m6	60	2.3634	2.3626	110	4.3307	4.3316	130	5.1181	5.1191
13	m6	65	2.5603	2.5595	120	4.7244	4.7253	140	5.5118	5.5128
14	n6	70	2.7574	2.7567	125	4.9213	4.9223	150	5.9055	5.9065
15	n6	75	2.9543	2.9536	130	5.1181	5.1191	160	6.2992	6.3002
16	n6	80	3.1511	3.1504	140	5.5118	5.5128	170	6.6929	6.6939
17	n6	85	3.3483	3.3474	150	5.9055	5.9065	180	7.0866	7.0876
18	n6	90	3.5451	3.5442	160	6.2992	6.3002	190	7.4803	7.4814
19	n6	95	3.7420	3.7411	170	6.6929	6.6939	200	7.8740	7.8751
20	n6	100	3.9388	3.9379	180	7.0866	7.0876	215	8.4646	8.4657
21	n6	105	4.1357	4.1348	190	7.4803	7.4814	225	8.8583	8.8594
22	n6	110	4.3325	4.3316	200	7.8740	7.8751	240	9.4488	9.4499
24	n6	120	4.7262	4.7253	215	8.4646	8.4657	260	10.2362	10.2375
26	n6	130	5.1201	5.1192	230	9.0551	9.0562	280	11.0236	11.0249
28	n6	140	5.5138	5.5129	250	9.8425	9.8436	300	11.8110	11.8123
30	p6	150	5.9082	5.9072	270	10.6299	10.6312	320	12.5984	12.5998
32	p6	160	6.3019	6.3009	290	11.4173	11.4186	340	13.3858	13.3872
34	p6	170	6.6956	6.6946	310	12.2047	12.2060	360	14.1732	14.1746
36	p6	180	7.0893	7.0883	320	12.5984	12.5998	380	14.9606	14.9620
38	p6	190	7.4834	7.4823	340	13.3858	13.3872	400	15.7480	15.7494
40	p6	200	7.8771	7.8760	360	14.1732	14.1746	420	16.5354	16.5370

*Shaft rotates–outer ring stationary.

Adapted from ABMA Standard 7, Tables 1, 2, 3 and 4. The above shaft (interference) fits and housing (clearance) fits are practical for most standard electric motor applications. Where wider tolerances (housing fits) are permissible, use tolerance class h7 instead of h6. Some applications such as hollow shaft motors, spindle motors and vibrator motors require a different tolerance class than shown in the table.

Section 3
Rewinding

3.1 INSPECTION

3.1.1 Core Laminations

Core testing is recommended before burnout or other equivalent process and after winding removal, and the results should be compared (see Paragraph 4.2.8). Any increase in losses should be investigated, and damaged laminations should be repaired or replaced.

3.1.2 Thermal Protectors or Sensors

Thermostats, resistance temperature detectors (RTDs), thermocouples and thermistors should be checked for electrical and physical defects.

3.2 REWIND SPECIFICATION

The winding should maintain the same electrical characteristics as the original. Winding data should be reviewed for accuracy.

3.3 STRIPPING OF WINDINGS

Defective windings should be removed from the core in a manner that will not damage the laminations or other components. Part temperature should be controlled to avoid degradation of the interlaminar insulation and distortion of any parts. The oven should use a water suppression system. Parts should be oriented and supported in the oven so as to avoid distortion of the parts. Core slots should be clean and free of sharp edges or particles.

3.4 INSULATION SYSTEM

The entire insulation system, materials, and methods of application should be equal to or better than that used by the original machine manufacturer. All components of the insulation system must be compatible with each other with respect to electrical, mechanical, and thermal characteristics. The insulation system should withstand the high-potential tests described in Subsection 4.4 and the normal operation of the machine.

3.5 CONDUCTORS

The current-carrying capacity, insulation, and mechanical qualities of the conductors should be suitable for the environment in which the machine is to operate. The temperature rating of the coil conductor insulation should be equal to or higher than that of the insulation system. If the conductor material is changed, it should be equal to or better than the original material in all aspects of performance and application.

3.6 STATOR, ROTOR, AND ARMATURE COILS

Coil extensions should not be longer than the originals. The wire cross-sectional area should be at least equal to the original manufacturer's specifications.

3.6.1 Random-Wound Coils

Coils should be wound and inserted in the core slots with a minimum of crossed conductors. Care should be taken not to damage the insulation or conductors. Coils should be wedged with full-length top sticks to hold them securely in the slots. Interphase insulation should be used (where applicable).

3.6.2 Form-Wound Coils

The fabricating of coil loops and the forming of these loops into the coil shape should be accomplished without damage to the conductor insulation. Each layer of coil insulation should be uniformly and tightly applied to minimize stress points and air voids.

Coils should be placed in the core slots without damaging the coil insulation. Coils should tightly fit slots. Coils should be wedged to hold them securely in the slots. Surge rings or similar supports should be secured to the coils and the coils laced to one another as necessary to minimize coil distortion and movement.

