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EASA Standard AR100-2020

RECOMMENDED PRACTICE FOR THE REPAIR OF ROTATING ELECTRICAL APPARATUS

EASA®
The Electro•Mechanical Authority

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Section 1
General

1.1 PURPOSE

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

1.2 SCOPE

This document describes record keeping, tests, analysis, and general guidelines for the repair of induction, synchronous and direct current rotating electrical apparatus. It is not intended to take the place of the customer's or the machine manufacturer's specific instructions or specifications or specific accepted and applicable industry standards or recommended practices.

This document should be supplemented by additional requirements applicable to specialized rotating electrical apparatus including, but not limited to, 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 or standalone components received for repair should have the repair company's name or identifying logo and shop order number permanently affixed to machine or standalone components 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 when received to confirm its condition and obtain data for any failure investigation. Initial 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, inappropriate lubrication, electrical tracking, or foreign object damage. If possible, obtain information about operating conditions at the time of failure. Collect and carefully examine any debris from any fault. The primary cause of failure should be determined, if practical, and documented in the repair record.

1.5 INSPECTION AND CLEANING

1.5.1 Inspection

If required clean the external surfaces of the equipment to avoid contaminating internal components during disassembly. Disassembly should be done methodically. Record the condition of all components, take dimensions necessary for reassembly, condition assessment and fault diagnosis. Each component should be clearly and indelibly marked so that it can be placed in the correct location upon re-assembly. It is important to preserve and carefully inspect any material or component that may have been involved in a failure. Inspect all parts for wear and damage.

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 Std. 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 agent residue should be removed. The parts that do not require immediate work should then be clearly labeled to identify the customer or job number and stored to prevent damage, contamination or corrosion.

1.6 TERMINAL LEADS

All apparatus equipped with lead wire should have insulated lead wire that meets or exceeds machine rated current, temperature class and voltage. 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. Leads should be protected from abrasion at the frame exit and from any sharp edges.

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

Note: If the machine has a service factor, the terminal leads should be rated for the service factor current.

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

Missing terminal boxes should be replaced, and damaged terminal boxes should be repaired or replaced. See NEMA Stds. MG 1 for guidance on replacement terminal boxes. Gaskets and seals that are removed should be replaced. If inspection indicates missing gaskets or seals, they should be replaced.

1.9 COOLING SYSTEM

The fans and cooling ducts should be clean and operational. Cover plates and air baffles should be clean and in place. Damaged or missing parts of the cooling system should be repaired or replaced. The locations of air baffles and any stator end winding spacers that are utilized for guiding airflow should be documented prior to any stator winding removal to allow duplication within a replacement winding.

1.10 EXTERIOR FINISH

Apparatus should be externally cleaned and painted, unless the customer requests otherwise.

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.

1.12 AUTHORIZATION TO SHIP

Repaired machines that have passed all required repair related tests and inspections should have the indication of acceptability, for example, “OK to ship” entered in the repair record. The service center should identify those authorized to make this determination.

Section 2
Mechanical Repair

2.1 SHAFTS

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

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 failure modes such as spalling, contamination, fretting, fluting, and scoring. Bearings and bearing arrangements should be identified and documented. Insulated bearings should be tested (see 4.2.7).

2.2.1 Ball or Roller Bearings

Bearing housing and shaft bearing fits should be measured and compared to machine manufacturer's specifications. Any fits that are not within tolerance should be restored. In the absence of the machine manufacturer's fits, see Tables 2-13 and 2-14 (Reference: ANSI/ABMA Stds. 7 as a guide). Replacement bearings should be equivalent to the original manufacturer's specifications unless redesigned by agreement with, or at the instruction of the customer.

2.2.2 Sleeve Bearings

The sleeve bearing fit in the housing and the diametral clearance should be measured and set to original equipment manufacturer's specifications if available. Use caution with guideline values for sleeve bearing clearance as most do not address the hydrodynamic-thermic variables that need to be considered to determine the appropriate clearance. 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 round within 0.015" (0.38 mm) 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

If bearings require grease lubrication, grease inlets should be equipped with fittings and the inlet passages and tubes cleaned and filled with appropriate grease. 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 LAMINATED CORES

Examine stator and rotating element laminations for evidence of hot spots, physical damage or missing components.

2.5.1 Rotating Elements

Inspect rotating element core for evidence of loose fit on the shaft, sleeve or spider on which the lamination stack is assembled. The runout of the rotating element core outside diameter relative to the bearing journals should not exceed 5 percent of the average radial air gap, or 0.003" (0.08 mm), whichever is the smaller value.

