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ANSI C50.41-2000

American National Standard

for

Polyphase Induction Motors for Power Generating Stations

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION
1300 NORTH 17TH STREET, SUITE 1847, ROSSLYN, VA 22209
(703) 841-3200 FAX: (703) 841-330

ANSI C50.41-2000

American National Standard

for

Polyphase Induction Motors for Power Generating Stations

Secretariat

National Electrical Manufacturers Association

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American National Standards Institute, Inc.

American National Standard

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Foreword (This Foreword is not a part of American National Standard for Polyphase Induction Motors for Power Generating Stations, ANS C50.41-2000.)

This standard was developed by the Subcommittee on Polyphase Induction Motors and Generators of American National Standards Committee on Rotating Electrical Machinery, C50. The subcommittee membership reflects wide industrial experience in both the manufacture and use of polyphase induction motors intended for application in power generating stations.

Portions of this standard are extracted from NEMA Standards Publication for Motors and Generators, NEMA MG1-1998, copyrighted by the National Electrical Manufacturers Association, and reproduced by permission.

Suggestions for improvement of this standard will be welcome. They should be sent to the American National Standards Institute, 11 West 42nd Street, New York, New York 10036.

This standard was processed and approved for submittal to ANSI by American National Standards Committee on Rotating Electrical Machinery, C50. Committee approval of the standard does not necessarily imply that all committee members voted for approval. At the time it approved this standard, the C50 Committee had the following members:

W. R. McCown, Chair
D. M. Threlkel, Secretary

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Chemical Manufacturers Association	David Pace
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National Electrical Contractors Association (NECA)	Don Johnson
National Electrical Manufacturers Association (NEMA)	Joseph A. Kline Roger H. Daugherty Joseph E. Martin Dale Rawlings
Technical Association of the Pulp & Paper Industry	C. Raymond Church

U. S. Department of the Navy	John Anderson Romulo R. Nicholas
Individual Members	Lorne W. Brotherton Joseph P. Fitzgerald Bjorn M. Kaupang Paul I. Nippes Perry A. Weyant

The Subcommittee on Polyphase Induction Motors for Power Generating Stations, which developed this standard, had the following members:

N. E. Nilsson, Chair
D. M. Threlkel, Secretary

J. C. Appiarius
R. Covarrubias
R. H. Daugherty
J. H. Dymond
N. K. Ghai
D. Hassan
T. A. Higgins
H. C. Karmaker
J. A. Kline
A. Koutsoukos
J. R. Michalec
P. Nippes
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D. Pace
R. D. Pettigrew, Jr.
B. Reichman
S. L. Rogan
J. Stein
L. A. Wall
R. E. Whetstine

for Polyphase Induction Motors for Power Generating Stations

Part I: General

1 Scope

1.1 Inclusions

The requirements in this standard apply to polyphase induction motors intended for use in power generating stations, including the following:

a) Frame size larger than NEMA 440 series
b) Squirrel-cage type
c) Single speed or multispeed
d) Horizontal or vertical construction
e) Form wound

1.2 Exclusions

Excluded from the scope of this standard are:

a) Additional specific features that may be required for application in nuclear power generating stations
b) Additional specific features required in motors for use in hazardous (classified) locations
c) Starting motors for reversible synchronous generator/motor units for pumped storage installations
d) Wound-rotor motors

2 Applicable Standards

Definitions, characteristics, and test methods not specifically covered in this standard shall comply with the following reference standards insofar as they are applicable. When the referenced American National Standards are superseded by a revision approved by the American National Standards Institute, Inc., the revision shall apply.

American National Standard Load Ratings and Fatigue Life for Ball Bearings, ANSI/ABMA 9-1990[1]

American National Standard Load Ratings and Fatigue Life for Roller Bearings, ANSI/ABMA 11-1990[1]

American National Standard Test Procedure for Polyphase Induction Motors and Generators, ANSI/IEEE 112-1996[2]

American National Standard Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electrical Motors, ANSI/IEEE 522-1993[2]

American National Standard Guide for Construction and Interpretation of Thermal Limit Curves for Squirrel-Cage Motors Over 500 Horsepower, ANSI/IEEE 620-1996[2]

American National Standard Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators, NEMA MG2-1994[3]

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[1] Available from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036 and from the Anti-Friction Bearing Manufacturers Association, Century Building, Suite 1015, 2341 Jefferson Davis Highway, Arlington, VA 22202.

[2] Available from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036 and from the Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, NY 10017.

[3] Available from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036 and from the National Electrical Manufacturers Association, 1300 North 17th Street, Rosslyn, VA 22209.

General Principles for Temperature Limits in the Rating of Electric Equipment, IEEE 1-1986 (R1992)[1]

Motors and Generators, NEMA MG1-1998[2]

Sound *Level Prediction for Installed Rotating Electrical Motors*, NEMA MG3-1974 (R1995)[2]

3 Definitions

3.1 Design Type

3.1.1 Design NT

A Design NT motor is a normal-torque squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor, pull-up, and breakdown torques as shown in Table 2. Typically, it is intended for service with equipment such as centrifugal pumps, fans, and compressors.

3.1.2 Design HT

A Design HT motor is a high-torque squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor, pull-up, and breakdown torques as shown in Table 2. Typically, it is intended for service with equipment such as pulverizers and crushers. Belt conveyors may require lower torques and should be considered individually.

3.2 Service Factor

The service factor (SF) is a multiplier that when applied to the rated horsepower indicates a permissible horsepower loading that may be carried under the conditions specified for the SF. (See Section 8, SF.)

3.3 Classification of Insulation Systems

Insulation systems are divided into classes according to the thermal endurance of the system for temperature rating purposes. Suitable insulation classes for motors covered by this standard are Class F and Class H. The definition, in general, corresponds with the principles set forth in IEEE 100, which is also the accepted basis for interpretation.

4 Service Conditions

4.1 Usual Service Conditions

Motors conforming to this standard shall be suitable for operation in accordance with their ratings under the following usual service conditions:

a) Exposure to a maximum ambient temperature of 40°C for air-cooled motors; a maximum water temperature of 32°C at the intake of the heat exchanger for water-cooled motors; and a minimum ambient temperature of -15°C[3] or, when water cooling is used, a minimum ambient temperature of +5°C
b) Exposure to a maximum altitude of 3300 feet (1000 meters) above sea level (see 9.2.1)
c) Exposure to a moderate combination of conducting or abrasive dust (such as coal, fly ash, etc.) with sulfur fumes, moisture, etc., as encountered in usual power plant applications

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[1] Available from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036 and from the Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, NY 10017.

[2] Available form the National Electrical Manufacturers Association, 1300 North 17th Street, Rosslyn, VA 22209.

[3] Outdoor motors may be exposed to ambient temperature below -15°C. Operation of motors in ambient temperatures below -15°C requires additional consideration with respect to the lubrication system, relative fits and clearances between dissimilar metals, and the transition temperature of the various metal parts. For applications below -15°C, the motor manufacturer should be consulted.

4.2 Unusual Service Conditions

Unusual Service conditions should be brought to the attention of those responsible for the design, manufacture, application, and operation of the motor. Among such unusual conditions are:

a) Exposure to:
   1. extreme amounts of abrasive or conducting dust
   2. chemical fumes, combustible dust, or flammable gases
   3. nuclear radiation
   4. oil vapor, salt laden air, or steam
   5. seismic events in excess of those specified in Section 23
   6. abnormal shock or vibration

b) Operation in pits, entirely enclosed boxes, poorly ventilated rooms, or damp locations
c) Operation at speeds other than rated
d) Conditions under which the variation from rated voltage or frequency, or both, exceeds limits given in Section 13 of this standard
e) Conditions under which the alternating-current supply voltage is unbalanced by more than 1 percent (see 13.4)
f) Mechanical loads involving thrust or overhang
g) Operation in an inclined position
h) Harmonic voltage factor exceeding 3 percent (see MG 1-30.1.2.1)
i) Repeated starts in excess of those described in Section 11

Part II: Ratings

5 Basis of Rating

Induction motors covered by this standard shall be rated on a continuous-duty basis. The output rating shall be expressed in horsepower available at the shaft at a specified speed, frequency, and voltage.

5.1 Horsepower

Motor horsepower ratings shall be as follows:

200	600	1,750	4,500	10,000	17,000	30,000
250	700	2,000	5,000	11,000	18,000	35,000
300	800	2,250	5,500	12,000	19,000	40,000
350	900	2,500	6,000	13,000	20,000	45,000
400	1,000	3,000	7,000	14,000	22,500	50,000
450	1,250	3,500	8,000	15,000	25,000	—
500	1,500	4,000	9,000	16,000	27,500	—

5.2 Frequency

Stator frequency shall be 60 Hz. For other frequencies, contact the manufacturer.

5.3 Speed

Synchronous speed ratings at 60 Hz, in revolutions per minute, shall be as follows:

3, 600	720	400	277
1, 800	600	360	257
1, 200	514	327	240
900	450	300	225

NOTE—It is not practical to build motors of all horsepower ratings at all speeds. For ratings not shown, the manufacturer should be consulted.