3.7 FIELD COILS

Where high rigidity and a complete bonding of all the components is required, a high bond strength varnish or a thixotropic resin should be applied to the ground insulation and to each layer of the coil during winding of the coil; otherwise, vacuum pressure impregnation may be utilized when a complete bond between insulation and conductors can be ensured.

3.7.1 Stationary Coils

Varnish treatment of shunt, series and interpole coils is acceptable for coils originally manufactured by this method.

The insulation of the outer coil layer should be sufficient to withstand surges or inductive voltage spikes.

3.7.2 Rotating Coils

Coils and pole pieces should be securely wedged and braced when installed.

3.8 SQUIRREL CAGE AND AMORTISSEUR WINDINGS

Bars for squirrel cage and amortisseur windings should fit tightly in the core slots. End rings should be secured to the bars by welding or brazing, as appropriate for materials used. The winding should maintain the same electrical, thermal and mechanical characteristics as the original unless redesigned by agreement with, or at the instruction of, the customer.

For balancing, see Subsection 2.6.

3.9 THERMAL PROTECTORS OR SENSORS

Thermostats, resistance temperature detectors (RTDs), thermocouples and thermistors should be identical with or equivalent to the original devices in electrical and thermal characteristics and placed at the same locations in the winding. Thermal protectors or sensors should be removed or omitted only with customer consent.

3.10 SHAPING AND LACING OF STATOR WINDINGS

End windings should be shaped and laced as needed to provide the necessary clearance to the rotor, stator, frame, bearing housings, air deflectors and frame hardware. On machines with surge rings (coil supports), the rings should be suitably insulated, accurately fitted and laced to the coils to ensure adequate support for the winding. The winding should maintain the same electrical, thermal and mechanical characteristics as the original unless redesigned by agreement with, or at the instruction of, the customer.

Restrictions to air flow should be avoided.

3.11 COIL CONNECTIONS

3.11.1 Making Connections

Connections which are made by crimping, soldering, brazing, or welding should use materials that have adequate conductivity and are mechanically strong enough to withstand the normal operating conditions. Materials such as solder paste, fluxes, inhibitors and compounds, where employed, should be neutralized after using. These materials should be suitable for the intended use and of a type that will not adversely affect the conductors. Soldered joints should not be used in place of brazed or welded joints.

Connections and splices should be so constructed as to have resistance no greater than that of the conductors.

3.11.2 Insulating Connections

Connections should be adequately insulated to withstand the temperature and voltage ratings of the machine and be mechanically adequate to withstand normal operation. Connections and leads should be laced, tied, or otherwise securely fastened to prevent movement.

The insulation should be applied so as to allow the varnish/resin to penetrate.

3.12 WEDGES

Wedges for stators, armatures and rotors should have adequate mechanical strength and thermal rating to withstand normal operation of the machine. Magnetic wedges should be replaced with equivalent magnetic wedges

Wedges should fit tightly in the slots.

3.13 BANDING OF ROTORS AND ARMATURES

Resin-filled glass banding tape may be applied directly to the winding. It should be applied at the manufacturer's recommended tension and method of curing. The banding should be of sufficient thickness and width to restrain the coils during normal operation.

When wire banding is used, it should be applied to the winding over banding insulation. The banding should match the original in location, material (magnetic or non-magnetic), wire size and number of turns. The wire should be applied with sufficient tension to hold the coils in place without distorting them.

Caution: Replacing wire banding with resin-filled glass banding may change the magnetic circuit configuration, affecting commutation and thermal rating of the winding. Similar effects may result from replacing glass banding with wire banding.

3.14 IMPREGNATION OF WINDINGS

Windings of rewound machines should be preheated, varnish/resin treated and cured using a method of application and a material of sufficient thermal rating to withstand the normal operation of the machine. The treatment should be compatible with the entire insulation system and suitable for the environment in which the machine is to operate.

Section 4
Testing

4.1 SAFETY CONSIDERATIONS

See Appendix for safety considerations.

4.2 INSULATION CONDITION INSPECTION AND TESTS

Tests should be performed to indicate the suitability of the insulation for continued operation. Insulation resistance tests should be performed with acceptable results before the high-potential tests. Other tests, indicated below, may also be applied. All test results should be retained. Trends in results are often better condition indicators than the absolute values (Reference: IEEE Stds. 95).

4.2.1 Insulation Resistance Test

Test voltage should be applied for one minute. (Reference: IEEE Stds. 43, Sec. 5.4 and 12.2.)

GUIDELINES FOR DC VOLTAGES TO BE APPLIED DURING INSULATION RESISTANCE TEST

Winding Rated Voltage (V)[a]	Insulation Resistance Test Direct Voltage (V)
<1000	500
1000 - 2500	500 - 1000
2501 - 5000	1000 - 2500
5001 - 12,000	2500 - 5000
>12,000	5000 - 10,000

[a] Rated line-to-line voltage for three-phase AC machines, line-to-ground for single-phase machines, and rated direct voltage for DC machines or field windings.