2.5.2 Stators

The stator laminations should not be loose in the frame. If applicable, 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 21940-11 (rigid rotors) and ISO 21940-12 (flexible rotors)] for machines rated 2500 rpm or slower, and to the level of grade G1.0 for machines rated above 2500 rpm 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 journals. The maximum total indicated runout should not exceed 0.0030” (0.076 mm) for surface speeds up to 5000 ft/min (1525 m/min) and should not exceed 0.0015” (0.038 mm) for greater than 5000 ft/min (1525 m/min).

The surface finish should be between 40 and 60 micro-inches (1.02 and 1.52 microns). For those designs where the slip rings are equipped with a spiral groove to reduce brush operating temperature, both edges of the groove should be lightly chamfered.

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 journals. The maximum total indicated runout should not exceed 0.0030” (0.076 mm) for surface speeds up to 5000 ft/min (1525 m/min) and should not exceed 0.0015” (0.038 mm) for greater than 5000 ft/min (1525 m/min).

The surface finish should be between 40 and 60 micro-inches (1.02 and 1.52 microns). 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 if available.

2.8.2 Undercutting and Beveling

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 useable bar length and to a depth of approximately 1 to 1.5 times 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, brushhold ers 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 circumferential spacing within 0.040” (1 mm) between brushes.

Brush pressure should be within a range recommended by the original equipment manufacturer or the brush manufacturer for the specific application and brush type.

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 maintain clearance to other components.

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.

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 MACHINES

The air gap of the machine should not vary from the average by more than 5% for two-pole machines or 10% for other machines, or should be to original manufacturer's specifications.

In a DC machine, the air gaps of the main poles should be uniform, and the air gaps of the interpoles should be uniform.

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 at operating voltage 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			EQUIVALENT 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					EQUIVALENT DIMENSIONS IN INCHES			
Tolerance Designation	Nominal Shaft Diameter Over	Up To	Tolerance		Shaft Diameter Over	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 inches are rounded off.

Table 2-3. PERMISSIBLE SHAFT EXTENSION RUNOUT
NEMA MACHINES

DIMENSIONS IN INCHES		EQUIVALENT 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			EQUIVALENT 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			EQUIVALENT 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				EQUIVALENT 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	(+0.002"/-0.000")	From	Up To	(+0.002"/-0.000")
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
EQUIVALENT DIMENSIONS IN MILLIMETERS					
Shaft Diameter* 3000 to 3600 rpm		Diametral Clearance**	Shaft Diameter* 1800 rpm or lower		Diametral Clearance**
From	Up To	(+0.050mm/-0.000mm)	From	Up To	(+0.050mm/-0.000mm)
76	89	0.230	76	89	0.305
89	102	0.255	89	102	0.355
102	114	0.305	102	114	0.405
114	127	0.355	114	127	0.455
127	140	0.380	127	140	0.510
140	152	0.430	140	152	0.560
152	165	0.455	152	165	0.610
165	178	0.510	165	178	0.660
178	191	0.535	178	191	0.710

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" (0.050 - 0.100 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				EQUIVALENT 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				EQUIVALENT 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					EQUIVALENT 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			EQUIVALENT 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			EQUIVALENT 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. Dimensions shown in inches are rounded off.

To avoid confusion between dimensions in millimeters and in inches, brushes and brushholders may have markings as follows: metric dimensions □; inch dimensions Δ.