5.4 Voltage

Voltage ratings shall be as follows:

460	2 300	6 600
575	4 000	13 200

NOTE—It is not practical to build motors of all horsepower ratings for all of these voltages. In general, based on motor design and manufacturing considerations, typical motor voltages are as shown in the following table:

Voltage	Horsepower
460 or 575	200 to 600
2,300	200 to 5,000
4,000	200 to 10,000
6,600	1,000 to 15,000
13,200	3,500 to 50,000

6 Horsepower Ratings of Multispeed Motors

6.1 General

The horsepower ratings of multispeed motors shall be selected in accordance with 6.2 through 6.4.

6.2 Constant Horsepower

The horsepower rating for each rated speed shall be selected from 5.1.

6.3 Constant Torque

The horsepower rating for the highest rated speed shall be selected from 5.1. The horsepower rating for each lower speed shall be determined by multiplying the horsepower rating at the highest speed by the ratio of the lower synchronous speed to the highest synchronous speed.

6.4 Variable Torque

6.4.1 Variable Torque Linear

Torque varies directly with speed, and the horsepower rating for the highest rated speed shall be selected from 5.1. The horsepower rating for each lower speed shall be determined by multiplying the horsepower rating at the highest speed by the square of the ratio of the lower synchronous speed to the highest synchronous speed.

6.4.2 Variable Torque Square

The torque varies as the square of speed, and the horsepower rating for the highest rated speed shall be selected from 5.1. The horsepower rating for each lower speed shall be determined by multiplying the horsepower rating at the highest speed by the cube of the ratio of the lower synchronous speed to the highest synchronous speed.

Part III: Performance

7 Insulation Systems

Motors covered by this standard shall have Class F or Class H nonhygroscopic insulation systems. The insulation class of the coil connections and motor leads shall be equivalent to that of the stator coil insulation. Coils shall be secured tightly in the slots. The insulation system shall withstand commonly encountered contaminants, moderately abrasive particles, and conductive dust. If extreme abrasion resistance is necessary, this requirement should be specified.

The winding end turns shall be adequately braced and supported to withstand starting, bus transfer, and multi-phase faults at the motor terminals.

NEMA Type I and Type II weather-protected motors with form-wound coils (and other types of motor enclosures when specified) shall have sealed insulation systems as defined in Part 1 of ANSI/NEMA MG1.

8 Service Factor

8.1 Service Factor of 1.0

Unless otherwise specified, motors furnished in accordance with this standard will have an SF of 1.0 and a temperature rise not in excess of that specified in Table 1 when operated at rated horsepower with rated voltage and frequency maintained.

NOTE—In those applications requiring an overload capacity, the use of a higher horsepower rating, as given in 5.1, is recommended to avoid exceeding the temperature rises in Table 1 and to provide adequate torque capacity.

8.2 Service Factor of 1.15

8.2.1 General

A motor having a 1.15 SF is suitable for continuous operation at rated load under the usual service conditions given in Section 4, "Service Conditions." When the voltage and frequency are maintained at the value on the nameplate, the motor may be overloaded up to the horsepower obtained by multiplying the rated horsepower by the SF shown on the nameplate. When the motor is operated at a 1.15 SF, it will have efficiency, power factor, and speed values different from those at rated load.

NOTE—The percent values of locked-rotor current, locked-rotor torque, and breakdown torque are based on the rated horsepower. Motors operating in the SF range may not be capable of momentary operation at 75 percent of rated voltage, as noted in 13.3.

8.2.2 Temperature Rise

Motors furnished in accordance with this standard, when operated at the 1.15 SF load shall have a temperature rise not in excess of that specified in Table 1, with rated voltage and frequency maintained. No temperature rise is specified or implied in this standard for operation at rated load.

Operation at the temperature-rise values given in Table 1 for a 1.15-service-factor load causes the motor insulation to thermally age at approximately twice the rate that occurs at the temperature-rise values given in Table 1 for a motor with a 1.0 service-factor load; that is, operating 1 hour at specified 1.15 SF temperature rise values is approximately equivalent to operating 2 hours at the temperature rise specified for a motor with a 1.0 SF.

Motors rated at 1.15 SF shall have a data sheet section listing the expected temperature rises at the 1.0 SF and the 1.15 SF operating points when operating at rated voltage.

9 Temperature

9.1 General

All temperatures shall be determined in accordance with ANSI/IEEE 112. Unless otherwise specified, motors rated 500 hp or greater and 2300 volts or greater shall be furnished with embedded temperature detectors in accordance with 9.4.

9.2 Temperature Rise

When operated at rated voltage and rated frequency, the observable temperature rise of the motor with Class F stator winding electrical insulation, above the temperature of the cooling air, shall not exceed the values in Table 1. For motors equipped with embedded detectors, this method shall be used to demonstrate conformity with this standard.

NOTE—Table 1 applies to a particular motor rating (that is, a 1.0 or 1.15 SF), and it is not intended or implied that this information be applied as a dual rating to an individual motor.

Table 1
LIMITING OBSERVABLE TEMPERATURE RISE FOR CLASS F INSULATION

			Temperature Rise (degrees Celsius)	
Item	Motor Part	Method of Temperature Determination	1.0 Service Factor	1.15 Service Factor
1.	Insulated windings			
	(a) All horsepower ratings	Resistance	80	90
	(b) 1500 horsepower and less	Embedded detector	90	100
	(c) More than 1500 horsepower			
	(1) 7000 volts and less	Embedded detector	85	95
	(2) More than 7000 volts	Embedded detector	80	90
2.	The temperatures attained by cores, squirrel-cage windings, and mechanical parts shall not injure the insulation or the motor in any respect.			

9.2.1 Barometric Pressure

It is recognized as good practice to use motors of standard temperature rise at altitudes greater than 3300 feet (1000 meters) in those locations where the decrease in ambient cooling air temperature compensates for the resultant increase in temperature rise. For applications above 3300 feet (1000 meters), the motor manufacturer should be notified.

For motors which operate under prevailing barometric pressure and which are designed not to exceed the specified temperature rise at altitudes from 3300 feet (1000 meters) to 13200 feet (4000 meters), the temperature rises, as checked by tests at low altitudes, shall be less than those listed in Table 1 by 1 percent of the specified temperature rise for each 330 feet (100 meters) of altitude in excess of 3300 feet (1000 meters).

9.2.2 Cooling Air

The temperature of the cooling air is the temperature of the external air as it enters the motor ventilating openings, and the temperature rises given in Table 1 are based on a maximum temperature of 40°C for this external air.

9.2.3 Reference Ambient Temperature

Temperature rises in Table 1 are based upon a reference ambient temperature of 40°C. However, it is recognized that induction motors may be required to operate in an ambient temperature higher than 40°C. For successful operation of motors in higher ambient temperatures, the temperature rises of the motors given in Table 1 shall be reduced by the number of degrees that the ambient temperature exceeds 40°C.

9.2.4 Totally Enclosed Water-Air-Cooled Motors

For totally enclosed water-air-cooled motors, the temperature of the cooling air is the temperature of the air leaving the coolers.

Totally enclosed water-air-cooled motors are normally designed for the maximum cooling water temperature encountered at the location where each motor is to be installed. For any specified cooling water temperature up to 32°C, the temperature of the air leaving the coolers shall not exceed 40°C. For specified cooling water temperatures above 32°C, the temperature of the air leaving the coolers may exceed 40°C provided that the temperature rises of the motor parts are then limited to values less than those given in Table 1 by the number of degrees that the temperature of the air leaving the coolers exceeds 40°C.

9.3 Resistance Method for Temperature Measurement

This method consists of comparing the resistance of a winding at operating temperature to its resistance at a known temperature. (See IEEE 112.)

9.4 Embedded-Detector Method for Temperature Measurement

This method utilizes resistance temperature detectors built into the winding to determine the temperature. Unless otherwise specified, embedded temperature detectors shall be of the resistance temperature detector type.

9.4.1 Resistance Temperature Detectors

Unless otherwise specified, the RTDs shall be 100 ohm platinum at 0°C.

9.4.2 Locations of Embedded Detectors

At least six detectors shall be built into the motor, suitably distributed around the circumference, located between the coil sides, and in positions having normally the highest temperature along the length of the slot.

The detector shall be located in the center of the slot (with respect to the slot width) and in intimate contact with the insulation of both the upper and lower coil sides whenever possible; otherwise, it shall be in contact with the insulation of the upper coil side (that is, the coil side nearest the air gap). Each detector shall be installed, and its leads brought out, so that the detector is effectively protected from contact with the cooling medium. If the detector does not occupy the full length of the core, suitable packing shall be inserted between the coils to the full length of the core to prevent the cooling medium from directly contacting the detector.

9.5 Motor Lead Total Temperature

The motor lead shall have sufficient ampacity such that the total temperature of the conductor will not exceed 130°C.

10 Torques

The locked-rotor, pull-up, and breakdown torques, with rated voltage and frequency applied, shall be not less than those shown in Table 2. Unless otherwise specified, a Design NT motor shall be supplied.

In addition, for NT motors, the developed torque, at any speed up to that at which breakdown torque occurs, with rated voltage and frequency applied, shall be at least 1.5 times the torque obtained from a curve that varies as the square of the speed and is equal to 100 percent of rated full-load torque at rated speed.

NOTE—The percent torque values with other than rated voltage applied are approximately the values shown in Table 2 multiplied by the square of the ratio of the actual voltage to rated voltage.