Reference: IEEE Stds. 43, Table 1.

4.2.2 Polarization Index (P.I.) Test

The polarization index (P.I.) test should be performed at the same voltage as the test in Paragraph 4.2.1 for ten minutes. The recommended minimum value of polarization index for windings rated Class B and higher is 2.0 (References: IEEE Stds. 43, Sec. 9.2; and IEEE Stds. 432, App. A2).

If the one minute insulation resistance is above 5000 megohms, 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).

4.2.3 Insulation Power Factor Tests

Insulation power factor, dissipation factor, and tip-up tests may be performed on large machines. Interpretation of results is by comparison with results of tests on similar machines. No standard interpretation of results has been established (Reference: IEEE Stds. 432, Sec. 8.1).

RECOMMENDED MINIMUM INSULATION RESISTANCE VALUES AT 40° C (All Values in MΩ)

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

Notes:

1 IR_{1min} is the recommended insulation resistance, in megohms, at 40° C of the entire machine winding.

2 kV is the rated machine terminal-to-terminal voltage, in rms kV.

Reference: IEEE Stds. 43, Table 3.

4.2.4 Step Voltage Test

Step voltage tests are useful if performed at regular maintenance intervals. Changes in results may indicate insulation degradation (Reference: IEEE Stds. 95).

4.2.5 Turn-To-Turn Test

Accepted methods of testing turn-to-turn insulation vary widely. No single standard procedure applies, although several standards touch on the subject (IEEE Stds. 432, 522, and 792; and NEMA Stds. MG 1, 12.5).

4.2.6 Surge Comparison Testing

The surge comparison test is most often applied to winding circuits using a test voltage of twice the circuit rating plus 1000 volts.

4.2.7 Interlaminar Insulation Test

Defects in laminated cores can be detected by loop or core tests (Reference: IEEE Stds. 432, Sec. 9.1, App. A4).

4.2.8 Bearing Insulation Test

Bearing insulation should be tested with a 500V megohmmeter. Insulation resistance should be 1 megohm or greater.

4.3 RECOMMENDED WINDING TESTS

Windings should be tested to ensure that there are no grounds, short circuits, open circuits, incorrect connections or high resistance connections.

4.3.1 Stator and Wound-Rotor Windings

One or more of the following tests should be performed:

(1) Insulation resistance test.
(2) Winding resistance test.
(3) Growler test.
(4) Phase-balance test.
(5) Surge comparison test.
(6) Polarity test.
(7) Ball rotation test (low voltage energization).

4.3.2 Squirrel Cage Windings

One or both of these tests should be performed:

(1) Growler test.
(2) Single-phase test.

4.3.3 Armature Windings

One or more of the following tests should be performed:

(1) Insulation resistance test.
(2) Growler test.
(3) Surge comparison test.
(4) Bar-to-bar resistance or voltage drop test.

4.3.4 Shunt, Series, Interpole, Compensating and Synchronous Rotor Windings

One or more of the following tests should be performed:

(1) Insulation resistance test.
(2) Winding resistance test.
(3) Surge comparison test.
(4) Voltage drop test (DC or AC voltage), coils in series.
The variation in DC voltage drops should not be greater than 5% between coils of same field circuit.
10% variation in AC test results is acceptable if the DC test is within limit.

4.3.5 Interconnection of Windings

Shunt, series, interpole, compensating, and synchronous rotor windings should be tested to ensure that the polarities and connections are correct. Terminal and lead markings should comply with Subsection 1.5.

4.4 HIGH-POTENTIAL TESTS

High-potential tests should be performed on windings and certain accessories of electrical machines at a specified voltage. To avoid excessive stressing of the insulation, repeated application of the high-potential test voltage is not recommended.

Machines to be tested must be clean and dry. Inspection and insulation resistance tests with acceptable results should be performed before the high-potential tests. Insulation resistance tests should be repeated at the completion of the high-potential tests.

When a high-potential test is conducted on an assembled brushless exciter and synchronous machine field winding, the brushless circuit components (diodes, thyristors, etc.) should be short-circuited (not grounded) during the test.

High-potential tests should be successively applied between each winding or electric circuit under test and the frame (or core) of the machine. All other windings or electric circuits not under test should be connected to the frame (or core).

Capacitors of capacitor-type motors must be left connected to the winding in the normal manner for machine operation (running or starting).

Electrical machines may be tested using AC or DC high-potential test equipment. A DC instead of an AC voltage may be used for high-potential tests. In such cases, the DC test voltage should be 1.7 times the specified AC voltage. A failure under test can be less damaging to the winding if a DC voltage is used.

AC high-potential testing should be performed by applying specified voltage at 50-60 Hz continuously for one minute.

DC high-potential testing should be performed by applying specified voltage for a duration of one minute after test voltage is reached. The DC potential should be increased gradually to the desired test voltage in order to limit the charging current.