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						Housing Fits (all H6)										
		Bearing	Shaft Diameter				Bearing	200 Series Housing Bore				Bearing	300 Series Housing Bore				
Basic	Tolerance	Bore	(inches)		(mm)		OD	(inches)		(mm)		OD	(inches)		(mm)		
Number	Class*	mm	Maximum	Minimum	Maximum	Minimum	mm	Minimum	Maximum	Minimum	Maximum	mm	Minimum	Maximum	Minimum	Maximum	
00	j5	10	0.3939	0.3936	10.004	9.998	30	1.1811	1.1816	30.000	30.016	35	1.3780	1.3786	35.000	35.016	
01	j5	12	0.4726	0.4723	12.005	11.997	32	1.2598	1.2604	32.000	32.016	37	1.4567	1.4573	37.000	37.016	
02	j5	15	0.5908	0.5905	15.005	14.997	35	1.3780	1.3786	35.000	35.016	42	1.6535	1.6541	42.000	42.016	
03	j5	17	0.6695	0.6692	17.005	16.997	40	1.5748	1.5754	40.000	40.016	47	1.8504	1.8510	47.000	47.016	
04	k5	20	0.7878	0.7875	20.011	20.002	47	1.8504	1.8510	47.000	47.016	52	2.0472	2.0479	52.000	52.019	
05	k5	25	0.9847	0.9844	25.011	25.002	52	2.0472	2.0479	52.000	52.019	62	2.4409	2.4416	62.000	62.019	
06	k5	30	1.1815	1.1812	30.011	30.002	62	2.4409	2.4416	62.000	62.019	72	2.8346	2.8353	72.000	72.019	
07	k5	35	1.3785	1.3781	35.013	35.002	72	2.8346	2.8353	72.000	72.019	80	3.1496	3.1503	80.000	80.019	
08	k5	40	1.5753	1.5749	40.013	40.002	80	3.1496	3.1503	80.000	80.019	90	3.5433	3.5442	90.000	90.022	
09	k5	45	1.7722	1.7718	45.013	45.002	85	3.3465	3.3474	85.000	85.022	100	3.9370	3.9379	100.000	100.022	
10	k5	50	1.9690	1.9686	50.013	50.002	90	3.5433	3.5442	90.000	90.022	110	4.3307	4.3316	110.000	110.022	
11	k5	55	2.1660	2.1655	55.015	55.002	100	3.9370	3.9379	100.000	100.022	120	4.7244	4.7253	120.000	120.022	
12	k5	60	2.3628	2.3623	60.015	60.002	110	4.3307	4.3316	110.000	110.022	130	5.1181	5.1191	130.000	130.025	
13	k5	65	2.5597	2.5592	65.015	65.002	120	4.7244	4.7253	120.000	120.022	140	5.5118	5.5128	140.000	140.025	
14	k5	70	2.7565	2.7560	70.015	70.002	125	4.9213	4.9223	125.000	125.025	150	5.9055	5.9065	150.000	150.025	
15	k5	75	2.9534	2.9529	75.015	75.002	130	5.1181	5.1191	130.000	130.025	160	6.2992	6.3002	160.000	160.025	
16	k5	80	3.1502	3.1497	80.015	80.002	140	5.5118	5.5128	140.000	140.025	170	6.6929	6.6939	170.000	170.025	
17	k5	85	3.3472	3.3466	85.018	85.003	150	5.9055	5.9065	150.000	150.025	180	7.0866	7.0876	180.000	180.025	
18	k5	90	3.5440	3.5434	90.018	90.003	160	6.2992	6.3002	160.000	160.025	190	7.4803	7.4814	190.000	190.029	
19	k5	95	3.7409	3.7403	95.018	95.003	170	6.6929	6.6939	170.000	170.025	200	7.8740	7.8751	200.000	200.029	
20	k5	100	3.9377	3.9371	100.018	100.003	180	7.0866	7.0876	180.000	180.025	215	8.4646	8.4657	215.000	215.029	
21	m5	105	4.1350	4.1344	105.028	105.013	190	7.4803	7.4814	190.000	190.029	225	8.8583	8.8594	225.000	225.029	
22	m5	110	4.3318	4.3312	110.028	110.013	200	7.8740	7.8751	200.000	200.029	240	9.4488	9.4499	240.000	240.029	
24	m5	120	4.7255	4.7249	120.028	120.013	215	8.4646	8.4657	215.000	215.029	260	10.2362	10.2375	260.000	260.032	
26	m5	130	5.1194	5.1187	130.033	130.015	230	9.0551	9.0562	230.000	230.029	280	11.0236	11.0249	280.000	280.032	
28	m5	140	5.5131	5.5124	140.033	140.015	250	9.8425	9.8436	250.000	250.029	300	11.8110	11.8123	300.000	300.032	
30	m5	150	5.9068	5.9061	150.033	150.015	270	10.6299	10.6312	270.000	270.032	320	12.5984	12.5998	320.000	320.036	
32	m5	160	6.3005	6.2998	160.033	160.015	290	11.4173	11.4186	290.000	290.032	340	13.3858	13.3872	340.000	340.036	
34	m6	170	6.6945	6.6935	170.040	170.015	310	12.2047	12.2060	310.000	310.032	360	14.1732	14.1746	360.000	360.036	
36	m6	180	7.0882	7.0872	180.040	180.015	320	12.5984	12.5998	320.000	320.036	380	14.9606	14.9620	380.000	380.036	
38	m6	190	7.4821	7.4810	190.046	190.017	340	13.3858	13.3872	340.000	340.036	400	15.7480	15.7494	400.000	400.036	
40	m6	200	7.8758	7.8747	200.046	200.017	360	14.1732	14.1746	360.000	360.036	420	16.5354	16.5370	420.000	420.040	