Table 2

MINIMUM TORQUES AT RATED VOLTAGE AND FREQUENCY

	Percentage of Full-Load Torque		
Design	**Locked-Rotor**	**Pull-Up**	**Breakdown***
NT	70	70	200
HT	200	150	200

*See also 13.3 of this standard.

11 Starting Requirements

11.1 Starting Capabilities

Motors shall be designed for across-the-line starting and shall be capable of making either of the starts described in 11.1.1 and 11.1.2, provided that the load inertia (Wk^2), the load torque during acceleration, the expected voltage and frequency, and the method of starting are those for which the motor was designed. Exclusive of specified starting voltage contractual requirements between the owner and the manufacturer, the motor shall comply with the starting voltage requirements of Section 13.2.1.

11.1.1 Two starts in succession, coasting to rest between starts with the motor initially at ambient temperature.

11.1.2 One start with the motor initially at a temperature not exceeding its rated-load operating temperature.

11.2 Number of Starts

It should be recognized that the number of starts should be kept to a minimum since the life of the motor is affected by the number of starts. If the normal starting duty exceeds three starts per day, the starting duty shall be specified. The number of starts should not exceed that specified as allowed by the manufacturer.

11.3 Starting Information Nameplate

11.3.1 A starting information nameplate, setting forth the starting capabilities specified in 11.1.1 and 11.1.2, shall be supplied mounted on the motor.

11.3.2 The starting information nameplate shall also include the minimum time at standstill and the minimum time running prior to an additional start. When specifying this additional information on the starting nameplate, the motor manufacturer shall be furnished the following information:

a) The expected voltage and frequency at the motor terminals under starting conditions
b) The total load inertia (Wk^2) referred to the motor shaft
c) The speed-torque characteristics of the load during starting conditions

12 Load Inertia (Wk^2)

12.1 Design NT Motors

Table 3 lists load Wk^2 values to which Design NT motors having performance characteristics in accordance with this standard shall be capable of accelerating without injurious temperature rise when the applied voltage is within the limits set in 13.2.

During the accelerating period, the connected torque shall be equal to or less than a torque that varies as the square of the speed and is equal to 100 percent of the motor full-load torque at rated speed.

12.2 Design HT Motors

Design HT motors having performance characteristics in accordance with this standard shall be capable of accelerating without injurious temperature rise against a constant value of load torque during the accelerating period (after breakaway) under the following conditions:

a) The applied voltage is within the limits set in 13.2.
b) The maximum value of load torque after breakaway does not exceed 100 percent of full-load torque.
c) The maximum value of the load Wk^2 does not exceed the value listed in Table 3.
d) The product of the load Wk^2 (in per unit of the values listed in Table 3) multiplied by the value of load torque (in per unit of full-load torque) is equal to or less than 0.30 per unit.

The values of Wk^2 of connected load given in Table 3 were calculated from the following formula:

$$\text{Load } Wk^2 = A\left[\frac{Hp^{0.95}}{\left(\frac{Rpm}{1000}\right)^{2.4}}\right] - 0.0685\left[\frac{Hp^{1.5}}{\left(\frac{Rpm}{1000}\right)^{1.8}}\right]$$

Where:

A = 24 for 300 to 1800 rpm, inclusive, motors
A = 27 for 3600 rpm motors

13 Variation from Rated Voltage and Rated Frequency

13.1 Running

Motors shall operate successfully under running conditions at rated load with variation in the voltage or the frequency up to the following:

a) Plus or minus 10 percent of rated voltage, with rated frequency.
b) Plus or minus 5 percent of rated frequency, with rated voltage.
c) A combined variation in voltage and frequency of 10 percent (sum of absolute values) of the rated values, provided that the frequency variation does not exceed plus or minus 5 percent of rated frequency. Performance within this voltage and frequency variation will not necessarily be in accordance with the standards established for operation at rated voltage and frequency.

13.2 Starting

13.2.1 Performance Characteristics

Motors having performance characteristics in accordance with this standard shall, at rated frequency, start and accelerate to running speed a load that meets the torque characteristics and inertia requirements specified in Section 12 of this standard, provided, that the voltage at the motor terminals during starting is not less than 85 percent of the rated voltage.[1]

13.2.2 Other Load-Torque Characteristics

Other load-torque characteristics, load inertias, or power supply system characteristics, or a combination of these, shall be treated as items for individual consideration. To determine starting capability, speed-torque requirements, and acceleration time, the motor manufacturer shall be furnished with the following information:

a) The expected voltage and frequency at the motor terminals under starting conditions
b) The total load inertia (Wk^2) referred to the motor shaft
c) The speed-torque characteristics of the load during starting conditions
d) When required, the speed-torque characteristics of the load during reaccelerating conditions, the maximum duration of voltage interruption (see Section 14), and the expected voltage and frequency at the motor terminals during reacceleration.

13.3 Momentary Operation

Motors shall be capable of operating at rated load for a minimum of 60 seconds when 75 percent of rated voltage at rated frequency is applied to the motor terminals.

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[1] Power-generating auxiliary systems are often incapable of maintaining 85 percent of rated motor voltage during starting of the largest motors. The limiting values of voltage and frequency under which a motor will successfully start and accelerate to running speed depend on the margin between the speed-torque curve of the motor and the speed-torque curve of the load under starting conditions (see 13.2.2).

Table 3
ALLOWABLE LOAD INERTIA (*Wk*^{2})

	Speed (revolutions per minute)											
	3600	**1800**	**1200**	**900**	**720**	**600**	**514**	**450**	**400**	**360**	**327**	**300**
Hp	**Load *Wk*^{2} (Exclusive of Motor *Wk*^{2}) (lb-ft^2)**											
200	-	-	-	4 508	7 750	12 060	17 530	24 220	32 200	41 540	52 300	64 500
250	210	1 017	2 744	5 540	9 530	14 830	21 560	29 800	39 640	51 200	64 400	79 500
300	246	1 197	3 239	6 540	11 270	17 550	25 530	35 300	46 960	60 600	76 400	94 300
350	281	1 373	3 723	7 530	12 980	20 230	29 430	40 710	54 200	69 900	88 100	108 800
400	315	1 546	4 199	8 500	14 670	22 870	33 280	46 050	61 300	79 200	99 800	123 200
450	349	1 714	4 666	9 460	16 320	25 470	37 090	51 300	68 300	88 300	111 300	137 400
500	381	1 880	5 130	10 400	17 970	28 050	40 850	56 600	75 300	97 300	122 600	151 500
600	443	2 202	6 030	12 250	21 190	33 110	48 260	66 800	89 100	115 100	145 100	179 300
700	503	2 514	6 900	14 060	24 340	38 080	55 500	76 900	102 600	132 600	167 200	206 700
800	560	2 815	7 760	15 830	27 440	42 950	62 700	86 900	115 900	149 800	189 000	233 700
900	615	3 108	8 590	17 560	30 480	47 740	69 700	96 700	129 000	166 900	210 600	260 300
1 000	668	3 393	9 410	19 260	33 470	52 500	76 600	106 400	141 900	183 700	231 800	286 700
1 250	790	4 073	11 380	23 390	40 740	64 000	93 600	130 000	173 600	224 800	283 900	351 300
1 500	902	4 712	13 260	27 350	47 750	75 100	110 000	153 000	204 500	265 000	334 800	414 400
1 750	1 004	5 310	15 060	31 170	54 500	85 900	126 000	175 400	234 600	304 200	384 600	476 200
2 000	1 096	5 880	16 780	34 860	61 100	96 500	141 600	197 300	264 100	342 600	433 300	537 000
2 250	1 180	6 420	18 440	38 430	67 600	106 800	156 900	218 700	293 000	380 300	481 200	596 000
2 500	1 256	6 930	20 030	41 900	73 800	116 800	171 800	239 700	321 300	417 300	528 000	655 000
3 000	1 387	7 860	23 040	48 520	85 800	136 200	200 700	280 500	376 500	498 400	620 000	769 000
3 500	1 491	8 700	25 850	54 800	97 300	154 800	228 600	319 900	429 800	559 000	709 000	881 000
4 000	1 570	9 460	28 460	60 700	108 200	172 600	255 400	358 000	481 600	627 000	796 000	989 000
4 500	1 627	10 120	30 890	66 300	118 700	189 800	281 400	395 000	532 000	693 000	881 000	1 095 000
5 000	1 662	10 720	33 160	71 700	128 700	206 400	306 500	430 800	581 000	758 000	963 000	1 198 000
5 500	1 677	11 240	35 280	76 700	138 300	222 300	330 800	465 600	628 000	821 000	1 044 000	1 299 000
6 000	-	11 690	37 250	81 500	147 500	237 800	354 400	499 500	675 000	882 000	1 123 000	1 398 000
7 000	-	12 400	40 770	90 500	164 900	267 100	399 500	565 000	764 000	1 001 000	1 275 000	1 590 000
8 000	-	12 870	43 790	98 500	181 000	294 500	442 100	626 000	850 000	1 114 000	1 422 000	1 775 000
9 000	-	13 120	46 330	105 700	195 800	320 200	482 300	685 000	931 000	1 223 000	1 563 000	1 953 000
10 000	-	13 170	48 430	112 200	209 400	344 200	520 000	741 000	1 009 000	1 327 000	1 699 000	2 125 000
11 000	-	-	50 100	117 900	220 000	366 700	556 200	794 000	1 084 000	1 428 000	1 830 000	2 291 000
12 000	-	-	51 400	123 000	233 500	387 700	590 200	844 800	1 155 000	1 524 000	1 956 000	2 452 000
13 000	-	-	52 300	127 500	244 000	407 400	622 400	893 100	1 224 000	1 617 000	2 078 000	2 608 000
14 000	-	-	52 900	131 300	253 600	425 800	652 800	934 200	1 289 000	1 707 000	2 195 000	2 758 000
15 000	-	-	53 100	134 500	262 400	442 900	681 500	983 100	1 352 000	1 793 000	2 309 000	2 904 000

NOTE—For values not shown in the table, the manufacturer should be consulted.