Caution: After completion of a DC high-potential test, the winding must be grounded to the frame (or core) until the charge has decayed to zero. (References: IEEE Stds. 4 and 95; and NEMA Stds. MG 1, 3.1.1.)

4.4.1 Windings

4.4.1.1 New Windings

High-potential tests should be applied as specified in Table 4-1 for AC voltage and Table 4-2 for DC voltage. To avoid excessive stressing of the insulation, repeated application of the high-potential test voltage is not recommended. Immediately after rewind, when equipment is installed or assembled and a high-potential test of the entire assembly is required, it is recommended that the test voltage not exceed 80% of the original test voltage. The tests should be applied once only at the specified voltage. (Reference: NEMA Stds. MG 1, 12.3.)

4.4.1.2 Reconditioned Windings

High-potential tests for reconditioned windings should be performed at 65% of the new winding test value.

4.4.1.3 Windings Not Reconditioned

Machines with windings not reconditioned should have an insulation resistance test instead of a high-potential test.

4.4.2 Accessories

4.4.2.1 New Accessories

Accessories such as surge capacitors, lightning arresters, current transformers, etc., which have leads connected to the machine terminals should be disconnected during the test, with the leads connected together and to the frame or core. These accessories should have been subjected to the high-potential test applicable to the class of machine at their point of manufacture. Capacitors of capacitor-type motors must be left connected to the winding in the normal manner for machine operation (running or starting).

Component devices and their circuits, such as space heaters and temperature sensing devices in contact with the winding (thermostats, thermocouples, thermistors, resistance temperature detectors, etc.), connected other than in the line circuit, should be connected to the frame or core during machine winding high-potential tests. Each of these component device circuits, with leads connected together, should then be tested by applying a voltage between the circuit and the frame or core. The high-potential tests should be applied as specified in Table 4-3 for AC voltage and Table 4-4 for DC voltage. During each device circuit test, all other machine windings and components should be connected together and to the frame or core. (Reference: NEMA Stds. MG 1, 3.1.8.)

4.4.2.2 Accessories of Machines with Reconditioned Windings

The high-potential test for accessory circuits of reconditioned machines should be performed at 65% of the new device test value.

4.4.2.3 Accessories of Machines with Windings Not Reconditioned

Accessory circuits of machines which have not had their windings reconditioned should have an insulation resistance test instead of a high-potential test.

4.5 NO-LOAD TESTS

4.5.1 Speed

For AC motors, no-load running tests should be made at rated voltage and rated frequency. The speed should be measured and compared with nameplate speed.

Shunt-wound and compound-wound DC motors should be run with rated voltage applied to the armature, and rated current applied to the shunt field. The speed should be measured and compared with nameplate speed.

Series-wound motors should be separately excited when tested due to danger of runaway.

DC generators should be driven at rated speed with rated current applied to the shunt field. The output voltage should be measured and compared with rated voltage.

4.5.2 Current

No-load current should be recorded.

4.5.3 Cooling System

The cooling system should be verified as being operational.

4.5.4 Sound Level

Tests may be made for sound level as an indication of fault or as an irritation to those in the machine ambient (Reference: NEMA Stds. MG 1, Part 9).

4.5.5 Bearing Temperature

Ambient and bearing housing temperatures may be measured periodically until temperatures are stabilized.

4.5.6 Vibration Tests

The vibration tests should be in accordance with NEMA Stds. MG 1, 7 for standard machines, as arranged with the customer, or as necessary to check the operating characteristics of the machine. When there are special requirements, i.e., lower than standard levels of vibration for a machine, NEMA Stds. MG 1, 7 for special machines is recommended.

The unfiltered vibration limits for resiliently mounted standard machines (having no special vibration requirements), based on rotational speed, are shown in Table 4-5. 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.

Note: International standards specify vibration velocity as rms in mm/s. To obtain an approximate metric rms equivalent, multiply the peak vibration in in/s by 18 (Reference: NEMA Stds. MG 1, 7.8).

4.6 TESTS WITH LOAD

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).

4.7 INSTRUMENT CALIBRATION

Each instrument and transducers, if applicable, required for test results should be calibrated at least annually 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).

Table 4-1. HIGH-POTENTIAL TEST USING AC

NEW WINDINGS

DESCRIPTION OF MACHINE	EFFECTIVE AC HIGH-POTENTIAL TEST VOLTAGE	
AC INDUCTION MACHINES AND NONEXCITED SYNCHRONOUS MACHINES	**STATOR WINDING**	**ROTOR WINDING**
Motors rated 0.5 hp and less, generators rated 373 watts (or equivalent) and less, and for operation on circuits: a) 250 volts or less	1000 volts	1000 volts + 2 times the secondary voltage
b) Above 250 volts	1000 volts + 2 times the rated voltage of the machine	1000 volts + 2 times the secondary voltage
Motors rated greater than 0.5 hp, generators rated greater than 373 watts (or equivalent), and for: a) Non-reversing duty	1000 volts + 2 times the rated voltage of the machine	1000 volts + 2 times the secondary voltage
b) Reversing duty	1000 volts + 2 times the rated voltage of the machine	1000 volts + 4 times the secondary voltage

