

Form-wound Squirrel Cage Induction Motors—375 kW (500 Horsepower) and Larger

API STANDARD 541
FIFTH EDITION, DECEMBER 2014

REAFFIRMED, MAY 2021



Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this Standard should consult with the appropriate authorities having jurisdiction.

Users of this Standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Where applicable, authorities having jurisdiction should be consulted.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the Standard. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

Copyright © 2014 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 General	1
1.1 Scope	1
1.2 Alternative Designs	1
1.3 Dimensions and Standards	1
1.4 Conflicting Requirements	2
2 Normative References	2
3 Terms and Definitions	6
4 Basic Design	8
4.1 General	8
4.2 Electrical Design	10
4.3 Winding and Insulation Systems	14
4.4 Mechanical Design	16
5 Accessories	40
5.1 Terminal Boxes	40
5.2 Winding Temperature Detectors	42
5.3 Bearing Temperature Detectors	42
5.4 Space Heaters	42
5.5 Screens and Filters	43
5.6 Alarms and Control Devices for Motor Protection	43
5.7 Ground Connectors	44
5.8 Vibration Detectors	44
6 Inspection, Testing, and Preparation for Shipment	45
6.1 General	45
6.2 Inspection	46
6.3 Final Testing	47
6.4 Preparation for Shipment	61
7 Guarantee and Warranty	62
8 Vendor's Data	63
8.1 Proposals	63
8.3 Contract Data	65
8.5 Drawings	66
8.6 Final Data	68
8.7 Instruction Manuals	68
Annex A Datasheets	70
Annex B Vendor Drawing and Data Requirements	97
Annex C Datasheet Guide	101
Annex D Procedure for Determination of Residual Unbalance	144
Annex E Procedure and Guidance for Determining the Allowable Resultant Vector Change During a Heat Run Test	152
Annex F Alternate Criteria for Defining a Well Damped Resonance	155
Annex G AC Stator Form Coil Data	157
Bibliography	160

Contents

Page

Figures

1	Typical Rotor Mode Shapes	27
2	Shaft Vibration Limits (Metric Units, Relative to Bearing Housing Using Noncontact Vibration Probes) for All Hydrodynamic Sleeve Bearing Machines with the Machine Securely Fastened to a Massive Foundation.	49
3	Shaft Vibration Limits (U.S. Customary Units, Relative to Bearing Housing Using Noncontact Vibration Probes) for All Hydrodynamic Sleeve Bearing Machines with the Machine Securely Fastened to a Massive Foundation	49
4	Bearing Housing Radial and Axial Vibration Limits (Metric Units) for Sleeve and Antifriction Bearing Machines with the Machine Securely Fastened to a Massive Foundation	50
5	Bearing Housing Radial and Axial Vibration Limits (U.S. Customary Units) for Sleeve and Antifriction Bearing Machines with the Machine Securely Fastened to a Massive Foundation	50
6	Adjacent Core	57
D.1	(Blank) Residual Unbalance Worksheet	146
D.2	(Blank) Residual Unbalance Polar Plot Worksheet	147
D.3	Sample Residual Unbalance Worksheet for Left Plane	148
D.4	Sample Residual Unbalance Polar Plot Worksheet for Left Plane	149
D.5	Sample Residual Unbalance Worksheet for Right Plane	150
D.6	Sample Residual Unbalance Polar Plot Worksheet for Right Plan	151
E.1	Example of a Polar Plot Complying with 6.3.3.13	153
E.2	Example of a Polar Plot Not Complying with 6.3.3.13	153
E.3	Example of a Polar Plot Not Complying with 6.3.3.12	154
E.4	Possible Option if a Motor Fails Basic Specification Criteria	154
F.1	Evaluation of Amplification Factor (AF) from Speed Amplitude Plots	156

Tables

1	Voltage Ratings for Three Phase 60 Hz Systems	11
2	Voltage Ratings for Three Phase 50 Hz Systems (British Standards)	11
3	Voltage Ratings for Three Phase 50 Hz Systems (General)	11
4	Starting Capabilities	13
5	Machine Enclosures and Corresponding NEMA or IEC Specifications	17
6	Maximum Severity of Defects in Castings	47
7	DC Test Voltages for Insulation Resistance and Determination of Polarization Index	52
8	DC High-Potential Test Voltage Levels	59

Form-wound Squirrel Cage Induction Motors— 375 kW (500 Horsepower) and Larger

1 General

1.1 Scope

1.1.1 This standard covers the minimum requirements for special purpose form-wound squirrel cage induction motors 375 kW (500 hp) and larger for use in petroleum, chemical, and other industry applications. This standard can also be used for induction generators by substituting “generator” for “motor” where applicable.

Notes following a paragraph in Sections 1 through 8 are informational only and are not enforceable as part of this standard.

NOTE A special purpose machine typically has one or more of the following characteristics:

- 1) is in an application for which the equipment is designed for uninterrupted, continuous operation in critical service, and for which there is usually no installed spare equipment;
- 2) is larger than 2250 kW (3000 hp) for speeds 1800 rpm and below;
- 3) is rated 600 kW (800 hp) or greater for two pole (3000 rpm or 3600 rpm) machines of totally enclosed construction, or rated 930 kW (1250 hp) or greater for two pole machines of open or guarded construction (including machines with WP-I or WP-II type enclosures);
- 4) drives a high-inertia load (in excess of the load Wk^2 listed in NEMA MG 1, Part 20);
- 5) uses an adjustable speed drive (ASD) as a source of power;
- 6) is an induction generator;
- 7) is a vertical machine rated 375 kW (500 hp) or greater; or
- 8) operates in abnormally hostile environments.

A round bullet (●) at the beginning of a paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information shall be indicated on the datasheets (see Annex A); otherwise, it shall be stated in the quotation request or in the order.

A diamond bullet (◆) at the start of a paragraph indicates additional requirements for motors applied with ASDs.

1.1.2 This standard requires the purchaser to specify details and features. The purchaser shall complete the datasheets in Annex A.

NOTE Guidance for completion of the datasheets is provided in Annex C.

1.2 Alternative Designs

The vendor may offer alternative designs (see 8.1.9).

1.3 Dimensions and Standards

- **1.3.1** Both the metric (SI) and U.S. customary (USC) system of units and dimensions are used in this standard. Data, drawings, and hardware (including fasteners) related to equipment supplied to this standard shall use the

system of units specified by the purchaser. An alternate system of units for hardware (including fasteners and flanges) may be substituted if mutually agreed upon by the purchaser and the vendor.

- **1.3.2** This document recognizes two different systems of standards for the manufacturing and testing of electrical machines: the North American ANSI, IEEE, and NEMA standards and the international IEC and ISO standards. The North American standards are the base documents. When specified by the purchaser, the corresponding international standards are acceptable for use as alternatives; however, this shall not be construed that they are identical to the North American standards.

NOTE The purchaser should be aware that specific requirements contained within corresponding standards may differ.

1.4 Conflicting Requirements

In case of conflict between the inquiry, order and datasheets, this document, and any referenced standards, the order of precedence shall be:

- 1) inquiry or purchase order,
- 2) datasheets,
- 3) purchaser's specifications,
- 4) this API 541 standard, and
- 5) referenced publications.

2 Normative References

The editions of the following standards, codes, and specifications that are in effect at the time of publication of this standard shall (to the extent specified herein) form a part of this standard. The purchaser and the vendor shall mutually agree upon the applicability of changes in standards, codes, and specifications that occur after the inquiry.

API Standard 614, *Lubrication, Shaft-Sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services*

API Standard 618, *Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services*

API Standard 670, *Machinery Protection Systems*

API Standard 671, *Special Purpose Couplings for Petroleum, Chemical and Gas Industry Services*

ABMA Standard 7 ¹, *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plan*

ABMA Standard 20, *Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types—Metric Design*

AGMA 9002 ², *Bores and Keyways for Flexible Couplings (Inch Series)*

AISI ³, *Standards of the American Iron and Steel Institute*

¹ American Bearing Manufacturers Association, 2025 M Street, NW, Suite 800, Washington, DC 20036, www.abma-dc.org.

² American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314, www.agma.org.

³ American Iron and Steel Institute, 1540 Connecticut Avenue, NW, Suite 705, Washington, DC 20036, www.steel.org.