13.4 Effects Of Unbalanced Voltages On The Performance Of Polyphase Squirrel-Cage Induction Motors

When the line voltages applied to a polyphase induction motor are not equal, unbalanced currents in the stator windings will result. A small percentage voltage imbalance will result in a much larger percentage current imbalance. Consequently, the temperature rise of the motor operating at a particular load and percentage voltage imbalance will be greater than for the motor operating under the same conditions with balanced voltages.

Voltages should be evenly balanced as closely as can be read on a voltmeter. If the voltages are unbalanced, the rated horsepower of polyphase squirrel-cage induction motors should be multiplied by the factor shown in Figure 1 to reduce the possibility of damage to the motor.[1] Operation of the motor with more than a 5-percent voltage imbalance is not recommended.

When the derating curve of Figure 1 (see NEMA MG 1-1998) is applied for operation on unbalanced voltages, the selection and setting of the overload device should take into account the combination of the derating factor applied to the motor and the increase in current resulting from the unbalanced voltages. This is a complex problem involving the variation in motor current as a function of load and voltage imbalance in addition to the characteristics of the overload device relative to $I_{maximum}$ or $I_{average}$. In the absence of specific information, it is recommended that overload devices be selected or adjusted, or both, at the minimum value that does not result in tripping for the derating factor and voltage imbalance that applies. When the unbalanced voltages are anticipated, it is recommended that the overload devices be selected so as to be responsive to $I_{maximum}$ in preference to overload devices responsive to $I_{average}$.

More sophisticated relay schemes can include protection for unbalanced conditions that monitor negative and zero sequence parameters.

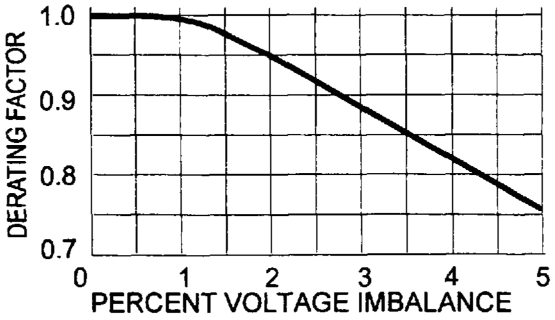

Figure 1
POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS DERATING FACTOR DUE TO UNBALANCED VOLTAGE

13.4.1 Effect on Performance - General

The effect of unbalanced voltages on polyphase induction motors is equivalent to the introduction of a "negative sequence voltage" having a rotation opposite to that occurring with balanced voltages. This negative-sequence voltage produces an air gap flux rotating against the rotation of the rotor, tending to produce high currents. A small negative-sequence voltage may produce current in the windings considerably in excess of those present under balanced voltage conditions.

13.4.2 Voltage Imbalance Defined

The voltage imbalance in percent may be defined as

$$\text{percent voltage imbalance} = 100 \times \frac{\text{maximum voltage deviation from average voltage}}{\text{voltage}}$$

EXAMPLE—With voltage of 2300, 2220, and 2185, the average is 2235, the maximum deviation from the average is 65, the percentage imbalance = 100 x 65/2235 = 2.9 percent

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[1] The derating factor shown in Figure 1 is applicable only to motors of design type NT. For motors with other torque characteristics, the motor manufacturer should be consulted.

13.4.3 Torques

The locked-rotor torque and breakdown torque are decreased when the voltage is unbalanced. If the voltage imbalance is extremely severe, the torques might not be adequate for the application.

13.4.4 Full-Load Speed

The full-load speed is reduced slightly when the motor operates at unbalanced voltages.

13.4.5 Currents

Locked-rotor current will be unbalanced to the same degree that the voltages are unbalanced, but the locked rotor kVA will increase only slightly.

The currents at normal operating speed with unbalanced voltages will be greatly unbalanced, in the order of 6 to 10 times the voltage imbalance.

14 Bus Transfer or Reclosing

14.1 General

Induction motors are inherently capable of developing transient current and torque considerably in excess of rated current and torque when exposed to out-of-phase bus transfer or momentary voltage interruptions and reclosing on the same bus. The magnitude of this transient current and torque may range from 2 to 20 times rated and is a function of the motor's electrical characteristics, operating conditions, switching time, rotating system inertia and torsional spring constants, number of motors on the bus, etc.

Any non-parallel bus transfer or reclosing subjects the motor (including the motor windings) and driven equipment to transient forces in excess of normal running values. Accordingly each bus transfer or reclosing reduces the life expectancy of the motor by some finite value, and it is recommended that, whenever possible, systems be designed to avoid (or minimize) bus transfer and reclosing.

The rotating masses of the motor-load system, connected by elastic shafts, constitute a torsionally responsive mechanical system that is excited by the motor electromagnetic (air-gap) transient torque that consist of the sum of an exponentially decaying, unidirectional component and an exponentially decaying oscillatory component at several frequencies, including power frequency and slip frequency. The resultant shaft torques may be either attenuated or amplified with reference to the motor electromagnetic (air-gap) torque.

Studies can be made of any particular system to determine the magnitude of the transient current and torque, and the electromagnetic interaction of the motor and the driven equipment. Although recommended, it is recognized that such studies are complex and require detailed knowledge of the motor, the driven equipment, and the power supply. In order to minimize this effect, the first torsional resonant frequency should not be within ±20 percent of rated electrical frequency.

For those applications where bus transfer or reclosing cannot be avoided, and where studies of the particular system have not been performed, the following may be employed as a guide and is based on limited studies and experience.

14.2 Slow Transfer or Reclosing

A slow transfer or reclosing is defined as one in which the length of time between disconnect of the motor from the power supply and reclosing onto the same or another power supply is delayed until the motor rotor flux linkages have decayed sufficiently so that the transient current and torque associated with the bus transfer or reclosing will remain within acceptable levels.

To limit the possibility of damaging the motor or driven equipment, or both, it is recommended that the system be designed so that the resultant volts per hertz vector between the motor residual volts per hertz vector and the incoming source volts per hertz vector at the instant the transfer or reclosing is completed does not exceed 1.33 per unit volts per hertz on the motor rated voltage and frequency bases. This recommendation requires that power factor correction capacitors shall not be connected to the motor terminals during the transfer.

Slow transfer or reclosing can be accomplished by a time delay relay equal to or greater than 1.5 times the open-circuit alternating-current time constant of the motor (see NEMA MG1-1.60). If several motors are involved, the time delay should be based on the longest open-circuit time constant of any motor on the system being transferred or reclosed.[1]

14.3 Fast Transfer or Reclosing

A fast transfer or reclosing is defined as one which:

a) occurs within a time period of 10 cycles or less,
b) the maximum phase angle (δ) between the motor residual volts per hertz vector and the system equivalent volts per hertz vector does not exceed 90 degrees, and
c) the resultant volts per hertz between the motor residual volts per hertz phasor and the incoming source volts per hertz phasor at the instant of transfer or reclosing is completed does not exceed 1.33 per unit volts per Hz on the motor rated voltage and frequency basis. See Figure 2.

For fast transfer or reclosing, calculations or tests should be performed by the user to determine the expected vectorial volts per hertz. Calculations or test conditions should account for any phase angle difference between the incoming and running power supplies. The results of the calculations shall be used to determine whether these requirements are met before fast transfer or reclosing is used on the system. If the user is concerned that the resultant volts per hertz during fast transfer or reclosing could be excessive based on testing, calculations, or other information, high-speed synchronizing check devices are available that can supervise this switching operation.

14.4 Recommendations

Power systems should be designed to limit bus transfer or reclosing to either slow transfer or reclosing as defined in 14.2 or fast reclosing as defined in 14.3, or both.

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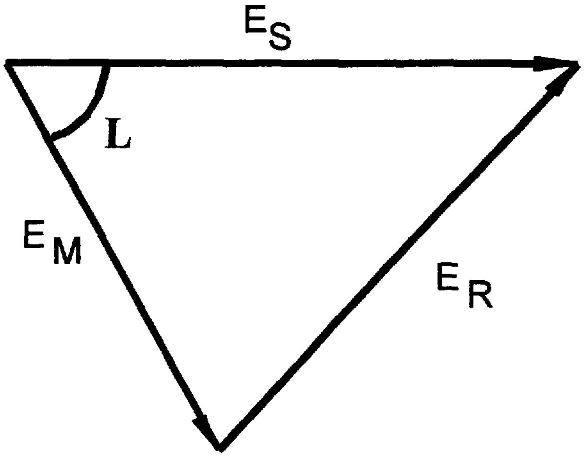
[1] The 1.5 times the open-circuit alternating-current time constant criterion is more conservative than the 1.33 per unit volts per hertz criterion for high speed transfer. The 1.5 value accounts for these factors including the effects of switching an unsynchronized system on relay protection schemes.