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

Shaft rotates–outer ring stationary. Adapted from ABMA Std. 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						Housing Fits (all H6)									
		Bearing Bore	Shaft Diameter (inches)		Shaft Diameter (mm)		Bearing OD	200 Series Housing Bore (inches)		200 Series Housing Bore (mm)		Bearing OD	300 Series Housing Bore (inches)		300 Series Housing Bore (mm)	
Basic Number	Tolerance Class	mm	Maximum	Minimum	Maximum	Minimum	mm	Minimum	Maximum	Minimum	Maximum	mm	Minimum	Maximum	Minimum	Maximum
00	m5	10	0.3942	0.3939	10.012	10.006	30	1.1811	1.1816	30.000	30.016	35	1.3780	1.3786	35.000	35.016
01	m5	12	0.4730	0.4727	12.015	12.007	32	1.2598	1.2604	32.000	32.016	37	1.4567	1.4573	37.000	37.016
02	m5	15	0.5911	0.5908	15.015	15.007	35	1.3780	1.3786	35.000	35.016	42	1.6535	1.6541	42.000	42.016
03	m5	17	0.6699	0.6696	17.015	17.007	40	1.5748	1.5754	40.000	40.016	47	1.8504	1.8510	47.000	47.016
04	m5	20	0.7881	0.7877	20.017	20.008	47	1.8504	1.8510	47.000	47.016	52	2.0472	2.0479	52.000	52.019
05	m5	25	0.9850	0.9846	25.017	25.008	52	2.0472	2.0479	52.000	52.019	62	2.4409	2.4416	62.000	62.019
06	m5	30	1.1818	1.1814	30.017	30.008	62	2.4409	2.4416	62.000	62.019	72	2.8346	2.8353	72.000	72.019
07	m5	35	1.3787	1.3783	35.020	35.009	72	2.8346	2.8353	72.000	72.019	80	3.1496	3.1503	80.000	80.019
08	m5	40	1.5756	1.5752	40.020	40.009	80	3.1496	3.1503	80.000	80.019	90	3.5433	3.5442	90.000	90.022
09	m6	45	1.7726	1.7720	45.025	45.009	85	3.3465	3.3474	85.000	85.022	100	3.9370	3.9379	100.000	100.022
10	m6	50	1.9695	1.9689	50.025	50.009	90	3.5433	3.5442	90.000	90.022	110	4.3307	4.3316	110.000	110.022
11	m6	55	2.1666	2.1658	55.030	55.011	100	3.9370	3.9379	100.000	100.022	120	4.7244	4.7253	120.000	120.022
12	m6	60	2.3634	2.3626	60.030	60.011	110	4.3307	4.3316	110.000	110.022	130	5.1181	5.1191	130.000	130.025
13	m6	65	2.5603	2.5595	65.030	65.011	120	4.7244	4.7253	120.000	120.022	140	5.5118	5.5128	140.000	140.025
14	n6	70	2.7574	2.7567	70.039	70.020	125	4.9213	4.9223	125.000	125.025	150	5.9055	5.9065	150.000	150.025
15	n6	75	2.9543	2.9536	75.039	75.020	130	5.1181	5.1191	130.000	130.025	160	6.2992	6.3002	160.000	160.025
16	n6	80	3.1511	3.1504	80.039	80.020	140	5.5118	5.5128	140.000	140.025	170	6.6929	6.6939	170.000	170.025
17	n6	85	3.3483	3.3474	85.045	85.023	150	5.9055	5.9065	150.000	150.025	180	7.0866	7.0876	180.000	180.025
18	n6	90	3.5451	3.5442	90.045	90.023	160	6.2992	6.3002	160.000	160.025	190	7.4803	7.4814	190.000	190.029
19	n6	95	3.7420	3.7411	95.045	95.023	170	6.6929	6.6939	170.000	170.025	200	7.8740	7.8751	200.000	200.029
20	n6	100	3.9388	3.9379	100.045	100.023	180	7.0866	7.0876	180.000	180.025	215	8.4646	8.4657	215.000	215.029
21	n6	105	4.1357	4.1348	105.045	105.023	190	7.4803	7.4814	190.000	190.029	225	8.8583	8.8594	225.000	225.029
22	n6	110	4.3325	4.3316	110.045	110.023	200	7.8740	7.8751	200.000	200.029	240	9.4488	9.4499	240.000	240.029
24	n6	120	4.7262	4.7253	120.045	120.023	215	8.4646	8.4657	215.000	215.029	260	10.2362	10.2375	260.000	260.032
26	n6	130	5.1202	5.1192	130.052	130.027	230	9.0551	9.0562	230.000	230.029	280	11.0236	11.0249	280.000	280.032
28	n6	140	5.5139	5.5129	140.052	140.027	250	9.8425	9.8436	250.000	250.029	300	11.8110	11.8123	300.000	300.032
30	p6	150	5.9082	5.9072	150.068	150.043	270	10.6299	10.6312	270.000	270.032	320	12.5984	12.5998	320.000	320.036
32	p6	160	6.3019	6.3009	160.068	160.043	290	11.4173	11.4186	290.000	290.032	340	13.3858	13.3872	340.000	340.036
34	p6	170	6.6956	6.6946	170.068	170.043	310	12.2047	12.2060	310.000	310.032	360	14.1732	14.1746	360.000	360.036
36	p6	180	7.0893	7.0883	180.068	180.043	320	12.5984	12.5998	320.000	320.036	380	14.9606	14.9620	380.000	380.036
38	p6	190	7.4834	7.4823	190.079	190.050	340	13.3858	13.3872	340.000	340.036	400	15.7480	15.7494	400.000	400.036
40	p6	200	7.8771	7.8760	200.079	200.050	360	14.1732	14.1746	360.000	360.036	420	16.5354	16.5370	420.000	420.040