ANSI/ASA S12.54 ⁴, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Engineering method in an essentially free field over a reflecting plane*

ASME Boiler and Pressure Vessel Code (BPVC) ⁵, Section II, “Materials” (Customary) and (Metric); Section V, “Nondestructive Examination”; Section VIII, “Pressure Vessels”; and Section IX, “Welding and Brazing Qualifications”

ASME B1.1, *Unified Inch Screw Threads (UN and UNR Thread Form)*

ASME B1.20.1, *Pipe Threads, General Purpose (Inch)*

ASME B16.1, *Gray Iron Pipe Flanges and Flanged Fittings*

ASME B16.5, *Pipe Flanges and Flanged Fittings*

ASME B16.11, *Forged Fittings, Socket-Welding and Threaded*

ASME B16.20, *Metallic Gaskets for Pipe Flanges, Ring-Joint, Spiral-Wound and Jacketed*

ASME B36.10M, *Welded and Seamless Wrought Steel Pipe*

ASME B106.1M, *Design of Transmission Shafting*

ASTM A278/A278M ⁶, *Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650 °F (350 °C)*

ASTM A345, *Standard Specification for Flat-Rolled Electrical Steels for Magnetic Applications*

ASTM A395, *Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*

ASTM A536, *Standard Specification for Ductile Iron Castings*

ASTM A668, *Standard Specification for Steel Forgings, Carbon, and Alloy, for General Industrial Use*

ASTM A976, *Standard Classification of Insulating Coatings for Electrical Steels by Composition, Relative Insulating Ability and Application*

ASTM D1868, *Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems*

ASTM E94, *Standard Guide for Radiographic Examination*

ASTM E125, *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*

ASTM E142, *Method for Controlling Quality of Radiographic Testing*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

AWS D1.1 ⁷, *Structural Welding Code—Steel*

⁴ Acoustical Society of America, 1305 Walt Whitman Road, Melville, NY 11747-4300, www.acousticalsociety.org.

⁵ ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

⁶ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁷ American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126, www.aws.org.

CENELEC EN 10250 ⁸, *Open steel die forgings for general engineering purposes—Part 1: General requirements*

CENELEC EN 60751, *Industrial platinum resistance thermometers and platinum temperature sensors*

IEC 60034 (all parts) ⁹, *Rotating electrical machines*

IEC 60038, *IEC standard voltages*

IEC 60072, *Dimensions and output series for rotating electrical machines*

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres*

IEC 60270, *High voltage test techniques—Partial discharge measurements*

IEC 60404-1, *Magnetic materials—Part 1: Classification*

IEC 60404-1-1, *Magnetic materials—Part 1-1: Classification—Surface insulations of electrical steel sheet, strip and laminations*

IEC 60894, *Guide for a test procedure for the measurement of loss tangent of coils and bars for machine windings*

IEEE 43 ¹⁰, *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*

IEEE 56, *IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10,000 kVA and Larger)*

IEEE 112, *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*

IEEE 286, *IEEE Recommended Practice for Measurement of Power-Factor Tip-Up of Electric Machinery Stator Coil Insulation*

IEEE 432, *IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 Hp to less than 10 000 Hp)*

IEEE 522, *IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines*

IEEE 620, *IEEE Guide for the Presentation of Thermal Limit Curves for Squirrel Cage Induction Machines*

IEEE 841, *IEEE Standard for Petroleum and Chemical Industry—Premium Efficiency Severe-Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)*

IEEE 1434, *IEEE Guide to Measurement of Partial Discharges in Rotating Machinery*

IEEE 1776, *IEEE Recommended Practice for Thermal Evaluation of Unsealed or Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-Insulated Stator Coils for Machines Rated 15,000 V and Below*

ISO 15 ¹¹, (ISO/DIN 15) *Rolling bearings—Radial bearings—Boundary dimensions, general plan*

⁸ European Committee for Standardization, Avenue Marnix 17, B-1000 Brussels, Belgium, www.cen.eu.

⁹ International Electrotechnical Commission, 3 rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

¹⁰ Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, New Jersey 08854, www.ieee.org.

¹¹ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 68, *(ISO/DIN 68) ISO General purpose metric screw threads—Basic profile*

ISO 261, *ISO General purpose metric screw threads—General plan*

ISO 286, *ISO code system for tolerances on linear sizes—Part 1: “Bases of tolerances, deviations and fits”; and Part 2 “Tables of standard tolerance classes and limit deviations for holes and shafts”*

ISO 492, *Rolling bearings—Radial bearings—Tolerances*

ISO 1940-1, *Mechanical vibration—Balance quality requirements for rotors in a constant (rigid) state—Part 1: Specification and verification of balance tolerances*

ISO 3452, *Non-destructive testing—Penetrant inspection—Part 1: General principles*

ISO 3453, *Non-destructive testing—Liquid penetrant inspection—Means of verification*

ISO 3506, *Mechanical properties of corrosion resistant stainless steel fasteners*

ISO 3744, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Engineering method in an essentially free field over a reflecting plane*

ISO 5579, *Non-destructive testing—Radiographic examination of metallic materials using X- or gamma rays—Basic rules*

ISO 5753, *Rolling bearings—Internal clearances—Part 1: Radial internal clearances for radial bearings*

ISO 6708, *Pipework components—Definition and selection of DN (nominal size)*

ISO 7005-1, *Metallic flanges—Part 1: Steel flanges for industrial and general service piping systems*

ISO 7483, *Dimensions of gaskets for use with flanges to ISO 7005*

ISO 9013, *Thermal cutting—Classification of thermal cuts—Geometrical product specification and quality tolerances*

ISO 9691, *Rubber—Recommendations for the workmanship of pipe joint rings—Description and classification of imperfections*

ISO 19232, *Non-destructive testing—Image quality of radiographs*

ISO Catalog 25.160, *Welding*

NEMA MG 1¹², *Motors and Generators*

ANSI/NEMA C50.41, *American National Standard for Polyphase Induction Motors for Power Generating Stations*

NEMA Standards Publication 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

NFPA 70¹³, *National Electrical Code*

¹² National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.

¹³ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1

accelerating torque

Accelerating torque is the difference between the input torque to the rotor (electromagnetic for a motor or mechanical for a generator) and the sum of the load and loss torque; the net torque available for accelerating the rotating parts.

3.2

adjustable speed drive

ASD

Refers to the electronic equipment used to regulate the operating speed of the motor and driven equipment by controlling the frequency and voltage.

NOTE Other terms commonly used are variable speed drive, adjustable frequency drive, and variable frequency drive; however, use of these terms is discouraged.

3.3

breakdown torque

Breakdown torque of a motor is the maximum torque that it will develop with rated voltage applied at rated frequency without an abrupt drop in speed.

3.4

cold start

A cold start is a motor start that occurs when the rotor and stator are initially at ambient temperature.

3.5

hot start

A hot start is any restart of the motor that occurs when the motor is at a temperature above ambient temperature.

3.6

lateral critical speed

Lateral critical speed is a shaft rotational speed at which the rotor-bearing-support system is in a state of resonance.

NOTE The basic identification of critical speeds is made from the natural frequencies of the system and of the forcing phenomena. If the frequency of any harmonic component of a periodic forcing phenomenon is equal to or approximates the frequency of any mode of rotor vibration, a condition of resonance may exist. If resonance exists at a finite speed, that speed is called a critical speed. This standard is concerned with actual resonant speeds rather than various calculated values. Actual critical speeds are not calculated undamped values but are critical speeds confirmed by test-stand data. Critical speeds above the maximum test speed should be calculated damped values.

3.7

locked-rotor torque

Locked-rotor torque of a motor is the minimum torque that it will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency.

3.8

oil mist lubrication

Oil mist lubrication is a lubrication system that employs oil mist produced by atomization in a central unit and transported to the bearing housing or housings by compressed air.

3.9

owner

Owner is the final recipient of the equipment who may delegate another agent as the purchaser of the equipment.

3.10**power factor**

Power factor of an AC motor (or generator) is the ratio of the kilowatt input (or output) to the kVA input (or output) and is usually expressed as a percentage.

3.11**pressure lubrication**

The term “pressure lubrication” applies to bearings that are either lubricated by filling the bearing with pressurized oil or bearings that are flood lubricated by oil directed at the bearing surfaces. This pressurized oil source may be either connected to or independent of the machine.

3.12**pull-up torque**

Pull-up torque of an AC motor is the minimum torque developed by the motor during the period of acceleration from rest to the speed at which breakdown torque occurs. For motors that do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to the rated speed.

3.13**purchaser**

Purchaser is the agency that issues the order and specification to the vendor.

3.14**pure oil mist lubrication**

Pure oil mist lubrication (dry sump) systems are those in which the mist both lubricates the bearing and purges the housing.