In this diagram,

$$E_R = \sqrt{E_S^2 \ E_M^2 - 2E_S E_M \cos\delta}$$

Where

E_S = System equivalent per unit volts per hertz
= System voltage in per unit of motor rated voltage divided by system frequency in per unit of rated frequency

E_M = Motor residual per unit volts per hertz
= Motor terminal voltage in per unit of motor rated voltage divided by motor speed in per unit of synchronous speed

E_R = Resultant vectorial voltage in per unit volts per hertz on the motor rated voltage and frequency base

Figure 2
DETERMINATION OF RESULTANT VOLTS PER HERTZ ON BUS TRANSFER OR RECLOSING

15 Power Factor Correction

WARNING—When power factor correction capacitors are to be switched with an induction motor, the maximum value of corrective kVAR should not exceed the value required to raise the no-load power factor to unity. Corrective kVAR in excess of this value may cause over-excitation resulting in high transient voltages, currents, and torques that can increase safety hazards to personnel and can cause possible damage to the motor or to the driven equipment. For applications where overspeed of the motor is contemplated (i.e., paralleled centrifugal pumps without check valves, etc.), the maximum corrective kVAR should be further reduced by an amount corresponding to the square of the expected per unit speed during the overspeed event.

15.1 Corrective KVAR

The maximum value of corrective kVAR to be switched with an induction motor can be calculated as follows.

$$kVAR \le \frac{0.9xI_{nl}\ x\,E\,x\sqrt{3}}{1000\ x\,(1+OS)^2}$$

Where:

I_{nl} = No-load current at rated voltage
E = Rated voltage
OS = Per unit maximum expected overspeed

15.2 Capacitors

The use of capacitors for power factor correction, switched at the motor terminals, is not recommended for motors subjected to bus transfer or reclosing, elevator motors, multi-speed motors, motors used on plugging or jogging application, and motors used with open transition autotransformer or wye delta starting. For such applications the motor manufacturer should be consulted before installing power factor corrective capacitors switched with the motor.

15.3 Autotransformer Starters

Closed transition autotransformer starters may introduce a large phase shift between the supply voltage and the motor internal voltage during the transition period when the autotransformer primary is in series with the motor winding. To minimize the resultant transient current and torque when the autotransformer is subsequently shorted out, capacitors for power factor correction should be connected on the line side of the autotransformer.

16 Efficiency

If specified, efficiency and losses shall be determined in accordance with ANSI/IEEE 112. The test method shall be as agreed upon by the manufacturer and the user. The stray-load loss shall be determined by direct measurement (see 5.4.2 of ANSI/IEEE 112) or indirect measurement (test loss minus conventional loss).

Power required for auxiliary items such as external pumps or fans necessary for operation of the motor shall be stated separately.

In determining I^2R losses, the resistance of each winding shall be corrected to a temperature equal to an ambient temperature of 25°C plus the observed rated-load temperature rise measured by the resistance method. When the rated-load temperature rise has not been measured, the resistance of the winding shall be corrected to the following temperature:

Class of Insulation System	Temperature, Degrees Celsius
B	95
F	115
H	130

This reference temperature shall be used for determining I^2R losses at all loads. If the rated temperature rise is specified as that of a lower class of insulation system, the temperature for resistance correction shall be that of the lower insulation class.

17 Stator current pulsations

When the driven load, such as that of reciprocating type pumps, compressors, etc., requires a variable torque during each revolution, it is recommended that the combined installation have sufficient inertia in its rotating parts to limit the variations[1] in motor stator current to a value not exceeding 66 percent of full-load current.

18 Surge Capabilities of AC Winding with Form-Wound Coils

18.1 General

Stator winding insulation systems of AC motors are exposed to stresses due to the steady state operating voltages and to steep-fronted voltage surges of high amplitudes. Both types of voltages stress the ground insulation. The steep-fronted surge also stresses the turn insulation. If the rise time of the surge is steep enough (0.1 to 0.2 µsec), most of the surge could appear across the first or line coil and its distribution in the coil could be non-linear.

The steep-fronted surges appearing across the motor terminals are caused by lightning strikes, normal circuit breaker operation, motor starting, aborted starts, bus transfers, switching windings (or speeds) in two-speed motors, or switching of power factor correction capacitors. Turn insulation testing itself also imposes a high stress on the insulation system.

The crest value and rise time of the surge at the motor depends on the transient event taking place on the electrical system design and on the number and characteristics of all other devices in the system. These include, but are not limited to, the motor, the cables connecting the motor to the switching device, the type of switching device used, the length of the busbar, and the number and sizes of all other loads connected to the same busbar.

18.2 Surge Capacitors

Although certain surge withstand capability levels must be specified for the windings, it may be desirable, because of the unpredictable nature of the surge magnitudes and rise times, to install surge protection devices for critical applications at or very close to the motor terminals to slope back the rise of the incoming surge thereby making it more evenly distributed across the entire winding.

18.3 Stator Windings

Stator windings of AC motors for power generating stations, unless otherwise specified, shall be designed to have a surge withstand capability of 3.5 pu (per unit) at a rise time of 0.1 to 0.2 µs or 5 pu at 1.2 µs, and longer, where one pu is the crest of the rated motor line-to-ground voltage, or

$$1\text{pu} = \sqrt{\frac{2}{3}} \times V_{L-L}$$

18.4 Method of Test

Unless otherwise agreed to between the customer and the manufacturer, the method of test and the test instrumentation used shall be per IEEE Std 522. Surge tests may be performed at the following steps in manufacturing:

a) On individual coils before installation in slots
b) On individual coils after installation in slots, prior to connection with stator slot wedging and endwinding support systems installed
c) On completely wound and finished stator

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[1] The basis for determining the variation should be by oscillograph or similar measurement and not by ammeter readings. A line should be drawn representing the full-load current of the motor. (The maximum value of the motor stator current is to be assumed as 1.41 times the rated full-load current.)

The actual step where testing is done shall be a matter of agreement between the customer and the manufacturer.

18.5 Test Voltage Adjustment

The test voltage steps at 18.4 a) and 18.4 b) shall be at least:

a) 65 percent of the values specified in 18.3 for unimpregnated coils
b) 80 percent of the values specified in 18.3 for resin-rich coils

19 Motors Operating on an Ungrounded System

Alternating-current motors are intended for continuous operation with the neutral at or near ground potential. Operation on ungrounded systems with one line at ground potential should be done only for infrequent periods of short duration, for example as required for normal fault clearance. If it is intended to operate the motor continuously or for prolonged periods in such conditions, a special motor with a level of insulation suitable for such operation is required. The motor manufacturer should be consulted before selecting a motor for such an application.

Grounding of the interconnection of the motor neutral points should not be undertaken without consulting the system designer because of the danger of zero-sequence components of currents of all frequencies under some operating conditions and the possible mechanical damage to the winding under line-to-neutral fault conditions.

Other auxiliary equipment connected to the motor, such as, but not limited to, surge capacitors, power factor correction capacitors, or lightning arresters, may not be suitable for use on an ungrounded system and should be evaluated independently.

20 Occasional Excess Current

Induction motors while running and at rated temperature shall be capable of withstanding a current equal to 150 percent of the rated current for 30 seconds.

Excess capacity is required for the coordination of the motor with the control and protective devices. The heating effect in the motor winding varies approximately as the product of the square of the current and the time for which this current is being carried. The overload condition will thus result in increased temperatures and a reduction in insulation life. The motor should therefore not be subjected to this extreme condition for more than a few times in its life.

21 Operation of Induction Motors from Variable-Frequency or Variable-Voltage Power Supplies, or Both

Induction motors to be operated from solid-state or other types of variable-frequency or variable-voltage power supplies, or both, for adjustable-speed applications may require individual consideration to provide satisfactory performance. Especially for operation below rated speed, it may be necessary to reduce the motor rating to avoid overheating. The induction motor manufacturer should be consulted before selecting or applying a motor for such service. (See NEMA MG 1 Parts 30 and 31, as appropriate.) In addition, consideration should be given to protecting bearings and seals, even if insulated, from stray shaft currents.

22 Belt, Chain, and Gear Drive

When induction motors are used for belt, chain, or gear drive, the manufacturer should be consulted.

23 Aseismatic Capability

23.1 Earthquake Damage

The susceptibility of induction motors to earthquake damage is particularly influenced by their mounting structures. Therefore, the aseismatic capability requirements for induction motors should be based on the response characteristics of the system consisting of the induction motor and mounting structure, or equipment on which the induction motor will be mounted when subjected to the specified earthquake ground motions.

23.2 System Requirements

System aseismatic capability requirements should preferably be given in terms of the peak acceleration which a series of "single-degree-of-freedom" oscillators, mounted on the induction motor support structure system, would experience during the specified earthquake. A family of continuous plots of peak acceleration versus frequency over the complete frequency range, and for various values of damping, is referred to as a "frequency response spectrum" for the induction motor and support structure system. This frequency response spectrum should be utilized by those responsible for the system or mounting structure, or both, to determine the aseismatic capability requirement which is to be applied to the induction motor alone when it is mounted on its supporting structure. The induction motor manufacturer should furnish the required data for induction motor natural frequency or mass stiffness, or both, to allow this determination to be made.