AC SYNCHRONOUS MACHINES WITH SLIP RINGS	STATOR WINDING	FIELD WINDING
MOTORS	1000 volts + 2 times the rated voltage of the motor	**Starting Method 1*** 10 times the rated excitation voltage but not less than 2500 volts nor more than 5000 volts
	1000 volts + 2 times the rated voltage of the motor	**Starting Method 2*** 2 times the IR drop across the resistor but not less than 2500 volts
GENERATORS a) With stator (armature) or field windings rated 35 volts or less	500 volts	500 volts
b) With output less than 250 watts and rated voltage 250 volts or less	1000 volts	1000 volts
c) With rated excitation voltage 500 volts DC or less	1000 volts + 2 times the rated voltage of the generator	10 times the rated excitation voltage but not less than 1500 volts
d) With rated excitation voltage above 500 volts DC	1000 volts + 2 times the rated voltage of the generator	4000 volts + 2 times the rated excitation voltage

* Starting Method 1: For a motor to be started with its field short-circuited or closed through an exciting armature.

Starting Method 2: For a motor to be started with a resistor in series with the field winding. The IR drop is taken as the product of the resistance and the current that would circulate in the field winding if short-circuited on itself at the specified starting voltage (Reference: NEMA Stds. MG 1, 21.22.3).

Table 4-1. HIGH-POTENTIAL TEST USING AC

NEW WINDINGS—continued

DESCRIPTION OF MACHINE	EFFECTIVE AC HIGH-POTENTIAL TEST VOLTAGE	
AC BRUSHLESS SYNCHRONOUS MACHINES AND EXCITERS	**MAIN STATOR WINDING**	**MAIN FIELD WINDING AND EXCITER ARMATURE**
Armature (stator) or field windings rated 35 volts or less	500 volts	
With rated output less than 250 watts and 250 volts or less	1000 volts	
With rated main excitation voltage 350 volts DC or less	1000 volts + 2 times the rated voltage of the machine	10 times the rated excitation voltage but not less than 1500 volts*
With rated main excitation voltage greater than 350 volts DC		2800 volts + 2 times the rated excitation voltage*
BRUSHLESS EXCITERS	**EXCITER STATOR (FIELDS)**	Alternatively, the brushless exciter rotor (armature) shall be permitted to be tested at 1000 volts plus 2 times the rated nonrectified alternating current voltage but in no case less than 1500 volts.*
a) With exciter field excitation voltage not greater than 350 volts DC	10 times the rated excitation voltage but not less than 1500 volts	
b) With exciter field excitation voltage greater than 350 volts DC	2800 volts + 2 times the rated excitation voltage	
c) With AC-excited stators (fields)	1000 volts + 2 times the AC-rated voltage of the stator	

DC MOTORS AND GENERATORS	FIELD WINDING	ARMATURE WINDING
With armature or field windings rated 35 volts or less	500 volts	
Motors rated 0.5 hp and less, generators rated less than 250 watts, and for operation on circuits: a) 240 volts or less	1000 volts	
b) Above 240 volts	1000 volts + 2 times the rated voltage of the machine	
Motors rated greater than 0.5 hp and generators rated 250 watts and larger		

UNIVERSAL MOTORS RATED 250 VOLTS OR LESS	FIELD WINDING	ARMATURE WINDING
Rated 0.5 hp and less, except motors marked for portable tools	1000 volts	
Rated greater than 0.5 hp, and all motors marked for portable tools	1000 volts + 2 times the rated voltage of the motor	

* The brushless circuit components (diodes, thyristors, etc.) should be short-circuited (not grounded) during the test.

References: NEMA Stds. MG 1, 12.3, 15.48, 20.17, 21.22.4, 21.22.5, 23.20 and 24.49.

Table 4-2. HIGH-POTENTIAL TEST USING DC

NEW WINDINGS

<table>
<tr><th>DESCRIPTION OF MACHINE</th><th colspan="2">DC HIGH-POTENTIAL TEST VOLTAGE</th></tr>
<tr><th>AC INDUCTION MACHINES AND NONEXCITED SYNCHRONOUS MACHINES</th><th>STATOR WINDING</th><th>ROTOR WINDING</th></tr>
<tr><td>Motors rated 0.5 hp and less, generators rated 373 watts (or equivalent) and less, and for operation on circuits:
a) 250 volts or less</td><td>1700 volts</td><td rowspan="3">1700 volts + 3.4 times the secondary voltage</td></tr>
<tr><td>b) Above 250 volts</td><td rowspan="3">1700 volts + 3.4 times the rated voltage of the machine</td></tr>
<tr><td>Motors rated greater than 0.5 hp, generators rated greater than 373 watts (or equivalent), and for:
a) Non-reversing duty</td></tr>
<tr><td>b) Reversing duty</td><td>1700 volts + 6.8 times the secondary voltage</td></tr>
</table>