Shaft rotates–outer ring stationary. Adapted from ABMA Std. 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 of stators and armatures should be performed before burnout or other equivalent process and after winding removal, and the results should be compared. Stator and armature cores should be tested for hot spots and losses (see Paragraph 4.2.6).

3.1.2 Thermal Protectors or Sensors

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

Replacement 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 and documented in the repair record.

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

Core temperature should be controlled to avoid degradation of the interlaminar insulation and distortion of any parts. The temperature should not exceed 700°F (370°C) . If a burnoff oven is used, the oven should have a water suppression system. Parts should be oriented and supported and allowed to cool sufficiently in the oven so as to avoid distortion of the parts. After the winding is removed, the core slots should be inspected to ensure they are free of sharp edges and foreign materials.

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. 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 and wedges notched as necessary for any stator vent ducts. 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 and wedges notched as necessary for any stator vent ducts. 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

3.7.1 Stationary Coils

Varnish treatment of shunt, series and interpole coils is acceptable for coils originally manufactured by this method; otherwise, vacuum pressure impregnation may be utilized when a complete bond between insulation and conductors can be ensured.

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

3.7.2 Rotating Coils

High rigidity and bonding of all the components is required to withstand centrifugal forces. For most salient pole rotors a high bond strength thixotropic resin should be used.

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 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 metal 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.

3.10 COIL CONNECTIONS

3.10.1 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.

3.10.2 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.

3.11 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.

3.12 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.

3.13 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 (IR) 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.

4.2.1 Insulation Resistance Test

Insulation resistance tests should be performed for one minute at the voltage levels specified in Table 4-1. (Reference: IEEE Std. 43, Sec. 5.3.) The recommended minimum insulation resistance value should be as specified in Table 4-2. (Reference: IEEE Std. 43, Sec. 12.3).

TABLE 4-1. 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 (earth) for single-phase machines, and rated direct voltage for DC machines or field windings.

Reference: IEEE Std. 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 Std. 43, Sec. 12.2; and IEEE Std. 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. 12.2.2).

TABLE 4-2. 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 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 and DC armatures.

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 Std. 43, Table 3.

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 Std. 432, Sec. 8.1).

4.2.4 Form-Wound Stator Surge Tests

The surge withstand capability of the winding should be verified at one or more of the following steps of the rewind: (a) individual coils before installation in slots (coil manufacturer tests are acceptable), (b) individual coils after installation but prior to connection, with wedging and bracing in place, (c) individual coils after series connections before connections between phase groups, (d) individual groups after connecting into phase groups but before connecting phase groups to one another, and/or (e) phases on the completely wound and fully-cured stator. Testing is recommended at steps (a) if not done by the coil manufacturer, (b) and (e) for quality assurance purposes.

Test levels are reduced for uncured coils and should be agreed upon in advance by the coil manufacturer, service center, and if required, the customer. The test values in Table 4-3 are adapted from IEEE 522 and

IEC 60034-15. IEEE 522 refers to 3.5 per unit (p.u.) as a standard withstand voltage and 2.0 p.u. as a reduced voltage test used for windings that are not likely to see high-magnitude, fast-fronted surges (where 1 p.u. = peak volts to ground of stator winding).

A single waveform surge pattern indicates that no faults or anomalies were detected. A multiple waveform surge pattern indicates a fault or anomaly requiring further analysis.

Note: Surge test results can be influenced by multiple factors, such as the presence of the rotor when testing a stator. Analysis of surge test results is subjective, even when using quantitative tools to compare waveforms.

4.2.5 All Other Windings Surge Test

The winding surge test is most often applied to other windings, including random wound stators, at twice rated voltage plus 1000 volts with a 0.2±0.1 microsecond front rise.

A single waveform surge pattern indicates that no faults or anomalies were detected. A multiple waveform surge pattern indicates a fault or anomaly requiring further analysis.