23.3 Motor Requirements

Induction motor aseismatic capability requirements should preferably be stated as a single acceleration or "g" value as determined from the system structural characteristics, and input data as outlined in 23.1 and 23.2.

23.4 Supporting Base Structure

For induction motors covered by this standard, it is recommended that the supporting base structure for the induction motor limit the peak acceleration due to earthquakes to the following maximum values:

a) One and one-half g's in any direction
b) One g vertically upward and downward in addition to the normal downward gravity of one g

The loads imposed as a result of the foregoing inputs can be assumed to have negligible effect upon the operation of the induction motor.

NOTES

1 - Accelerations are given in g's or multiples of the "standard" gravitational acceleration (32.2 ft/sec^2) (9.81 meter/sec^2) and are based on an assumed damping factor of 1 percent. Horizontal and vertical accelerations are assumed to act individually but not simultaneously.

2 - The axial restraint of the shaft in most horizontal applications is provided by the driven (or driving) equipment or other devices external to the induction motor. In such cases, the axial seismic loading of the shaft should be included in the requirements for the driven (or driving) equipment. In other applications, restraint of the driven (or driving) equipment rotor may be provided by the induction motor. In such cases, the axial seismic loading of the shaft should be included in the requirements for the induction motor.

3 - When a single g value is given, it is implied that this g value is the maximum value of peak acceleration on the actual frequency response curve for the induction motor when mounted on its supporting structure for a particular value of system structural damping and specified earthquake ground motion. Values for other locations are frequently inappropriate because of nonrigid characteristics of the intervening structure.

24 Airborne Sound

24.1 Sound Quality

Sound quality is determined by the distribution of effective sound intensities as a function of frequency. It plays a significant role in determining how acceptable the sound is to the human ear.

A measurement of total sound does not completely define sound acceptability because motors with the same overall decibel sound level may have a different sound quality. It may be necessary in some cases to describe sound profile in more detail, including octave-band values. In such cases the manufacturer should be consulted.

24.2 Sound Measurement

Motor sound shall be measured in accordance with one of the methods described in NEMA MG 1 Part 9.

Motor sound tests shall be taken under no-load conditions so that the motor is isolated from other sound sources.

It should be recognized that decibel readings are not exact and are subject to many external influences. For further information see NEMA MG 3-1974 (R1995).

24.3 Sound Power Levels

The no-load overall sound power level in dBA (referred to 10^{-12} watt) of polyphase induction motors covered by this standard shall not exceed the values shown in Table 4 when measured in accordance with MG 1 Part 9. Motors with various types of acoustic treatment may have lower values of sound power level than the values shown.

The numerical values of mean sound pressure level in dBA (referred to 20 micropascals) will typically be lower than corresponding values of sound power level in accordance with the following:

Table 4
MOTOR SOUND LEVEL

			Overall Sound Power Level Decibels, A-Weighted (Reference: 10^{-12} Watts)		
Rated Horsepower	Rated Kilowatts	Speed, Rpm	Dripproof	Totally Enclosed Fan-Cooled	Weather-Protected Type II
200-250	150-200	3600	...	107	...
300-450	250-350	3600	107	110	102
500-800	400-600	3600	110	113	105
900-1500	700-1000	3600	111	116	106
1750-2500	1250-2000	3600	112	118	107
3000-5000	2250-3500	3600	114	120	109
200-	150-	1800	...	103	...
250-400	200-300	1800	103	105	99
450-700	350-500	1800	106	108	102
800-1250	600-900	1800	108	111	104
1500-2250	1000-1750	1800	109	113	105
2500-4000	2000-3000	1800	110	115	106
150-	125-	1200	96	98	...
200-350	150-250	1200	99	100	97
400-700	300-500	1200	102	103	99
800-1250	600-900	1200	105	106	101
1500-2500	1000-2000	1200	107	109	103
3000-3500	2250-2500	1200	109	111	105
125-	100-	900-600	93	96	92
150-250	125-200	900-600	95	97	92
300-400	250-300	900-600	98	100	96
450-700	350-500	900-600	99	102	98
800-1250	600-900	900-600	101	105	100
1500-2250	1000-1750	900-600	103	107	102

Part IV: Mechanical Features

25 Bearings

25.1 Horizontal Motors

Horizontal motors with ratings through 1500 hp may use antifriction-type or sleeve-type bearings. Two pole motors are an exception with a more restrictive horsepower limit on the application of antifriction-type bearings.

Horizontal motors with ratings greater than 1500 hp shall have split-sleeve bearings and split bearing brackets. The design shall permit bearing replacement without removing the bottom bearing bracket.

25.2 Vertical Motors

Vertical motors shall have thrust bearings designed to carry all specified axial thrust conditions imposed by the driven equipment.

25.3 Oil Lubrication

Motors with oil lubrication shall be fitted with a sight gage marked with the proper oil level and shall be supplied with fill and drain openings. When oil rings are used, means shall be provided for observing oil ring rotation while the motor is operating. Totally-enclosed fan-cooled motors may be limited to observing the drive end only.

25.4 Antifriction Bearings

All direct connected motors with antifriction bearings shall have an L_{10} life of at least 50,000 hours.

25.5 Shaft Currents

Motors shall have one or more insulated bearings or otherwise shall be protected against the damaging effects of shaft currents, unless otherwise agreed to between the user and the manufacturer.[1]

26 Lubrication System

26.1 Supplied From the Driven Equipment System

Motors whose lubricating oil is supplied from the driven equipment system shall be supplied with oil rings (horizontal motors) and reservoirs to allow for safe start-up and emergency shutdown[2] if the oil lubrication system malfunctions.

26.2 Auxiliary Lubrication System

When an auxiliary lubrication system is supplied with the motor, the system should include the following, as a minimum:

a) A shaft-driven or separate motor-driven pump[3]
b) A cooling system, if required
c) Oil rings for start-up and emergency shutdown (horizontal motors)[1]

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[1] For motors with double ended drives, consideration should be given to using an insulated coupling on the same end as an insulated bearing.

[2] Some high-speed horizontal motors may be equipped with pivoted-pad-type sleeve bearings. In such cases, lubricating oil flow must be maintained during start-up and coast-down.

[3] For motors with a shaft-driven pump, consideration should be given to insulating the coupling.

d) A filter
e) A bypass relief valve
f) A pressure gage (downstream of the filter)
g) Sight flow indicators or flow gages

27 Overspeed

Motors shall be so constructed that, in an emergency not to exceed 2 minutes, they will withstand, without mechanical damage, overspeeds above synchronous speed in accordance with the following. During this over-speed condition, the motor is not electrically connected to the supply.

Synchronous Speed (r/min)	Overspeed (Percent of Synchronous Speed)
3600	20
1800 or less	25

28 Construction Features

28.1 Protection of Motor Leads from Mechanical Damage

Motor terminal leads and accessory leads that pass outside the motor enclosure shall be protected from mechanical damage.

28.2 Drainage

Totally-enclosed fan-cooled motors shall have means for continuously draining condensed moisture from the interior of the motor [IPXX/ICXX][1].

28.3 Cooler-Tube Leakage

Totally-enclosed water-air-cooled motors shall have interior baffles, or other means, to prevent cooler-tube leakage and condensation from contacting the motor winding. The cooler shall be provided with low-point drain fittings. The interior of the motor base shall be constructed so that cooler leakage will collect and drain from the motor before reaching the level of the windings.

28.4 Space Heaters

When space heaters are specified, they shall be completely wired with flame-retardant leads brought into a separate terminal box.

Space heaters shall be single phase, 60 Hz, 120 volts, 240 volts, 480 volts (three-phase), or 575 volts (three-phase) as specified by the purchaser. Space heaters and connections shall be protected against accidental contact by personnel but shall be accessible for service.

28.5 Horizontal Sleeve Bearing Motors

Horizontal sleeve bearing motors shall be provided with access at each end for measuring the air gap. Totally enclosed fan-cooled motors may have access on the drive end only.

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[1] For an explanation of IP/IC Codes, see NEMA Standards Publication MG 1, Parts 1, 5, and 6.

28.6 Grounding

Motors shall have grounding provisions at diagonally opposite locations on the base of the motor, for a total of two. Each location shall have two 1/2-13 tapped holes on 1-3/4-inch centers for equipment ground connection. The ground connection shall be on a flat surface and on a part of the motor not normally disassembled during operation or servicing.

29 Terminal Housing and Boxes

29.1 General

A motor terminal housing shall be supplied for terminating the motor leads.

29.2 Dimensions and Volumes

The minimum dimension and usable volume for terminal housing shall be as indicated in Table 5 for Type I terminal housings or Figure 3 for Type II terminal housings. Unless otherwise specified, a Type I terminal housing shall be supplied.

29.3 Accessory Leads

For motors rated 601 volts and higher, the accessory leads (RTDs, TCs, space heaters, etc.) shall terminate in a terminal box or boxes separate from the motor terminal housing. Current transformers and potential transformers located in the motor terminal housing may have their secondary connections terminated in the motor terminal housing if separated from the motor leads by a suitable physical barrier.