3.15**purge oil mist lubrication**

Purge oil mist lubrication (wet sump) systems are those in which the mist purges the bearing housing. Bearing lubrication is by a conventional oil-bath, flinger, or oil ring lubrication system.

3.16**self-lubrication**

Self-lubricated hydrodynamic bearings utilize rotation of the shaft to continuously apply lubricant to the bearing surfaces. These bearings utilize an oil reservoir located beneath the bearing. Self-lubricated bearings include bearings partially immersed in the oil reservoir and bearings with rings in contact with the shaft.

3.17**service factor**

Service factor of an AC motor 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 service factor (see NEMA MG 1). (IEC standards do not recognize service factor.)

3.18**special tool**

A special tool is a tool that is not a commercially available catalog item.

3.19**torsional critical speeds**

Torsional critical speeds correspond to resonant frequencies of the complete mass-elastic system in the drive train including motor, couplings, and driven equipment.

NOTE The first torsional natural frequency of motor-driven equipment combinations normally lies between twice the line frequency and zero frequency and may be excited from the motor or driven equipment. Depending on the mechanical

characteristics of the drive train at the resonant speed defined by the intersection of the natural torsional frequency and the frequency of potential torque oscillations, the torque oscillation may be escalated to a point at which unacceptably high torsional stress occurs in the rotating system if there is not sufficient damping within the system.

3.20

trip speed

Trip speed (in revolutions per minute) is the speed at which the independent emergency speed device operates to shut down the machine.

3.21

unit responsibility

Unit responsibility refers to the responsibility for coordinating the technical aspects of the equipment and all auxiliary systems included in the scope of the order. The technical aspects to be considered include but are not limited to such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications, and testing of components.

3.22

vendor

Vendor (also known as supplier) is the agency that supplies the equipment.

3.23

vibration forcing phenomena

Vibration forcing phenomena are excitation forces that may cause vibration. The exciting frequency may be less than, equal to, or greater than the synchronous frequency of the rotor. Potential excitations to be considered in the design of the machine shall include but are not limited to the following sources:

- a) mechanical unbalance in the rotor system;
- b) oil film instabilities (whirl or whip);
- c) alignment tolerances;
- d) gear problems (e.g. unbalance and pitch line runout);
- e) start-up condition frequencies;
- f) twice the line frequencies;
- g) electrical unbalance;
- h) mechanical pulsations produced by the driven equipment;
- i) short circuits (faults) and other transient conditions on the electrical system; and
- j) ASDs.

4 Basic Design

4.1 General

4.1.1 The equipment (including auxiliaries) covered by this standard shall be suitable for the specified operating conditions and shall be designed and constructed for a minimum service life of 25 years and at least 5 years of uninterrupted continuous operation. It is recognized that this is a design criterion and that uninterrupted operation for this time period involves factors beyond the vendor's control.

NOTE A self-lubricated bearing will require periodic lubricating oil changes. A five year continuous uninterrupted operation may require the installation of a forced oil lubrication system for the bearings.

- **4.1.2** Machines shall be designed for continuous operation and long periods of inactivity in an atmosphere that is made corrosive by traces of chemicals normally present in a petroleum processing facility. This environment may also include high humidity, storms, salt-laden air, insects, plant life, fungus, and rodents. Machines shall be suitable for operation, periods of idleness, storage, and handling at the ambient temperatures specified under “Site Data” on the datasheets (see Annex A). If additional considerations are necessary, the purchaser shall specify them.
- **4.1.3** Unless otherwise specified, the A-weighted maximum sound pressure level of the motor shall not exceed 85 dBA at any location at a reference distance of 1 m (3 ft) with the motor operating at no load, full voltage, rated frequency, and sinusoidal power. The measuring and reporting of sound pressure level data shall be in accordance with 6.3.5.1.1 g).
- ◆• **4.1.4** When specified, a mutually agreed upon sound level shall be measured while the motor is being driven by the contract ASD or one that gives a similar waveform. The purchaser and vendor shall mutually decide the supply frequency.

NOTE Some ASDs may cause increased motor sound levels due to increased operating speed (if operated above line frequency), excitation of mechanical resonances, and magnetic noise caused by supply source harmonics. Purchaser should address these issues with the ASD and motor suppliers and reach agreement on resolution.

- ◆• **4.1.5** All equipment shall be designed to be mechanically stable at the overspeed and duration specified in NEMA MG 1, Part 20; IEC 60034-1; or at the specified trip speed (including overshoot) of the connected equipment, whichever is greater. For machines driven by ASDs, the purchaser and vendor shall mutually decide the overspeed capability (see 6.3.5.6).

4.1.6 The arrangement of the equipment including number of bearings, terminal housings, conduit, piping, and auxiliaries shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for installation, operation, and maintenance.

4.1.7 The design of piping systems shall achieve the following:

- a) proper support and protection to prevent damage from vibration and during shipment, operation, and maintenance;
 - b) easily accessible for operation, maintenance, and thorough cleaning;
 - c) installation in a neat and orderly arrangement adapted to the contour of the machine without obstructing access openings;
 - d) elimination of air pockets and traps;
 - e) complete drainage through low points without disassembly of piping; and
 - f) provision for easy removal of covers for maintenance and inspection.
- **4.1.8** The machine and all of its auxiliary devices shall be suitable for and in accordance with the area classification system specified by the purchaser on the datasheets. Auxiliary devices shall be listed or certified where required in accordance with the area classification system specified [e.g. NFPA 70, Article 500, Article 501, Article 502, and Article 505 (Class, Group, Division or Zone, and Temperature Code) or IEC 60079-10 (Zone, Class, Group, and Temperature Code)] and specified local codes.

NOTE See IEEE 303, IEEE 1349, and IEC 60079 for additional guidance and information on application of motors and accessories in hazardous locations.

4.1.9 All equipment shall be designed to permit rapid and economical maintenance and inspection. Major parts (e.g. frame components and bearing housings) shall be designed and manufactured to ensure accurate alignment on reassembly. This shall be accomplished by the use of shouldering, cylindrical dowels, or keys.

4.1.10 Easily removable covers shall be provided for the inspection of the air gap in at least three places, each separated by 90° as specified in 4.4.7.2.4, and also for the inspection of the coil end turns. Inspection covers may not be possible on cast frames and smaller fabricated frames. The manufacturer shall bring to the attention of the purchaser any and all cases where the above requirements cannot be met.

- **4.1.11** Every effort shall be made to avoid requirements for special tools. However, when tools and fixtures not commercially available are required to disassemble, assemble, or maintain the unit, they shall be included in the quotation and furnished as part of the initial supply. For multiple-unit installations, the purchaser and vendor shall mutually agree upon the requirements for quantities of special tools and fixtures.

4.1.12 When special tools are provided, they shall be packaged in separate, rugged, reusable steel boxes and marked as "special tools for (tag or item number)." Each tool shall be tagged to indicate its intended use.

4.1.13 The equipment (machine and auxiliary equipment) shall perform on the test stand and on their permanent foundation within the specified acceptance criteria. The performance on the permanent foundation may differ from performance on the test stand (see 4.4.6). After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

4.1.14 The vendor shall supply a machine with all components and material constructed with the latest field proven design (minimum two years) and in current production. If the design dictates the necessity for equipment that has not been in continuous service for at least two years, the vendor shall provide adequate written documentation at the time of proposal describing the particular components and the extent of their experience with such a design or equipment. Obsolete components or those scheduled for discontinuation within the next two years shall not be used.

4.2 Electrical Design

4.2.1 Rating and Voltage

- **4.2.1.1** Unless otherwise agreed by the purchaser, NEMA or IEC standard ratings shall be used. If the required rating falls between two listed ratings, the larger listed rating shall be selected.
- **4.2.1.2** Unless otherwise specified, induction machines shall have rated voltages in accordance with 4.2.1.2.1, 4.2.1.2.2, and 4.2.1.2.3. The rated voltage shall be specified on the datasheets.

4.2.1.2.1 Refer to Table 1 for voltage ratings for three phase 60 Hz systems.

4.2.1.2.2 For 50 Hz supply systems, two different voltage systems are standardized in IEC 60038. Table 2 is widely used in countries following British standards. Table 3 is used for 50 Hz systems in general.

NOTE 1 Either one of the 50 Hz voltage series may be used as listed in IEC 60038.

NOTE 2 Other voltages may be necessary to conform to nonstandard voltages not listed above.