Note: Surge test results can be influenced by multiple factors, such as the presence of the rotor when testing a stator. Analysis of surge test results is subjective, even when using quantitative tools to compare waveforms.

4.2.6 Interlaminar Insulation Test

Testing of alternating current cores should be performed with a core loss tester or by the loop test method; or by a low energy flux test also known as an EL CID (ELectromagnetic Core Imperfection Detection) test (Reference: IEEE Std. 56). The magnetic flux level for the after winding removal test should be within 5% of the before winding removal level. Increase in losses or hot spots should be investigated; and damaged laminations should be repaired or replaced.

4.2.7 Bearing Insulation Test

Insulation resistance (IR) tests should be 1 megohm or greater for motors operating from a sinusoidal or direct current power supply. Bearing insulation systems used in variable frequency drive applications should be evaluated to provide adequate impedance for the given drive application. [Note: There is no industry consensus on a minimum insulation resistance or impedance value for bearings used with variable frequency drives.]

TABLE 4-3. FORM COIL NEW WINDING SURGE TEST VOLTAGES

Rated Voltage (V)	IEEE 522[1,4,5] 2.0 p.u. (kV)	IEEE 522[2,4,5] 3.5 p.u. (kV)	IEC 60034-15[3,4] $U'_p = 0.65\ U_p$	2E+1kV[6] per section 4.2.5
400	–	–	–	1.8
460	–	–	–	1.9
575	–	–	–	2.2
690	–	–	–	2.4
2300	3.8	6.6	9.2	–
3300	5.4	9.4	11.8	–
4000	6.5	11.4	13.7	–
6600	10.8	18.9	20.4	–
11000	18.0	31.4	31.9	–
13800	22.5	39.4	39.1	–

1. 2.0 p.u. = $2 \cdot V_{L-L}\sqrt{2/3}$ kV, 0.2 μs front rise
2. 3.5 p.u. = $3.5 \cdot V_{L-L}\sqrt{2/3}$ kV, 0.1 μs front rise
3. 1.0 $U_p = 4 \cdot V_{L-L} + 5$ kV, 0.2±0.1 μs front rise
4. Coils not fully processed, e.g. uncured resin-rich or dry (green) VPI, should be tested at a reduced voltage, generally 40-80% of the calculated value.
5. Maintenance tests of reconditioned windings may be performed at 75% of the calculated value. Caution: If the insulation design is unknown, use 75% of the 2.0 p.u. column values.
6. For machines rated below 2300 V, use section 4.2.5.

4.2.8 Phase Balance Test

The phase balance test applies balanced reduced voltage 3-phase power to the stator and the current is measured and checked for balance.

4.2.9 Polarity Test

The polarity test applies direct current, usually to a single phase, and the magnetic polarity of the coil groups are checked.

4.2.10 Dummy Rotor Test

The dummy rotor test uses an artificial rotor such as a small rotor with a loose fit on a shaft. Reduced voltage 3-phase power is supplied to the stator and the rotor is moved circumferentially along the bore to check for continuous rotor rotation.

4.2.11 Impedance Test

The impedance test applies an AC voltage to the two leads of a coil and the voltage and current are measured. Using Ohm's Law the impedance is calculated. The impedance of the individual coils is then compared for relative equality among coils that are intended to have equal electromagnetic qualities.

4.3 RECOMMENDED WINDING TESTS

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

4.3.1 Stator and Wound-Rotor Windings

The IR, winding surge and winding resistance tests should be performed. In addition one or more of the following tests may be performed:

(1) Phase-balance test.
(2) Polarity test.
(3) Artificial rotor (dummy rotor) test (low voltage energization).
(4) Polarization index test or dielectric absorption test.
(5) Insulation dissipation or power factor test.
(6) Turn-to-turn test.
(7) Partial discharge testing for inception and extinction voltage levels.

Note: Per CSA C392 the resistance unbalance limit for random windings should be 2% from the average, and 1% from the average for form coil windings.

Note: Some concentric windings may exceed the 2% limit.

4.3.2 Squirrel Cage Windings

One or more of these test methods should be used to produce currents in bars and end rings to detect a defect in the squirrel cage:

(1) Growler test.
(2) Single-phase test.
(3) Measurement and analysis of the magnetic field along the circumference of the rotor with current applied to the rotor cage via induction or direct connection to the end rings.

Caution: The use of shaft clamps can result in stray current paths that reduce the effectiveness of the test and can affect the physical condition of the rotor or shaft.

4.3.3 Armature Windings

An insulation resistance test should be performed. In addition, one or more of the following tests should be performed:

(1) Growler test.
(2) Single-phase test.
(3) Bar-to-bar test.