The termination of leads for accessory items normally operating at 50 volts (rms) or less shall be separated from other accessory leads by a suitable physical barrier or terminated in a separate box.

30 Coupling End Play and Rotor Float

30.1 General

Where motors are provided with sleeve bearings, the rotor total end float shall be as indicated in Table 6.

30.2 Flexible Couplings

Flexible couplings used with sleeve bearing motors shall be of the limited end-float type, with the end float as indicated in Table 6.

30.3 Assembly

To facilitate the assembly of driven equipment and sleeve bearing motors, the motor manufacturer shall:

a) Indicate on the motor outline drawing the minimum rotor end play.
b) Include on the motor means to indicate rotor end play limits.
c) Include means for indicating the shaft magnetic center position.

31 Motor Vibration

31.1 General

Motor vibration shall be measured with the motor operating at no load with rated voltage and frequency. The total velocity of vibration (unfiltered) shall be measured on the bearing housing with the axis of the shaft in the normal position. Measurements shall be taken in accordance with NEMA MG 1 Part 7 with the motor rigidly mounted. The motor shall be equipped with one-half of a standard key in the keyseat; that is, a key having a full length flush with the top of the keyseat.

Table 5

TYPE I TERMINAL HOUSING: UNSUPPORTED AND INSULATED TERMINATIONS

Voltage	Maximum Full-Load Current	Minimum Usable Volume, Cubic Inches	Minimum Internal Dimension, Inches	Minimum Centerline Distance,* Inches
460 or 575	400	900	8	...
	600	2000	8	...
	900	3200	10	...
	1200	4600	14	...
2300	160	180	5	...
	250	330	6	...
	400	900	8	...
	600	2000	8	12.6
	900	3200	10	12.6
	1500	5600	16	20.1
4000	160	2000	8	12.6
	700	5600	14	16
	1000	8000	16	20
	1500	10740	20	25
	2000	13400	22	28.3
13200	260	5600	14	16
	680	8000	16	20
	1000	9400	18	25
	1500	11600	20	25
	2000	14300	22	28.3
6901-13800	400	44000	22	28.3
	900	50500	25	32.3
	1500	56500	27.6	32.3
	2000	62500	30.7	32.3

* Minimum distance from the entrance plate for conduit entrance to the centerline of motor leads.

*Terminal housings containing surge capacitors, surge arresters, current transformers, or potential transformers require individual consideration.

	Minimum Dimensions (Inches)									
Machine Voltage	**L**	**W**	**D**	**A**	**B**	**C**	**X**	**E**	**F**	**G**
460-600	24	18	18	9½	8½	4	5	2½	4	12
2300-4800	26	27	18	9½	8½	5½	8	3½	5	14
6600-6900	36	30	18	9½	8½	6	9	4	6	30
13200-13800	48	48	25	13½	11½	8½	13½	6¾	9½	36

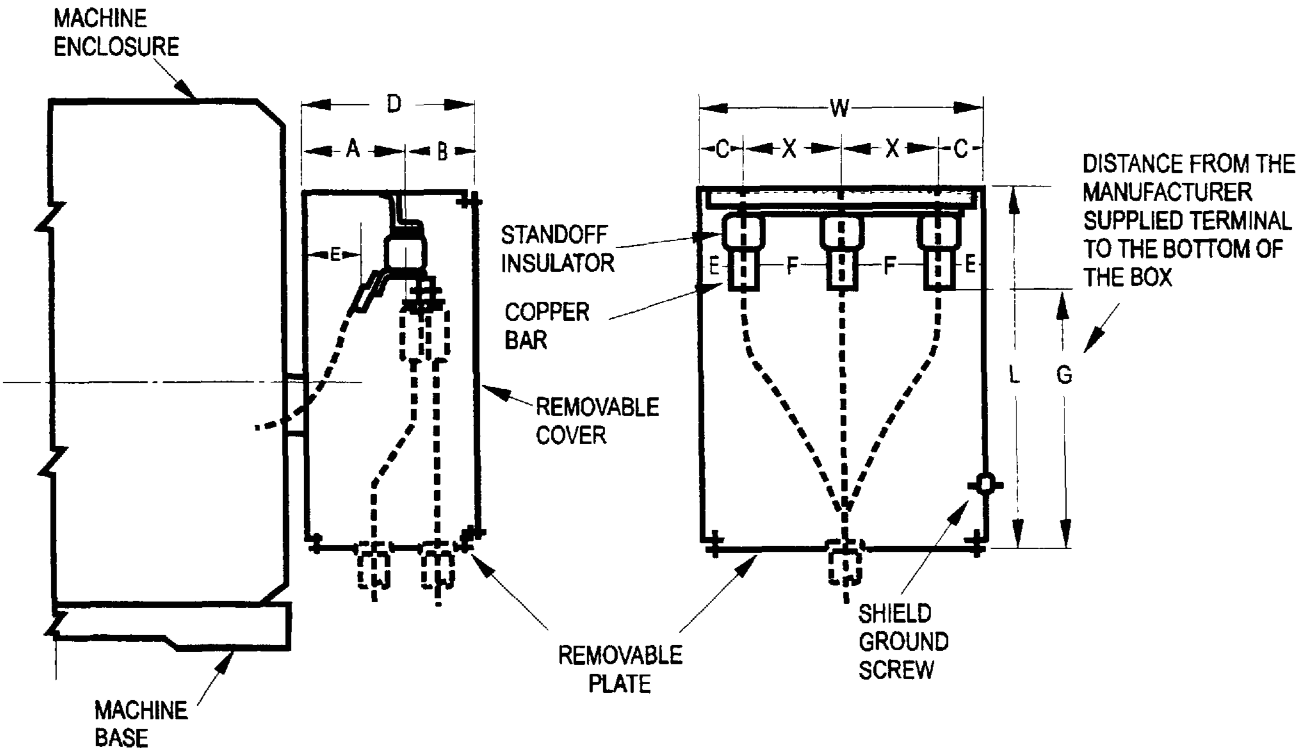

Figure 3
TYPE II MOTOR TERMINAL HOUSING STAND-OFF-INSULATOR-SUPPORTED

Table 6
END-FLOAT VALUES FOR SLEEVE BEARING MOTORS

Motor hp	Synchronous Speed of Motor (r/min)	Minimum Motor Rotor End Float (inch)	Maximum Coupling End Float* (inch)
125 through 500	1800 or less	0.25	0.09
300 through 500	3600	0.50	0.19
501 and higher	All speeds	0.50	0.19

*Couplings with elastic axial centering forces are usually satisfactory without these precautions.

INSULATED OR UNINSULATED TERMINATIONS

31.2 Limits

The vibration when measured in accordance with 31.1 shall not exceed the limits in Table 7:

Table 7

UNFILTERED VIBRATION LIMITS

Speed, rpm	Rotational Frequency, Hz	Velocity, in/s peak
3600	60	0.12
1800	30	0.12
1200	20	0.12
900	15	0.096
720	12	0.072
600	10	0.064

31.3 Reed Frequency of Vertical Motors

31.3.1 Static Deflection

In a single degree of freedom system , the static deflection of the mass (Δ_s, inches) is related to the resonant frequency of the system (f_n, cycles per minute) as follows.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\Delta_s}}$$

Where: $g = 1{,}389{,}600$ in/min^2

31.3.2 Radial Resonant Frequency

Vertical or other flange-mounted induction motors are frequently mounted on some part of the driven (or driving) motor such as a pump adapter. The resulting system may have a radial resonant frequency (reed frequency) the same order of magnitude as the rotational speed of the induction motor. This system frequency can be calculated from the preceding equation. When the resonant frequency of the system is too close to the rotational speed, a damaging vibration level may result.

31.3.3 Determining System Resonant Frequency

The vertical induction motor manufacturer should supply the following information to aid in determining the system resonant frequency, f_n.

a) Motor weight
b) Center of gravity location - This is the distance from the motor mounting flange to the center of gravity of the motor.
c) Motor static deflection - This is the distance the center of gravity would be displaced downward from its original position if the motor were horizontally mounted. This value assumes that the motor uses its normal mounting and fastening means but that the foundation to which it is fastened does not deflect.

Part V: Tests, Nameplate Marking, and Performance Specification Form

32 High-Potential Tests

32.1 Safety Precautions and Test Procedure

WARNING—The following tests involve the potential for electrical shock. Follow the instructions of the electrical test set manufacturer. Be aware that draining static charge after high voltage tests can involve extended time intervals. See NEMA MG 1-3.1.

32.2 Test Voltage

The test voltage shall be an alternating voltage whose effective value is 1000 volts plus twice the rated voltage of the motor.[1]

33 Motor with Sealed Windings – Conformance Tests

An alternating-current squirrel-cage motor with sealed windings shall be capable of passing the following tests.