- ♦• **4.2.1.2.3** For motors operating only on ASDs, the voltage and frequency ratings shall be mutually agreed upon by the purchaser and vendor.

NOTE In general, ASD output voltage, harmonics, and voltage to frequency ratio should match motor design parameters (voltage and flux). The motor vendor should be informed by the purchaser of any deviations and appropriate design accommodations should be mutually agreed between purchaser and vendor.

Table 1—Voltage Ratings for Three Phase 60 Hz Systems

Horsepower	Motor Voltage	Bus Voltage
Up to 4,000	2,300	2,400
Up to 7,000	4,000	4,160
1,000 to 12,000	6,600	6,900
3,500 or Above	13,200	13,800

Table 2—Voltage Ratings for Three Phase 50 Hz Systems (British Standards)

kW	Motor Voltage	Bus Voltage
Up to 4,000	3,300	3,450
Up to 12,000	6,600	6,900
4,000 or Above	11,000	11,500

Table 3—Voltage Ratings for Three Phase 50 Hz Systems (General)

kW	Motor Voltage	Bus Voltage
450 to 4,000	3,000	3,150
450 to 12,000	6,000	6,300
4,000 or Above	10,000	10,500

- **4.2.1.3** Unless otherwise specified, the machine shall operate with a maximum voltage variation of $\pm 10\%$ and a maximum frequency variation of $\pm 5\%$ and a total combined variation not to exceed $\pm 10\%$, per NEMA MG 1 or IEC 60034.

4.2.1.4 Machines shall have a 1.0 service factor rating. Machines shall be capable of continuous operation at rated load and temperature rise in accordance with 4.3.1.1 when operated both mechanically and electrically at rated power, voltage, and frequency. In applications that require an overload capacity, a higher base rating instead of a service factor rating shall be used to avoid exceeding the temperature rise specified in 4.3.1.1 and to provide adequate torque capacity.

NOTE Applying a motor such that it will operate at greater than its rated power (i.e. using a service factor higher than 1.0), shortens the life of the machine. All motors that are rated for Class B rise have the inherent capacity to operate above rated power by utilizing the higher temperature capability of Class F insulation (i.e. they will run hotter at the higher power). This higher temperature operation negatively impacts the life of the insulation and other components of the machine. Therefore, machines should only be sized and selected based upon a standard 1.0 service factor rating (see datasheet guide for nameplate rating information).

4.2.2 Load Requirements

- **4.2.2.1** Unless otherwise specified, the load torque characteristics and total load inertia referred to the motor shaft shall be in accordance with NEMA MG 1, Part 20. When the loads have characteristics other than those listed in NEMA MG 1, Part 20, the purchaser shall fully specify the load characteristics of the driven equipment. These characteristics include the following.
 - a) The speed-torque characteristics of the load under the most stringent starting conditions.
 - b) The speed-torque characteristics of the load during reaccelerating conditions when reacceleration following bus transfer is specified.

NOTE Electrical machines are capable of developing transient current and torque considerably in excess of rated values when exposed to an out of phase bus transfer or momentary voltage interruption and reclosing. The magnitude of this transient torque may be many times rated torque and is a function of the machine design, operating conditions, switching time, rotating machine inertias, torsional spring constants, the number of motors on the bus, etc. See NEMA MG 1, Part 20 for bus transfer or reclosing information

- c) The total load inertia J (Wk^2) referred to the motor shaft speed, where W is the rotating mass and k is the radius of gyration. This total load inertia shall include all loads connected to the motor shaft (e.g. couplings, gearbox and driven equipment).

NOTE To obtain Wk^2 (lb-ft²), multiply J (kg-m²) by 23.73.

$$J = 0.25GD^2$$

$$D = 2R$$

where

J is the polar mass moment of inertia (kg-m²);

G is the rotating mass (kg);

D is the diameter (m); and

R is the radius of inertia (m).

4.2.3 Starting and Running Conditions

- **4.2.3.1** Unless otherwise specified, the motor shall be designed to start and accelerate the connected load to running speed with 80 % of rated voltage at the motor terminals.
- **4.2.3.2** When specified, the requirements for starting capability, speed-torque, and acceleration time shall be determined with the following information (as applicable) furnished by the purchaser:

a) starting method (e.g. captive transformer, reactor, autotransformer, solid state);

b) the minimum available voltage at motor terminals under specified locked rotor current; or

c) the minimum available system short circuit MVA and X/R ratio, the base voltage, and the minimum motor terminal voltage during starting in percent of rated motor voltage.

4.2.3.3 When the motor speed-torque curve at the conditions specified in 4.2.3.2 a) or 4.2.3.2 b) is plotted over the load speed-torque curve, the motor developed torque shall exceed the load torque by a minimum of 10 % (motor rated torque as base) at all locations throughout the speed range up to the motor breakdown torque point.

NOTE Some ASDs may limit motor accelerating torque at reduced speeds due to insufficient flux (V/Hz) levels or limitations in the drive's momentary current capacity. If a special motor design is required to compensate for such ASDs, the purchaser should so advise the motor supplier and appropriate design changes should be agreed upon.

4.2.3.4 For certain machine designs, high inertia loads or power system limitations, the requirements provided in 4.2.3.1, 4.2.4.1, and 4.2.4.4 may not be practical. In these cases, the motor starting characteristics shall be jointly developed between the purchaser and vendor.

- **4.2.3.5** When reacceleration is specified, the length of maximum voltage interruptions or fault related voltage collapse and the expected voltage at the motor terminals during reacceleration shall be furnished by the purchaser.

- **4.2.3.6** Unless otherwise specified for reciprocating loads, the current pulsations under the actual operating conditions shall not exceed 40 % of full load current as required by API 618.

NOTE The inertias and torque versus crank angle data at rated and worst-case operating conditions are needed to determine the current pulsation. The results of this analysis and any subsequent design changes may impact the drive train torsional analysis, which is commonly performed by a party other than the motor vendor (see 4.4.5.1.6).

4.2.4 Starting Capabilities

- **4.2.4.1** Unless otherwise specified, the machine shall be designed for a minimum of 5,000 full voltage starts. Fixed-speed motors shall also have the starting capabilities in Table 4.

Table 4—Starting Capabilities

Number of Consecutive Successful Starts Under Starting Conditions Specified in 4.2.3 and with the Motor Coasting to Rest Between Starts	
Motor initially at ambient temperature (cold start)	3
Motor at a temperature above ambient but not exceeding its rated operating temperature (hot start)	2

NOTE 1 Typical petroleum process plant operations are such that a motor will have a period of initial use of about two months for pump and compressor run-in and initial plant operations. During this time, the maximum starting capability may be used. A need for maximum capability may also occur during subsequent start-ups. Between these start-up periods, there are usually longer periods of continuous running.

NOTE 2 The starting capabilities for large motors are normally a result of an individual design for the specific load characteristics of the driven equipment and the electrical power system for the most stringent conditions. Therefore, it may be necessary to reduce the number of starts by one or add waiting time between starts for large, high inertia drives like gear-type turbo compressors. For pumps and other low inertia applications, the number of starts may be increased to allow maximum starting flexibility for the operation.

4.2.4.2 The motor vendor shall provide motor thermal capacity data necessary for the purchaser to determine the waiting time before allowing a restart and to develop settings for the thermal time constant in the motor protective relay. As a minimum, this data shall include the following:

- thermal limit curves (per IEEE 620) with the motor initially at ambient temperature;
 - thermal limit curves (per IEEE 620) with the motor initially at rated temperature;
 - acceleration time curves with the defined shaft load at rated voltage and at the starting voltage conditions specified in 4.2.3;
 - required wait time prior to another start after exhausting the defined number of starts, with the motor running at rated load; and
 - required wait time prior to another start after exhausting the defined number of starts, with the motor stopped.
- **4.2.4.3** The minimum safe hot stall (locked rotor) time shall be the greater of either five seconds more than or 150 % of the time required to accelerate the specified driven load with the starting voltage specified in 4.2.3.1 or 4.2.3.2. If these conditions cannot be met, the vendor shall notify the purchaser so that a workable solution can be jointly developed. When specified, the method of safe stall time calculation and the limits shall be described with the proposal.

4.2.4.4 With rated voltage and frequency applied, machines shall comply with the characteristics listed below. This does not apply to units started by or operated on ASDs. Where these limits shall have an adverse effect on other characteristics (particularly efficiency), the vendor shall state the effect and recommend preferred values.

- a) The maximum locked-rotor current shall be between 450 % and 650 % of the rated full-load current unless otherwise specified.