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

An insulation resistance test should be performed. In addition, one or more of the following tests should be performed:

(1) Winding resistance test.
(2) Winding surge test.
(3) AC voltage drop test.
(4) Impedance test.

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 1.6.

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/earthed) during the test.

High-potential tests should be successively applied between each winding or electric circuit under test and the grounded (earthed) frame (or core) of the machine. All other windings or electric circuits not under test should be connected to the grounded (earthed) 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. 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 in steps or ramps to the desired test voltage in order to limit the charging current.

Caution: After completion of a DC high-potential test, ground (earth) the winding 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 4-4 for AC voltage and Table 4-5 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 a high-potential test of the winding 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.

4.4.1.2 Reconditioned Windings

High-potential tests for reconditioned windings if approved by the customer 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 grounded (earthed) 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 grounded (earthed) 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 grounded (earthed) frame or core , equal to 1500 volts AC (2600 volts DC). During each device circuit test, all other machine windings and components should be connected together and to the grounded (earthed) 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 with a 500v megohmmeter. Insulation resistance should be 1 megohm or greater.

4.5 NO-LOAD TESTS

After a motor has been assembled it should be run under no load conditions to ensure it operates satisfactorily. To prepare for this, the motor should be securely mounted on a base plate or resilient pad and energized. A secured half-key should be fitted in the keyseat (keyway).

Caution: If the weight of a rotating element is not sufficient to provide the minimum preload for a bearing, an artificial load should be used to provide the required bearing preload.

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.

For VFD-powered AC motors that run above base speed, additional testing should be done at maximum rated motor frequency.

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 base speed and should be within 1% for both directions. If the motor is rated for speeds above base speed, field power should be varied to achieve maximum rated speed. Note field current at maximum speed.

Series-wound motors should be separately excited or mechanically loaded 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 currents 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 4-6. 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 transducer, 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: ISO/IEC 17025 and ISO 10012).

Table 4-4. HIGH-POTENTIAL TEST USING AC

NEW WINDINGS

<table>
<tr><th>DESCRIPTION OF MACHINE</th><th colspan="2">EFFECTIVE AC 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>1000 volts</td><td rowspan="3">1000 volts + 2 times the secondary voltage</td></tr>
<tr><td>b) Above 250 volts</td><td rowspan="3">1000 volts + 2 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>1000 volts + 4 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">1000 volts + 2 times the rated voltage of the motor</td><td>Starting Method 1*
10 times the rated excitation voltage but not less than 2500 volts nor more than 5000 volts</td></tr>
<tr><td>Starting Method 2*
2 times the IR drop across the resistor but not less than 2500 volts</td></tr>
<tr><td>GENERATORS
a) With stator (armature) or field windings rated 35 volts or less</td><td colspan="2">500 volts</td></tr>
<tr><td>b) With output less than 250 watts and rated voltage 250 volts or less</td><td colspan="2">1000 volts</td></tr>
<tr><td>c) With rated excitation voltage 500 volts DC or less</td><td rowspan="2">1000 volts + 2 times the rated voltage of the generator</td><td>10 times the rated excitation voltage but not less than 1500 volts</td></tr>
<tr><td>d) With rated excitation voltage above 500 volts DC</td><td>4000 volts + 2 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).

Table 4-4. 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 4-5. 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 4-5. HIGH-POTENTIAL TEST USING DC

NEW WINDINGS—continued

<table>
<tr><th>DESCRIPTION OF MACHINE</th><th colspan="2">DC HIGH-POTENTIAL TEST VOLTAGE</th></tr>
<tr><th>AC BRUSHLESS SYNCHRONOUS MACHINES AND EXCITERS</th><th>MAIN STATOR WINDING</th><th>MAIN FIELD WINDING AND EXCITER ARMATURE</th></tr>
<tr><td>Armature (stator) or field windings rated 35 volts or less</td><td colspan="2">850 volts</td></tr>
<tr><td>With rated output less than 250 watts and 250 volts or less</td><td colspan="2">1700 volts</td></tr>
<tr><td>With rated main excitation voltage 350 volts DC or less</td><td rowspan="2">1700 volts + 3.4 times the rated voltage of the machine</td><td>17 times the rated excitation voltage but not less than 2550 volts*</td></tr>
<tr><td>With rated main excitation voltage greater than 350 volts DC</td><td>4750 volts + 3.4 times the rated excitation voltage*</td></tr>
<tr><th>BRUSHLESS EXCITERS</th><th>EXCITER STATOR (FIELDS)</th><td rowspan="4">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.*</td></tr>
<tr><td>a) With exciter field excitation voltage not greater than 350 volts DC</td><td>17 times the rated excitation voltage but not less than 2550 volts</td></tr>
<tr><td>b) With exciter field excitation voltage greater than 350 volts DC</td><td>4750 volts + 3.4 times the rated excitation voltage</td></tr>
<tr><td>c) With AC-excited stators (fields)</td><td>1700 volts + 3.4 times the AC-rated voltage of the stator</td></tr>
</table>