<table>
<tr><th>AC SYNCHRONOUS MACHINES WITH SLIP RINGS</th><th>STATOR WINDING</th><th>FIELD WINDING</th></tr>
<tr><td rowspan="2">MOTORS</td><td rowspan="2">1700 volts + 3.4 times the rated voltage of the motor</td><td>Starting Method 1*
17 times the rated excitation voltage but not less than 4250 volts nor more than 8500 volts</td></tr>
<tr><td>Starting Method 2*
3.4 times the IR drop across the resistor but not less than 4250 volts</td></tr>
<tr><td>GENERATORS
a) With stator (armature) or field windings rated 35 volts or less</td><td colspan="2">850 volts</td></tr>
<tr><td>b) With output less than 250 watts and rated voltage 250 volts or less</td><td colspan="2">1700 volts</td></tr>
<tr><td>c) With rated excitation voltage 500 volts DC or less</td><td rowspan="2">1700 volts + 3.4 times the rated voltage of the generator</td><td>17 times the rated excitation voltage but not less than 2550 volts</td></tr>
<tr><td>d) With rated excitation voltage above 500 volts DC</td><td>6800 volts + 3.4 times the rated excitation voltage</td></tr>
</table>

* Starting Method 1: For a motor to be started with its field short-circuited or closed through an exciting armature.

Starting Method 2: For a motor to be started with a resistor in series with the field winding. The IR drop is taken as the product of the resistance and the current that would circulate in the field winding if short-circuited on itself at the specified starting voltage (Reference: NEMA Stds. MG 1, 21.22.3).

Caution: After completion of a DC high-potential test, the winding must be grounded to the frame (or core) until the charge has decayed to zero. (References: IEEE Stds. 4 and 95; and NEMA Stds. MG 1, 3.1.)

Table 4-2. HIGH-POTENTIAL TEST USING DC

NEW WINDINGS—continued

DESCRIPTION OF MACHINE	DC HIGH-POTENTIAL TEST VOLTAGE	
AC BRUSHLESS SYNCHRONOUS MACHINES AND EXCITERS	**MAIN STATOR WINDING**	**MAIN FIELD WINDING AND EXCITER ARMATURE**
Armature (stator) or field windings rated 35 volts or less	850 volts	
With rated output less than 250 watts and 250 volts or less	1700 volts	
With rated main excitation voltage 350 volts DC or less	1700 volts + 3.4 times the rated voltage of the machine	17 times the rated excitation voltage but not less than 2550 volts*
With rated main excitation voltage greater than 350 volts DC		4750 volts + 3.4 times the rated excitation voltage*
BRUSHLESS EXCITERS	**EXCITER STATOR (FIELDS)**	Alternatively, the brushless exciter rotor (armature) shall be permitted to be tested at 1700 volts plus 3.4 times the rated nonrectified alternating current voltage but in no case less than 2550 volts.*
a) With exciter field excitation voltage not greater than 350 volts DC	17 times the rated excitation voltage but not less than 2550 volts	
b) With exciter field excitation voltage greater than 350 volts DC	4750 volts + 3.4 times the rated excitation voltage	
c) With AC-excited stators (fields)	1700 volts + 3.4 times the AC-rated voltage of the stator	

DC MOTORS AND GENERATORS	FIELD WINDING	ARMATURE WINDING
With armature or field windings rated 35 volts or less	850 volts	
Motors rated 0.5 hp and less, generators rated less than 250 watts, and for operation on circuits: a) 240 volts or less	1700 volts	
b) Above 240 volts	1700 volts + 3.4 times the rated voltage of the machine	
Motors rated greater than 0.5 hp and generators rated 250 watts and larger		

UNIVERSAL MOTORS RATED 250 VOLTS OR LESS	FIELD WINDING	ARMATURE WINDING
Rated 0.5 hp and less, except motors marked for portable tools	1700 volts	
Rated greater than 0.5 hp, and all motors marked for portable tools	1700 volts + 3.4 times the rated voltage of the motor	

* The brushless circuit components (diodes, thyristors, etc.) should be short-circuited (not grounded) during the test.
References: NEMA Stds. MG 1, 12.3, 15.48, 20.17, 21.22.4, 21.22.5, 23.20 and 24.49.

Caution: After completion of a DC high-potential test, the winding must be grounded to the frame (or core) until the charge has decayed to zero. (References: IEEE Stds. 4 and 95; and NEMA Stds. MG 1, 3.1.)

Table 4-3. HIGH-POTENTIAL TEST USING AC

NEW ACCESSORIES

Accessory*	Rated Voltage**	Effective AC High-Potential Test Voltage
Thermostats	600 volts	1000 volts + 2 times the rated voltage of the accessory or equal to the high-potential test voltage of the machine, whichever is lower.
Thermocouples Thermistors Resistance temperature dectectors (RTDs)	50 volts	
Space heaters	All	

* Accessories not connected in the line circuit.
** Unless otherwise stated.