NOTE Induction motors with locked rotor currents less than 450 % may compromise important performance characteristics (e.g. efficiency, breakdown torque, and rotor thermal stability). The purchaser should use caution when specifying a motor with a locked rotor current less than 450 % and verify the vendor has satisfactory experience.

- b) The minimum locked-rotor, pull-up, and breakdown torques shall not be less than the values listed in NEMA MG 1, Part 20 or IEC 60034-1.

- ◆◆ **4.2.4.5** When the motor supply is from an ASD only (no bypass operation), the characteristics may be different from those specified in 4.2.4.4 and shall be determined to optimize performance on the ASD.

NOTE 1 Use of motors on ASDs may lead to higher rotor and stator temperatures due to harmonic currents, which should be assessed for application in Division 2 and Zone 2 applications. In addition, the “displaced neutral” effect of some drive topologies may lead to the shaft being at an elevated voltage to ground. The possibility of electric discharge across the bearings and consequent ignition of flammable mixture should be considered.

NOTE 2 Torsional oscillations may be caused by the drive harmonics, and a torsional study should be performed.

NOTE 3 Damage to the motor and drive may be caused by improper application of system capacitance. Also, possible resonances may be caused by application of surge capacitors, which are not recommended for adjustable speed applications.

4.3 Winding and Insulation Systems

4.3.1 Minimum Insulation Requirements

4.3.1.1 Insulation Class and Preparation

Winding and insulation systems shall have the following properties.

- a) Stator windings including lead and coil connections shall have an epoxy base, vacuum pressure impregnated (VPI) nonhygroscopic insulation system. When bus bars are used as interface connections, they shall have the same insulation properties as the wire lead and coil connections. As a minimum, the insulation system shall meet the criteria for Class F insulation listed in NEMA MG 1 or IEC 60034-1 as applicable. Strand insulation shall adhere tightly to the strand in order to minimize voids. Turn and ground wall insulation shall be resistant to the effects of partial discharge. The integrity of strand and turn insulation shall be maintained during forming, winding and VPI treatment. For windings operating at voltages of 6000 volts (line-to-line) or greater, the use of partial discharge suppressant materials is required.
- b) The allowable temperature rise above ambient, normally 40 °C (104 °F) unless otherwise specified, shall not exceed that listed for Class B insulation. The Class B temperature rise requirements shall be satisfied by both resistance and RTD when corrected to the design maximum ambient temperature, normally 40 °C (104 °F). For ambient temperatures above 40 °C (104 °F), the allowable temperature rise shall be reduced accordingly, so as not to exceed the total temperature limits (ambient, rise, and hot spot) for Class B insulation.
- ◆◆ **4.3.1.2** Motors for use on ASDs shall have temperature rises in accordance with 4.3.1.1 throughout the defined speed range when applied to the specified ASD and load. If the ASD output current harmonics are significant, purchaser shall provide the motor supplier with complete harmonic data.

NOTE The motor should be designed for the complete range of speed and torque requirements of the application to avoid excessive winding temperature due to insufficient cooling or excessive torque levels. Purchaser should supply motor vendor with these parameters.

- ◆● **4.3.1.2.1** If the ASD has an output waveform with repetitive high amplitude voltage spikes, the purchaser shall advise motor vendor so that the insulation system can be modified accordingly to avoid premature insulation breakdown.
- ◆● **4.3.1.2.2** Motors used on ASD designs which impose common mode voltage shall be provided with motor ground insulation capable of continuous operation with the resulting level of voltage at the motor terminals. The purchaser shall supply the motor vendor with the value of common mode voltage that will be imposed.

4.3.2 The insulation system shall be capable of withstanding the surge test specified in 6.3.4.2.

4.3.3 All stator insulation systems shall be service proven and shall have been subjected to thermal evaluation in accordance with IEEE 1776 or IEC 60034-18.

4.3.4 The total insulation system shall be impervious to the operating conditions specified in 4.1.2. All insulation, including lead insulation, shall be impervious to attack by the lubricating oil specified.

4.3.5 The stator windings including the lead connections shall have a sealed insulation system that is capable of withstanding a sealed winding conformance test in accordance with NEMA MG 1, Part 20.

4.3.6 Motors 750 kW (1000 hp) and larger or where differential protection is to be applied shall have both ends of each stator-phase winding brought out to a single terminal box.

4.3.7 The entire stator winding insulation system including winding connections and terminal leads shall be tightly secured to prevent insulation cracking and fatigue as a result of motion and vibrations during starting, operation, and electrical transient conditions that produce electromechanical forces in the stator windings. The windings shall withstand electromagnetic and mechanical forces under normal operating conditions, the starting requirements specified in 4.2.4, and the forces associated with phase-to-phase and three phase short circuits with 110 % of rated voltage.

4.3.8 Conductors from the stator windings to the main terminals shall be insulated and be separated from ground planes so that the effects of partial discharge are minimized. The machine leads shall have Class F (minimum) insulation and be sized for a minimum of 125 % of rated current at Class B temperature rise. Conductors shall be braced and protected from chafing against the motor frame and terminal box. If electrical grade fiberglass is used for this purpose, it shall be vacuum pressure impregnated so as to be made nonhygroscopic.

- **4.3.9** When specified, machines rated 6 kV and above shall use bus bar insulated for the rated voltage from the stator winding to the main terminal box connection.

4.3.10 When magnetic slot wedges are used, the vendor shall advise the purchaser in the proposal. This wedge system shall comply with the following:

- a) the magnetic slot wedge installation shall be a system that includes a rigid slot wedge and a global VPI system;
- b) the magnetic slot wedge shall be of the amorphous or composite design;
- c) magnetic wedges shall be limited to machines of 630 mm shaft height or less; and
- d) the manufacturer shall demonstrate a minimum of 10 years proven experience with the magnetic slot wedge machine designs offered.

4.3.11 All winding connections except those completed in the main terminal box shall be brazed using a silver-based brazing material. Soft soldered connections are not permitted. Any exposed connections shall use a phosphorus free silver brazing material that is not subject to attack by hydrogen sulfide.

4.4 Mechanical Design

4.4.1 Enclosures

4.4.1.1 General Requirements

The following general requirements apply to enclosures.

- a) Enclosure parts shall be made of cast or nodular iron, cast steel, or steel plate. Purchaser-approved fiber-reinforced materials may be used for parts (e.g. covers or nonsupportive enclosure sections). All enclosure parts shall have a minimum rigidity equivalent to that of sheet steel with a nominal thickness of 3.0 mm ($1/8$ in.). Machines utilizing the foundation as part of the enclosure (e.g. large diameter machines) shall be identified in the proposal.
- b) Air deflectors shall be made of corrosion-resistant material or shall have corrosion-resistant plating or treatment.
- c) All the enclosure's bolts, studs, and other fastening devices up through M12 ($1/2$ in.) size shall be ISO 3506 series or AISI 300 series stainless steel. When the motor is specified to be installed offshore on a production platform or similar marine installation, AISI 316 material shall be supplied in lieu of the 300 series fasteners. Internal fastening devices shall use locknuts, lock washers, locking plates, or tie wires.
- d) The risks due to possible circulating currents in the enclosure shall be considered for machines using multi-section enclosures installed in classified locations. Overheating or sparking due to possible circulating currents shall be avoided (where necessary) by bonding together the conducting components in a secure electrical and mechanical manner, or by the provision of adequate bonding straps between the motor housing components. The means shall be functional over the design life of the machine.
- e) When enclosure pre-start purging is specified, machines shall be provided with provisions for effective purging as described on the datasheet. The vendor shall state the maximum allowed purge pressure on the datasheet.

NOTE See IEEE 303, IEEE 1349, and IEC 60079 for additional information.

- f) Unless otherwise specified, machines rated 6 kV and above shall have TEFC, TEAAC, or TEWAC enclosures (IP44 or higher with IC411, IC511/16, IC611/16/66, or IC81W/6W type cooling; see Table 5).
- **4.4.1.2 Motor Enclosures and Corresponding NEMA Specifications**

4.4.1.2.1 Table 5 lists representative types of machine enclosures and the NEMA or IEC specifications to which they conform. The purchaser shall specify the type of enclosure on the datasheets. Designs in which the stator laminations form a part of the external enclosure are not acceptable. Enclosures shall also conform to the requirements of 4.4.1.2.2, 4.4.1.2.3, and 4.4.1.2.4.