33.1 Test for Stator Which Can Be Submerged

After the stator winding is completed, join all leads together leaving enough length to avoid creepage to terminals and perform the following tests in the sequence indicated.

a) The sealed stator shall be tested while all insulated parts are submerged in a tank of water containing a wetting agent. The wetting agent shall be non-ionic and shall be added in a proportion sufficient to reduce the surface tension of water to a value of 31 dyne/cm (3.1μN/m) or less at 25°C.
b) Using 500 volts direct-current, take a 10 minute insulation resistance measurement. The insulation resistance value shall not be less than the minimum recommended in IEEE Std 43. (Insulation resistance in megohms ≥ motor rated kilovolts plus 1.)
c) Subject the winding to a 60 hertz high-potential test of 1.15 times the rated line-to-line rms voltage for 1 minute. Water must be at ground potential during this test.
d) Using 500 volts direct-current, take a 1 minute insulation resistance measurement. The insulation resistance value shall be not less than the minimum recommended in IEEE Std 43. (Insulation resistance in megohms ≥ motor rated kilovolts plus 1.)

Note—When performing this test on new windings, Section 9.3.4 of IEEE Std.43 suggests that good insulation should have an insulation resistance higher than the minimum level.

e) Remove winding from water, rinse if necessary, dry, and apply other tests as may be required.

33.2 Test for Stator Which Cannot Be Submerged

When the wound stator, because of its size or for some other reason, cannot be submerged, the tests shall be performed as follows.

a) Spray windings thoroughly for one-half hour with water containing a wetting agent. The wetting agent shall be non-ionic and shall be added in a proportion sufficient to reduce the surface the surface tension of water to a value of 31 dyne/cm (3.1μN/m) or less at 25°C.

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[1] A direct instead of an alternating voltage is sometimes used for high-potential test on primary windings of motors rated 6000 volts or higher. In such cases, a test voltage equal to 1.7 times the alternating-current test voltage (effective value) as given in 32.2 is recommended. Following a direct-voltage high-potential test, the tested winding should be thoroughly grounded. The insulation rating of the winding and the test level of the voltage applied determine the period of time required to dissipate the charge to avoid hazard to personnel.

b) Using 500 volts direct-current, take a 10 minute insulation resistance measurement. The insulation resistance value shall not be less than the minimum recommended in IEEE Std 43. (Insulation resistance in megohms ≥ motor rated kilovolts plus 1.)
c) Subject the winding to a 60 hertz high-potential test of 1.15 times the rated line-to-line rms voltage for 1 minute.
d) Using 500 volts direct-current, take a 1-minute insulation resistance measurement. The insulation resistance value shall be not less than the minimum recommended in IEEE Std 43. (Insulation resistance in megohms ≥ motor rated kilovolts plus 1.)
e) Rinse winding if necessary, dry, and apply other tests as may be required.

34 Tests on Complete Motors

34.1 General

The method of testing polyphase induction motors shall be in accordance with ANSI/IEEE 112 and NEMA MG 1 Part 9, "Sound Power Limits and Measurement Procedure."

34.1.1 All tests shall be made by the manufacturer except those listed in 34.3.2. The order of the listing does not necessarily indicate the sequence in which the tests shall be made.

34.1.2 Multispeed motors shall be tested at each winding speed.

34.2 Tests on Motors Completely Assembled in the Factory

34.2.1 Required Factory Tests

The following tests shall be made on motors completely assembled in the factory and furnished with a shaft and a complete set of bearings:

a) Measurement of winding resistance
b) No-load readings of current, power, and nominal speed at rated voltage and frequency
c) Mechanical vibration
d) Direction of rotation versus phase sequence
e) Insulation resistance
f) High-potential test

34.2.2 Optional Tests

Any or all of the following tests may be specified on units that are completely assembled at the factory. Unless otherwise specified, when duplicate motors are provided, the tests shall be conducted on one motor only.

a) Determination of locked-rotor (zero-speed) torque and current
b) Determination of speed-torque curve
c) Determination of speed-current curve
d) Temperature tests
e) Determination of full-load current and slip
f) Determination of efficiency at 100 percent, 75 percent, and 50 percent of full load
g) Determination of power factor at 100 percent, 75 percent, and 50 percent of full load
h) Airborne sound pressure level
i) Airborne sound power level
j) Dielectric absorption test

34.3 Tests on Motors Not Completely Assembled in the Factory

34.3.1 Required Tests

The following factory tests shall be made on all motors not completely assembled in the factory:

a) Measurement of winding resistance
b) Insulation resistance
c) High-potential test

34.3.2 Recommended Field Tests

The following field tests are recommended after installation on all motors not completely assembled in the factory:

a) Insulation resistance
b) Measurement of bearing insulation resistance (on motors furnished with one or more insulated bearings). (This test may not be practical on assembled motors with only one insulated bearing.)
c) No-load readings of current and nominal speed
d) Direction of rotation
e) Mechanical vibration

35 Rotation

35.1 Nameplate

The motor nameplate shall identify the relationship between motor terminals, phase sequence, and motor rotation. Motor terminals shall be suitably identified.

35.2 Unidirectional Fans

Motors having unidirectional fans shall be supplied with a permanent marker on the motor frame indicating the direction of rotation.

36 Nameplate

36.1 Construction

A permanent marking of nameplate information shall appear on each motor, displayed in a readily visible location on the motor enclosure.

36.2 Marking

A nameplate shall be provided, and the information given thereon shall include the following:

a) Manufacturer's name and serial number or other suitable identification
b) Manufacturer's type and frame designation
c) Horsepower
d) Revolutions per minute (r/min) at rated load
e) Enclosure type
f) Voltage
g) Number of phases
h) Connection for rotation
i) Frequency
j) Temperature rise at service factor

k) Time rating
l) Current at rated load
m) Locked-rotor current[1]
n) Type NT or Type HT[2]
o) Service factor
p) Starting information[2]
q) Total weight of motor[2]
r) Weight of rotor
s) Connection diagram for dual-voltage motors or motors having six or more leads[2]
t) Space heater voltage and wattage (when space heaters are provided)[2]
u) Bearing designation
v) Recommended lubricant[2]
w) Recommended pressure, flow rate, and orifice size if pressurized lubrication system[2]
x) Temperature detector type and number, if supplied[2]

37 Documentation

The following minimum documentation shall be provided.

37.1 General

The following information shall be on all documentation:

a) Purchaser's or user's corporate name
b) Power station name and unit (as appropriate)
c) Purchase order or project number, or both
d) Equipment name and application
e) Purchaser's identification number
f) Manufacturer's shop order number
g) Manufacturer's model number and serial number

37.2 Motor Data

a) Nameplate data (see clause 36)
b) Axial end float
c) Open circuit time constant
d) Recommended temperature detectors alarm and trip levels
e) Insulation system designation
f) Maximum ambient temperature

37.3 Performance Curves

a) Torque versus speed (100 percent and minimum starting voltage)
b) Current versus speed (100 percent and minimum starting voltage)
c) Thermal limit (in accordance with IEEE Std 620)
d) Current versus time (100 percent and minimum starting voltage)

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[1] When agreed to between the user and the manufacturer, the locked-rotor code letter may be used.

[2] May be on separate nameplate.

37.4 Performance Data

a) Locked rotor current, torque, and power factor
b) Pull-up torque
c) Breakdown torque
d) Rated torque and speed
e) Current, efficiency, and power factor at 25 percent, 50 percent, 75 percent, 100 percent, and service factor loading
f) Allowable stall times at 100 percent voltage and minimum starting voltage
g) Acceleration times at 100 percent voltage and minimum starting voltage

37.5 Accessories

When accessories are supplied with the motor, the appropriate following data shall be provided:

a) Terminal lug size
b) Cooler data
c) Air filter and pressure switch data
d) Vibration monitor data
e) Current transformer data
f) Surge arrester and surge capacitor data, or both
g) Coupling information

37.6 Test Reports

The test data recorded in Sections 33 and 34.

37.7 Drawings

a) Outline drawing (including dimensions, weights, and mounting details of all components)
b) Foundation drawing (loading details)
c) General assembly drawing showing components
d) Connection diagrams (main terminals, temperature detectors, space heaters, etc.)
e) Bearing fit tolerances

37.8 Instruction Manual

37.8.1 General

The manufacturer shall provide written instructions to enable the user to install, operate, and maintain the motor.

This information shall be compiled in a manual with a title page containing section titles and list of drawings. All required documentation shall be included in the instruction manual. It is preferred that the information be specific to the motor, rather than "typical" information. If sections apply to more than one motor or model line, the appropriate information shall be clearly indicated. Approval and submittal details for instruction manuals and other documents should be addressed in the purchaser's specification. Unless otherwise specified, the instruction manual shall be submitted for review and approval prior to motor shipment and then updated with actual test results.

37.8.2 Equipment Handling

The requirements for handling the equipment at the job site shall include such data as location of balance point, jacking points and lift points, type of hoisting sling and methods of attachment, use of spreader bars, susceptibility to shock damage and precautions concerning possible contamination. If dimensions and locations are not easily defined otherwise, a drawing or sketch should be included.

37.8.3 Equipment Storage

The requirements for storing the equipment at the job site shall cover such items as inside or outside storage, temperature and humidity control, maintenance, tests and any other precautions considered pertinent to ensure the integrity of the equipment or material.

37.9 Optional Documentation

a) Accessories
b) Spare parts list
c) Any exceptions to specifications
d) Air gap dimensions
e) Equivalent circuit model data
f) Short-circuit reactance and X/R at rated speed
g) Speed versus time curve (100 percent and minimum starting voltage)
h) Rotor drawing (suitable for torsional analysis)