Reference: NEMA Stds. MG 1, 3.1.8.

Table 4-4. HIGH-POTENTIAL TEST USING DC

NEW ACCESSORIES

Accessory*	Rated Voltage**	DC High-Potential Test Voltage
Thermostats	600 volts	1700 volts + 3.4 times the rated voltage of the accessory or equal to the high-potential test voltage of the machine, whichever is lower.
Thermocouples Thermistors Resistance temperature dectectors (RTDs)	50 volts	
Space heaters	All	

* Accessories not connected in the line circuit.
** Unless otherwise stated.

Reference: NEMA Stds. MG 1, 3.1.8.

Table 4-5. UNFILTERED VIBRATION LIMITS

RESILIENTLY MOUNTED MACHINES

RPM @ 60 Hz	Velocity in/s peak	Velocity mm/s	RPM @ 50 Hz	Velocity in/s peak	Velocity mm/s
3600	0.15	3.8	3000	0.15	3.8
1800	0.15	3.8	1500	0.15	3.8
1200	0.15	3.8	1000	0.13	3.3
900	0.12	3.0	750	0.10	2.5
720	0.09	2.3	600	0.08	2.0
600	0.08	2.0	500	0.07	1.7

Note: For machines with rigid mounting, multiply the limiting values by 0.8.

Reference: NEMA Stds. MG 1, 7.8.2, Table 7-1.

Appendix
Electrical Testing Safety Considerations

(This Appendix is not a part of EASA AR100-2010, *Recommended Practice for the Repair of Rotating Electrical Apparatus*.)

A.1 PERSONAL SAFETY

A.1.1 Training

Employees should be trained and qualified in safe operation of all electrical equipment within their responsibility. Training should be provided by use of relevant equipment operational manuals, hands-on training and other multi-media methods. Employees should be informed of the relevant safety rules, and employers should enforce compliance.

A.1.2 Clothing

Clothing should be suitable for the work to be performed. Arc-rated material is recommended. Exposed jewelry should not be worn. Safety glasses and safety shoes should be worn at all times.

When working on or near energized electrical conductors or circuit parts, personnel should adhere to safe work practices as outlined in NFPA 70E, *Standard for Electrical Safety in the Workplace*.

A.1.3 Supervision

Employees should work under the direction of an experienced and qualified person within the test area. At least two qualified persons should be within the test area at all times.

A.1.4 First Aid And CPR

Personnel should be trained in the procedures for first aid, cardiopulmonary resuscitation (CPR), and securing emergency medical aid.

A.2 TEST AREA

A.2.1 Enclosure

The test area should be enclosed with a fence or other physical barricade. Red or yellow strobe lights may be placed at test corner areas for additional warning.

A.2.2 Gates

When a metallic fence or cage is used, it should be grounded. Gates provided for entry of equipment and personnel should be equipped with interlocks so power to test area is interrupted if gate is opened.

A.2.3 Signs

Signs should be posted concerning the electrical hazards, warning unauthorized personnel to stay out of the test area.

A.2.4 Lighting

Test areas should be well illuminated.

A.2.5 Safety Equipment

Fire extinguishers and first aid equipment should be readily available and personnel should be trained in their use.

A.2.6 Test Unit Clearance

Clearance should be provided between the unit under test and the test area boundaries to allow ease of movement for personnel. Lead length should allow a minimum of ten feet (3 meters) between test center operator and the unit under test. Exposed shafts and couplings/sheaves should be guarded.

A.3 UNIT UNDER TEST

A.3.1 Suitability For Test

Test personnel should verify that the unit is mechanically and electrically suitable to undergo the proposed test procedures.

A.3.2 Exclusive Attention

Only the unit under test should be in the test area.

A.3.3 Grounding

An equipment ground should be installed on all apparatus under test.

A.3.4 Base

Units under test should be secured to prevent rolling or tipping during testing.

A.4 TEST PANELS

A.4.1 Construction

Construction should be of the "dead front" type. Instantaneous over-current trips or fuses should limit fault currents in the main power supply to the panel capacity.

A.4.2 Voltages

Output voltages should be clearly marked. Voltages above 600V should require special selection procedures to prevent inadvertent application.

A.4.3 Warning Lights

A warning light should indicate when the panel is energized. An additional warning light should indicate when power leads to a unit under test are energized.

A.4.4 Disconnect

A means for disconnecting the line-side power supply to the test panel should be located within sight from the test panel.

A.4.5 Safety Switch

An emergency hand or foot operated switch or push button to de-energize the power source should be located in the test area. A remote emergency safety switch adjacent to the test area also is recommended.

A.4.6 Leads

Test leads and insulated clips should be of adequate ampacity and voltage class for the machine being tested.

A.5 High-Potential Ground Test

AC or DC high-potential testing current should be limited by impedance or instantaneous trips to limit damage when breakdown occurs.

Bibliography

All references are to the revision dates listed below.