NOTE The designation used for degree of protection consists of the letters IP followed by two characteristic numerals signifying conformity with the conditions indicated in the tables. When it is required to indicate a degree of protection by only one characteristic numeral, the omitted numeral is replaced by the letter X (e.g. IPX5 or IP2X).

4.4.1.2.2 Dripproof guarded (DPG), weather protected type I (WP-I), and weather protected type II (WP-II) enclosures (or the IEC equivalents) shall meet the following criteria.

- a) Ventilation openings shall be limited to a maximum size of 6.0 mm ($1/4$ in.) by design or by the use of metal screens in accordance with 4.4.10.5 and 5.5.1.
- b) Weather protected enclosures shall be constructed so that any accumulation of water shall drain from the motor.

Table 5—Machine Enclosures and Corresponding NEMA or IEC Specifications

Common Enclosure Type	Designation NEMA MG 1	Specifications NEMA MG 1	Minimum Degree of Protection ^a IP Code	Method of Cooling ^b
Drip-proof guarded	DPG	1.25.5	IP22	IC01
Weather protected				
Type I	WP-I	1.25.8.1	IP23	IC01
Type II	WP-II	1.25.8.2	IPW24	IC01
Totally enclosed				
Fan cooled	TEFC	1.26.2	IP44/54	IC411
Pipe ventilated	TEPV	1.26.4	IP44	IC31/37
Water to air cooled	TEWAC	1.26.7	IP44/54	IC81W ^c IC86W ^d
Air to air cooled	TEAAC	1.26.8	IP44/54	IC511 ^c IC516 ^d IC611 ^c IC616 ^d IC666 ^d
a) IEC 60034, Part 5 to NEMA MG 1, Section 5. b) IEC 60034, Part 6 to NEMA MG 1, Section 6. c) Shaft driven secondary fan. d) Auxiliary secondary fan.				

- c) When abrasive dust conditions have been specified, the exposed winding insulation shall be protected from the abrasive action of airborne particles. This protection shall be in addition to the VPI resin and the vendor's standard coating.

NOTE Drip-proof or weather protected type I (WP-I) enclosures are not recommended for the operating conditions specified in 4.1.2 (e.g. outdoor operation without a protective shelter). Purchasers applying this degree of protection should expect reduced reliability (see 4.1.1 and Table 5).

4.4.1.2.3 Totally enclosed machines (TEFC, TEPV, TEWAC, and TEAAC) shall meet the following criteria.

- Fan covers shall be made of metal having a minimum rigidity equivalent to that of steel plate with a nominal thickness of 3.0 mm ($1/8$ in.). Purchaser-approved fiber-reinforced materials may be used. The air intake opening shall be guarded by a grill or a metal screen fastened on the outside of the fan cover. Requirements for grills or metal screens are covered in 4.4.10.5.
- Sheet metal covers or wrappers used to form air passages over the enclosure shall have a minimum rigidity equivalent to that of steel plate with a nominal thickness of 3.0 mm ($1/8$ in.).
- Totally enclosed machines shall be equipped with a plugged, threaded drain connection located at the lowest point of the frame. This connection shall be shown on the outline drawing.
- Requirements for heat exchanger tubes are outlined in 4.4.10.8.
- Where an enclosure make-up air intake is required, the intake shall be provided with filters suitable for the site data given on the datasheets.

4.4.1.2.4 Totally enclosed water to air cooled (TEWAC) machines shall be designed for the following conditions.

- a) Cooling water systems shall be designed for the following conditions unless the vendor notifies the purchaser that conflict will arise affecting performance, size, cost, or integrity of the cooler. The purchaser shall approve the final selection. When specified, coolers shall be designed to operate with a water and glycol solution.

Velocity over heat exchange surfaces	1.5 m/s to 2.5 m/s	5 ft/s to 8 ft/s
Maximum allowable working pressure (MAWP) (gauge)	≥ 7.0 bar	≥ 100 psig
Test pressure (≥ 1.5 MAWP)	≥ 10.5 bar	≥ 150 psig
Maximum pressure drop	1 bar	15 psig
Maximum inlet temperature	32 °C	90 °F
Maximum outlet temperature	49 °C	120 °F
Maximum temperature rise	17 K	30 °F
Minimum temperature rise	11 K	20 °F
Water side fouling factor	0.35 m ² K/kW	0.002 hr-ft ² -°F/Btu
Corrosion allowance for carbon steel	3 mm	1/8 in.

NOTE The criterion for velocity over heat exchange surfaces is intended to minimize water-side fouling; the criterion for minimum temperature rise is intended to minimize the use of cooling water.

- b) When specified, machines shall be provided with multiple coolers to allow one cooler to be removed from service without reducing the continuous operating capability.
- c) The location of the cooler, orientation of the water box inlet and outlet, materials and construction of the cooler, and means of leak detection shall be specified on the datasheets. Leak detectors shall be provided to sense tube leakage. For double tube coolers, these detectors shall sense inner tube leakage and when specified, outer tube leakage.
- d) Cooler designs shall be of the water-tube type (water in the tubes). U-tube construction is not permitted. The construction of the water box and header shall be such that leaking tubes can be plugged and all tubes are accessible for cleaning. When specified, coolers shall be of double tube construction.
- e) The machine's interior shall be baffled or otherwise constructed to prevent cooler-tube leakage or condensation from striking the windings and so that leakage will collect and drain.
- f) In pressurized enclosures, a liquid seal shall be provided for drain holes.
- g) Unless otherwise specified, a flow-sensing device with a local indicator and remote monitoring capability shall be provided for mounting in the water supply piping to each cooler.
- h) Unless otherwise specified, temperature sensors shall be provided to sense air temperature into and out of the coolers.
- i) Provision shall be made for complete venting and draining of the system or systems.

4.4.2 Frame and Mounting Plates

4.4.2.1 The frame shall be of cast or nodular iron, cast steel, or welded steel plate construction with removable end brackets or end plates to permit removal of the rotor and facilitate repairs. The frame of the completely assembled

machine on its permanent foundation with the rotor installed and rotating shall be free from structural resonance between 40 % and 60 % of operating speed and the frequency ranges defined by Equation (1) and Equation (2):

$$N = nN_{\text{op}} \pm 0.15N_{\text{op}} \quad (1)$$

$$N = nN_{\text{el}} \pm 0.15N_{\text{el}} \quad (2)$$

where

N is the frequency range (in Hz);

N_{op} is the operating speed frequency (in Hz);

N_{el} is the electrical power frequency (in Hz); and

n is 1 and 2.

NOTE Transfer of vibration from surrounding equipment is avoided by proper layout of the foundation, which is the responsibility of the purchaser. After the machine is erected, the natural frequency of the foundation and machine system should differ by at least $\pm 15\%$ from one and two times the running-speed frequency, by at least $\pm 15\%$ from one and two times the electric power frequency, and not occur between 40 % and 60 % of running speed [e.g. for 2×60 Hz electric operating frequency, $N = (2 \times 60) \pm (0.15 \times 60) = 111$ Hz or 129 Hz]. See API 686.

- ◆ **4.4.2.1.1** For machines operating at adjustable speed with an operating speed range where it may not be possible to avoid all machine frame or enclosure resonances, the purchaser and machine supplier shall agree on a strategy to avoid damage to the machine or drive train. The owner may waive this requirement if the supplier can demonstrate that the vibration requirements of 6.3.3.13 are satisfied. Other strategies may include limiting speed range, blocking problematic frequency range(s), or adding stiffeners or damping means to the base and mounting arrangement.

- **4.4.2.2** The stress values used in the design of the frame shall not exceed the values given for that material in Section II of the ANSI/ASME BPVC at the maximum operating temperature. For cast materials, the factors specified in Section VIII, Division I of the ANSI/ASME BPVC shall be applied. The conditions evaluated shall include short circuits, out-of-phase reclosing per ANSI/NEMA C50.41, thrusts, handling, and specified seismic loading.

4.4.2.3 The frame (including transition base if supplied with the machine and the bearing supports) shall be designed to have sufficient strength and rigidity to limit changes of alignment caused by the worst combination of torque reaction, conduit and piping stress, magnetic imbalance, and thermal distortion to 0.05 mm (0.002 in.) at the coupling flange. (This is not to be confused with the normal repeatable thermal growth between ambient and operating temperatures.)

4.4.2.4 Supports and the design of jackscrews and their attachments shall be rigid enough to permit the machine to be moved by the use of its lateral and axial jackscrews.