<table>
<tr><th>DC MOTORS AND GENERATORS</th><th>FIELD WINDING</th><th>ARMATURE WINDING</th></tr>
<tr><td>With armature or field windings rated 35 volts or less</td><td colspan="2">850 volts</td></tr>
<tr><td>Motors rated 0.5 hp and less, generators rated less than 250 watts, and for operation on circuits:
a) 240 volts or less</td><td colspan="2">1700 volts</td></tr>
<tr><td>b) Above 240 volts</td><td colspan="2" rowspan="2">1700 volts + 3.4 times the rated voltage of the machine</td></tr>
<tr><td>Motors rated greater than 0.5 hp and generators rated 250 watts and larger</td></tr>
</table>

<table>
<tr><th>UNIVERSAL MOTORS RATED 250 VOLTS OR LESS</th><th>FIELD WINDING</th><th>ARMATURE WINDING</th></tr>
<tr><td>Rated 0.5 hp and less, except motors marked for portable tools</td><td colspan="2">1700 volts</td></tr>
<tr><td>Rated greater than 0.5 hp, and all motors marked for portable tools</td><td colspan="2">1700 volts + 3.4 times the rated voltage of the motor</td></tr>
</table>

* 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 4-6. UNFILTERED VIBRATION LIMITS

RESILIENTLY MOUNTED MACHINES

RPM†	Limit (inch)	Limit (metric)	Characteristics
1200 & above	0.15 in/sec pk	2.7 mm/sec rms	Constant velocity
Below 1200	2.4 mils pk-pk	0.061 mm pk-pk	Constant displacement

† For IEC Standard 60034-14 use constant displacement below 600 rpm and constant velocity at or above 600 rpm.
Note: For machines with rigid mounting, multiply the limiting values by 0.8.

Appendix
Electrical Testing Safety Considerations

(This Appendix is not a part of EASA AR100-2020, *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 Personal Protective Equipment (PPE)

Personal protective equipment (PPE) 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, and hearing protection if necessary, 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 (earthed). 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 (Earthing)

An equipment ground (earth) 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 (Earth) 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.

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IEEE Standard 56-2016: *IEEE Guide for Insulation Maintenance of Electric Machines.* Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2016.

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, 2002; Reaffirmed 2012.

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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.

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ISO 21940-11: *Mechanical vibration – rotor balancing – Part11: Procedures and tolerances for rotors with rigid behaviour*. International Organization for Standardization. Geneva, Switzerland, 2016.

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ISO 20816-1:2016: *Mechanical vibration -- Measurement and evaluation of machine vibration -- Part 1: General guidelines*. International Organization for Standardization. Geneva, Switzerland, 2016.

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29CFR1910.331 - .335 OSHA: *Electrical Safety-Related Work Practices*. Occupational Safety And Health Administration. Washington, DC; revised 2014.

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
Website: www.americanbearings.com
Email: 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
Website: www.ansi.org
Email: info@ansi.org

CSA–Canadian Standards Association
178 Rexdale Blvd.
Rexdale, ON M9W 1R3
Canada
416-747-4000
866-797-4272
Fax: 416-747-4149
Website: www.csa-international.org
Email: certinfo@csa-international.org

IEC–International Electrotechnical Commission*
3, rue de Varembé
P.O. Box 131
CH-1211 Geneva 20
Switzerland
41-22-919-02-11
Fax: 41-22-919-03-00
Website: www.iec.ch
Email: custserv@iec.ch
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IEEE–Institute of Electrical and Electronics Engineers, Inc.
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ISO–International Organization for Standardization*
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Switzerland
41-22-749-01-11
Fax: 41-22-733-34-30
Website: www.iso.org
Email: central@iso.org
Publications
Available from IHS, Inverness, CO
Website: www.globalihs.com
Email: global@ihs.com

MIL-STD–United States Government Printing Office
710 North Capitol St. N.W.
Washington, DC 20420
202-512-1800
866-512-1800
Fax: 202-512-2104
Website: www.gpo.gov
Orders
Website: bookstore.gpo.gov (Do **not** put "www." in front of this address)

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

NEMA–National Electrical
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Rosslyn, VA 22209
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Sales
800-854-7179
303-397-7956
Fax: 303-397-2740
Website: globalihs.com
Email: global@ihs.com

NFPA–National Fire
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95-800-844-6058 (Mexico-toll free)
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Website: www.nfpa.org
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Fax: 508-895-8301

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