ANSI/ABMA Standard 7-1995: *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plans.* American Bearing Manufacturers Association, Inc. and American National Standards Institute. New York, NY, 1995.

ANSI S2.41-1985: *Mechanical Vibration of Large Rotating Machines With Speed Ranges From 10 to 200 RPS. Measurement And Evaluation of Vibration Severity In Situ*. American National Standards Institute. New York, NY, 1985; reaffirmed 1997. (Note: Published originally by International Organization for Standardization; Geneva, Switzerland, 1985; withdrawn by ISO in 1995 but retained by ANSI.)

ANSI/NCSL Z540-1-1994: *Calibration–Calibration Laboratories and Measuring and Test Equipment—General Requirements*. American National Standards Institute. New York, NY, 1994.

IEC Standard Publication 60034-8: *Rotating Electrical Machines, Part 8: Terminal Markings and Direction of Rotation of Rotating Machines*. International Electrotechnical Commission. Geneva, Switzerland, 2002; second edition, 2007.

IEC Standard Publication 60072-1*: Part 1–Frame Numbers 56 to 400 and Flange Numbers 55 to 1080*. International Electrotechnical Commission. Geneva, Switzerland; seventh edition, 2000.

IEC Standard Publication 60136: *Dimensions of Brushes and Brush-holders for Electric Machinery*. International Electrotechnical Commission. Geneva, Switzerland; second edition, 1986.

IEEE Standard 4-1995: *Standard Techniques for High-Voltage Testing*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1995.

IEEE Standard 43-2000: *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2000.

IEEE Standard 95-2002: *IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.* Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1977; 2002.

IEEE Standard 112-2004*: IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.* Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2004.

IEEE Standard 115-1995: *IEEE Guide: Test Procedures for Synchronous Machines*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1996.

IEEE Standard 432-1992: *IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp).* Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1992.

IEEE Standard 522-2004: *IEEE Guide for Testing Turn-To-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2004.

IEEE Standard 792-1995: *IEEE Recommended Practice for the Evaluation of the Impulse Voltage Capability of Insulation Systems for AC Electric Machinery Employing Form-Wound Stator Coils*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1995.

IEEE Standard 1068-1996: *IEEE Recommended Practice for the Repair and Rewinding of Motors for the Petroleum and Chemical Industry.* Institute of Electrical and Electronics Engineers, Inc. New York, NY, 1997.

ISO 10012-1: *Quality Assurance Requirements for Measuring Equipment*. International Organization for Standardization. Geneva, Switzerland, 1992.

ISO 1940-1: *Mechanical Vibration–Balance Quality Requirements of Rigid Rotors.* International Organization for Standardization. Geneva, Switzerland, 1986.

ISO 1940-2: *Determination of Permissible Residual Unbalance*. International Organization for Standardization. Geneva, Switzerland, 1997.

ISO 10816-1: *Mechanical Vibration–Evaluation of Machine Vibration by Measurements on Non-Rotating Parts–Part 1: General Requirements*. International Organization for Standardization. Geneva, Switzerland, 1995.

NEMA Standards MG 1-2006: *Motors and Generators*. National Electrical Manufacturers Association. Rosslyn, VA; 2006.

NFPA Standard 70E-2009: *Standard for Electrical Safety in the Workplace*. National Fire Protection Association, Quincy, MA; 2009.

29CFR1910.331 - .335 OSHA: *Electrical Safety-Related Work Practices*. Occupational Safety And Health Administration. Washington, DC; revised 2002.

Standards Organizations & Other Resources

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

ABMA–American Bearing
Manufacturers Association
2025 M St., NW, Ste. 800
Washington, DC 20036
202-367-1155
Fax: 202-367-2155
Web Site: www.americanbearings.com
E-mail: abma@dc.sba.com

ANSI–American National
Standards Institute
Headquarters
1819 L St., NW, 6th Floor
Washington, DC 20036
202-293-8020
Fax. 202-293-9287
Operations
25 West 43rd St., 4th Floor
New York, NY 10036
212-642-4900
Fax: 212-398-0023
Web Site: www.ansi.org
E-mail: info@ansi.org

CSA–Canadian Standards Association
178 Rexdale Blvd.
Rexdale, ON M9W 1R3
Canada
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866-797-4272
Fax: 416-747-4149
Web Site: www.csa-international.org
E-mail: certinfo@csa-international.org

IEC–International Electrotechnical
Commission*
3, rue de Varembé
P.O. Box 131
CH-1211 Geneva 20
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Fax: 41-22-919-03-00
Web Site: www.iec.ch
E-mail: custserv@iec.ch

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ISO–International Organization
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Fax: 41-22-733-34-30
Web Site: www.iso.org
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"www." in front of this address)

NEMA–National Electrical
Manufacturers Association
1300 North 17th St., Ste. 1752
Rosslyn, VA 22209
703-841-3200
Fax: 703-841-5900
Web Site: www.nema.org

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

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Fax: 617-770-0700
Web Site: www.nfpa.org
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800-344-3555, Option 1
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