4.4.2.5 Horizontal machines shall be equipped with vertical jackscrews appropriately located to facilitate alignment. If size and weight prohibit the use of jackscrews, other provisions shall be made for vertical jacking.

- **4.4.2.6** When specified, the machine shall be furnished with soleplates or a baseplate.

4.4.2.7 The term mounting plate refers to both baseplates and soleplates.

4.4.2.7.1 Mounting plates shall be equipped with vertical jackscrews to permit leveling of the mounting plates.

- a) For baseplates, a minimum 16 mm ($5/8$ in.) diameter jackscrew hole shall be located a minimum of 100 mm (4 in.) from each anchor bolt hole along the same centerline as the anchor bolt holes.

- b) For soleplates, a minimum of four jackscrew holes shall be supplied. These holes shall be designed for a minimum of 16 mm ($\frac{5}{8}$ in.) jackscrew and shall be located in each corner of the soleplate. In addition, for soleplates longer than 0.9 m (3 ft) two additional jackscrew holes shall be installed in the soleplate at midspan with their centerlines similar to the corner jackscrew holes. Sole plates 1.8 m (6 ft) and longer shall have a maximum span of 0.9 m (3 ft) between jackscrew holes on each side of the soleplate. All jackscrew holes shall be located a minimum of 100 mm (4 in.) from the anchor bolt holes.
- c) Jackscrew holes shall be drilled and tapped a length equal to the diameter of the jackscrew. The soleplate shall be counterbored at the jackscrew hole locations to a diameter large enough to allow the use of a socket drive over the head of the jackscrew. The depth of the counterbore shall be equal to the thickness of the soleplate minus the diameter of the jackscrew.

4.4.2.7.2 To assist in machine positioning, the mounting plates shall be furnished with horizontal jackscrews (for machine movement in the horizontal plane) the same size as or larger than the vertical jackscrews. The lugs holding these jackscrews shall be attached to the mounting plates so that they do not interfere with the installation or removal of the drive element and the installation or removal of shims used for alignment.

4.4.2.7.3 To minimize grout stress cracking, mounting plates that are to be grouted shall have 50 mm (2 in.) radius on the outside corners (in the plan view). The bottom edges of the soleplate shall have a 25 mm (1 in.) 45° chamfer.

4.4.2.7.4 Mounting plate anchor bolts shall not be used to fasten the machine to the mounting plates.

4.4.2.7.5 Mounting plates shall be designed to extend at least 25 mm (1 in.) beyond the outer sides of the machine feet.

4.4.2.7.6 The vendor of the mounting plates shall furnish AISI 300 series stainless steel shim packs at least 3.0 mm ($\frac{1}{8}$ in.) thick between the machine feet and the mounting plates. All shim packs shall straddle the hold-down bolts.

4.4.2.7.7 Anchor bolts shall be furnished by the purchaser.

4.4.2.7.8 Fasteners for attaching the components to the mounting plates and jackscrews for leveling the soleplates shall be supplied by the vendor.

4.4.2.7.9 The horizontal and vertical jackscrews shall be M16 ISO 68 ($\frac{5}{8}$ in. minimum diameter with UNC threads) and have a round nosed end.

4.4.2.8 Frame mounting surfaces shall meet the following criteria.

- a) They shall be machined to a finish of 6.3 μ m (250 μ in.) arithmetic average roughness (R_a) or better.
- b) To prevent a soft foot, they shall be in the same horizontal plane within 125 μ m (0.005 in.).
- c) Each mounting surface shall be machined within a flatness of 40 μ m per linear m (0.0005 in. per linear ft) of mounting surface.
- d) Different mounting planes shall be parallel to each other within 0.17 mm per m (0.002 in. per ft).
- e) In a horizontal machine, the mounting planes shall be parallel to a horizontal plane through the bearing centerline within 0.17 mm per m (0.002 in. per ft).
- f) The upper machined or spot faced surface shall be parallel to the mounting surface.
- g) Hold-down bolt holes shall be drilled perpendicular to the mounting surface or surfaces and be drilled 13 mm (0.5 in.) larger in diameter than the hold-down bolt. Due to the extra large clearance hole, properly designed load

bearing washers shall be provided. The mounting faces shall be parallel to the feet mounting surfaces and large enough so that the load bearing washers can still contact the mounting faces when the machine is aligned in its extreme position where a bolt is touching one side of its clearance hole.

4.4.2.9 The mounting surface on a vertical motor shall be machined perpendicular to the motor's centerline and this surface shall not deviate from that perpendicular plane by more than 0.17 mm per m (0.002 in. per ft).

4.4.2.10 The machined finish of the mounting surface shall not exceed 6.35 μm (250 $\mu\text{in.}$) arithmetic average roughness (R_a). Hold-down or foundation bolt holes shall be drilled perpendicular to the mounting surface or surfaces, and when the surface is a cast or other unmachined uneven surface, it shall be spot faced to a diameter three times that of the hole diameter.

4.4.2.11 The frame support or supports shall be provided with two pilot holes for dowels. The holes shall be as near the vertical as practical and shall be located to provide adequate space for field drilling and reaming (if required), and placement of dowels. Only the supports or mounting feet on the drive end of horizontal machines shall be doweled. Vertical machines shall have a rabbeted fit to the base and two dowels.

4.4.2.12 Alignment dowels or rabbeted fits shall be provided to facilitate disassembly and reassembly of end bells or plates, bearing housing mounting plates, and bearing housings. When jackscrews are used as a means of parting contacting faces, one of the faces shall be counterbored or recessed to prevent a leaking joint or an improper fit caused by marring of the face.

4.4.2.13 When the vendor provides tapered dowel pins, the top end of the dowel shall have an undercut shank threaded to the nominal diameter nearest the dowel's outside diameter. The first two threads shall be machined off, and the shank shall be beveled to prevent damage when the pin is driven. A hex nut shall be provided with each pin.

- **4.4.2.14** Lifting lugs, through holes or eyebolts shall be provided for lifting major components and the assembled machine. Any special mechanisms for lifting major components and the assembled machine shall be supplied in the quantities shown on the datasheets.

4.4.2.15 All fabricated-welded structural steel shall be postweld stress relieved. This does not apply to sheet metal components. If postweld stress relieving is not possible, the vendor shall advise methods to keep the frame free of unacceptable internal stresses.

4.4.3 Frame Connections

- **4.4.3.1** Unless otherwise specified, inlet and outlet connections for field piping including those for air, lubrication, cooling medium, instrumentation, conduit, and drains shall have the vendor's standard orientation and size, except ISO-6708 sizes of DN 32, DN 65, DN 90, DN 125, DN 175, and DN 225 (1 $\frac{1}{4}$ in., 2 $\frac{1}{2}$ in., 3 $\frac{1}{2}$ in., 5 in., 7 in., and 9 in.) shall not be used.

4.4.3.2 Tapped openings not connected to piping or conduit shall be plugged with solid round head steel plugs furnished in accordance with ANSI B16.11 or ISO 7005-1. Plugs that may later require removal shall be of a compatible corrosion-resistant material. Threads shall be lubricated. Tape shall not be applied to threads of plugs inserted into oil passages. Plastic plugs are not permitted.

4.4.3.3 Bolting and threading shall be furnished as specified in 4.4.3.3.1 through 4.4.3.3.3.

4.4.3.3.1 The details of threading shall conform to ASME B1.1 or ISO 68 and ISO 261.

4.4.3.3.2 Hexagonal head bolts or cap screws shall be supplied on all frame connections except oil piping unless the purchaser specifically approves studs.

4.4.3.3.3 Adequate clearance shall be provided at bolting locations to permit the use of socket or box wrenches.

4.4.3.4 Openings for piping connections, except bearing oil inlet lines, shall be at least 20 mm ($\frac{3}{4}$ in.) nominal pipe size. Oil inlet lines shall be not less than 12 mm ($\frac{1}{2}$ in.). All pipe connections shall be flanged. Where flanged openings are impractical, threaded openings in sizes through 40 mm ($\frac{1}{2}$ in.) nominal pipe size shall be fitted in accordance with the requirements below:

- a) a pipe nipple, preferably not more than 150 mm (6 in.) long, shall be screwed into the threaded opening;
- b) pipe nipples shall be a minimum of Schedule 80, ASME B36.10M; and
- c) tapped openings and bosses for pipe threads shall conform to ASME B16.5.

4.4.3.5 Piping flanges shall conform to ASME B16.20, ASME B16.5, ISO 7483, or ISO 9691 as applicable, except as specified in 4.4.3.5.1 and 4.4.3.5.2.

4.4.3.5.1 Cast iron flanges shall be flat faced and shall have a minimum thickness of Class 250 for sizes 200 mm (8 in.) and smaller.

4.4.3.5.2 Flat-faced flanges with full raised-face thickness are acceptable on frames other than cast iron.

4.4.3.6 Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.1 or ASME B16.5. Studs and nuts shall be furnished installed.

4.4.3.7 Tapped openings and bosses for pipe threads shall conform to ASME B16.5. Pipe threads shall be taper threads conforming to ASME B1.20.1.

4.4.3.8 Openings for duct connections shall be flanged and bolted. Connection facings shall be adequate to prevent leakage with proper gaskets and bolts. Gaskets and bolts shall be provided by the vendor.

4.4.3.9 Studded connections shall be furnished with studs installed. Blind stud holes in casings shall be drilled deep enough to allow a preferred tap depth of $1\frac{1}{2}$ times the major diameter of the stud. The first $1\frac{1}{2}$ threads at both ends of each stud shall be removed.

• **4.4.4 External Moments and Forces**

Frames and housings are generally designed to accept small external forces and moments from duct, conduit, and piping connections. If the auxiliary equipment (e.g. ducting, coolers, silencers, and filters) is not supplied by the vendor, it is the purchaser's responsibility to specify on the datasheets the external loads expected to be imposed on the enclosures from this equipment. The vendor shall design the frame to accept the specified loads.

4.4.5 Rotating Element

4.4.5.1 General

- **4.4.5.1.1** The rotating element shall be designed and constructed to withstand the starting duties specified in 4.2.4, with a minimum fatigue life of 5000 full-voltage starts or as specified by the purchaser.

4.4.5.1.2 Shafts shall comply with the following:

- a) suitable fillets shall be provided at all changes in diameter and in keyways; stress concentration factor calculations shall be performed to ensure that the shaft stresses have a fatigue life as required in 4.1.1 and 4.2.4;
- b) welded shaft, bar shaft, and spider constructions are not allowed for two pole machines; and
- c) shaft straightening techniques are not permitted during or after fabrication of the rotor.

4.4.5.1.3 Heat-treated forged steel shafts shall be used for machines having any of the following characteristics:

- a) finished shaft diameter 200 mm (8 in.) and larger;
- b) two pole machine;
- c) operation above the first lateral critical speed;
- d) driving a reciprocating load; or
- e) using a tapered hydraulic fit coupling.

Hot-rolled shafts may be used for all other machines if the vendor can demonstrate a minimum of two years successful operating experience with the design in that application.

- **4.4.5.1.4** When specified, the shaft and spider shall be machined from a one-piece heat-treated forging.

4.4.5.1.5 Heat-treated forged steel shafts shall be AISI 4000 series and comply with ASTM A668 or equivalent in EN 10250. Any inclusions in the forging shall be limited to a value that shall not have any adverse impact on the finished shaft.

4.4.5.1.6 For motors driving reciprocating loads and generators driven by a reciprocating type prime mover, a complete torsional analysis shall be performed in accordance with 4.4.6.2.2 by the party specified by the purchaser. This analysis shall include all operating conditions including transient starting, no load, and full load. The stress concentration shall not exceed the values specified in ANSI/ASME B106.1M and shall have a safety factor of at least two for all continuous cyclic load conditions and shall have a fatigue life as specified in 4.2.4.

4.4.5.1.7 When vibration and axial position probes are furnished or when provisions for probes are required as described in 5.8, the rotor shaft sensing areas to be observed by the radial probes shall be concentric with the bearing journals. All sensing areas (both radial vibration and axial position) shall be free from stencil and scribe marks or any other surface discontinuity (e.g. an oil hole or a keyway) for a minimum of one probe-tip diameter plus one half of the total end float on each side of the probe. These areas shall not be metallized, sleeved, or plated. The final surface finish shall be a maximum of 0.8 μm (32 $\mu\text{in.}$) R_a , preferably obtained by honing or burnishing. These areas shall be properly demagnetized to the levels specified in API 670 or otherwise treated so that the combined total electrical and mechanical runout does not exceed the following when measured in accordance with 6.3.3.1:

- a) for areas to be observed by radial vibration probes, 25 % of the allowed unfiltered peak-to-peak vibration amplitude or 6.4 μm (0.25 mil), whichever is greater; and
- b) for areas to be observed by axial position probes, 12.7 μm (0.5 mil).

- **4.4.5.1.8** When specified, shaft forgings shall be ultrasonically inspected in accordance with 6.2.2.3.1.
- **4.4.5.1.9** The shaft extension type shall be as specified on the datasheets. Tapered shaft extensions shall conform to the requirements of API 671. Cylindrical shaft extensions shall conform to the requirements of AGMA 9002. Surface finish of the shaft for a hydraulic mounting or removal design coupling hub shall be 0.8 μm (32 $\mu\text{in.}$) R_a or better at the hub mounting area. When a tapered shaft extension is supplied, the fit shall be verified with a ring gage supplied by the purchaser of the coupling. When an integral flange is supplied, the machine purchaser shall provide flange geometry and the drill fixture (or template) if required.

4.4.5.2 Assembly

4.4.5.2.1 Rotor laminations shall have no burrs larger than 0.076 mm (0.003 in.). Laminations shall be distributed to minimize uneven buildup and evenly distribute magnetic properties in grain orientation.

The method of assembly shall prevent scoring of the shaft surface, assure positive positioning, and minimize bowing. All load torque and starting torque conditions shall be transmitted via rotor core and shaft interference fit.

4.4.5.2.2 Rotor cages shall be of fabricated-bar construction with copper or copper alloy bars and end rings. If approved by the purchaser, cast or fabricated aluminum cage designs may be used if the vendor can demonstrate successful experience and can meet the starting duty requirements specified in 4.2.3 and 4.2.4.

NOTE Industry experience has demonstrated that aluminum cage designs through 1000 hp are generally acceptable.

4.4.5.2.3 End rings without circumferential joints are required for motors intended to operate at synchronous speeds greater than or equal to 1000 revolutions per minute.

4.4.5.2.4 To ensure good heat transfer to the rotor core and to limit vibration and fatigue of bars, all bars shall be maintained tightly in their slots. The rotor cage shall be maintained centered (e.g. swedged, center locked or pinned) to prevent axial movement.

4.4.5.2.5 The method by which the bars are attached to the end ring shall be selected to minimize localized heating and the nonuniform stresses that result. The bars shall be radially supported as necessary in the current-carrying end ring to prevent the braze or weld from being overstressed and to maximize the joint contact area. The metal joining material shall not be subject to attack by hydrogen sulfide (e.g. it shall be free from phosphorus). Inert gas welding, induction brazing, and multi-torch full-circle gas brazing are the acceptable methods. Outward bending of the ends of the rotor bars and articulation of the end ring shall be limited by design, material selection, or shrunk-on or fitted nonmagnetic metallic retaining rings.

4.4.5.2.6 The material and processes used to fabricate copper and copper alloy bars and end rings shall be selected to minimize hydrogen embrittlement.

- **4.4.5.2.7** Rotors shall be designed to withstand overspeeds without permanent mechanical deformation (see 4.1.5). Overspeed requirements more stringent than those of NEMA MG 1 or IEC 60034-1 shall be specified by the purchaser where required.

4.4.5.2.8 Two, four, or six pole machines shall not have fans bolted to the end rings. Separable fans shall be permanently indexed angularly and axially to allow field removal and reassembly of the fans on the rotor without increasing the machine vibration. Slip-fitted fans secured to the shaft by means of setscrews only are not acceptable.

4.4.5.2.9 Fans shall be capable of being balanced in accordance with 4.4.6.3. Welding is not an acceptable means of balancing a fan. Removal and reassembly of the fans on the rotor shall not change the rotor balance enough to exceed the allowable residual unbalance limits.

4.4.5.2.10 The design of the stressed parts of fans shall include fillets and proper evaluation of stress concentration factors (SCF) for the geometry to fulfill the combined operational requirements defined in 4.2. Areas of concern include the fan, blade-to-disk intersections, keyways, and shaft section changes. For machines having fans with tip speeds in excess of 75 m/s (250 ft/s), all accessible areas of welds on fans shall be subjected to magnetic particle or liquid penetrant inspection (see 6.2.2.4 and 6.2.2.5).

4.4.6 Dynamics

4.4.6.1 Resonances

4.4.6.1.1 Lateral natural frequencies which can lead to resonance amplification of vibration amplitudes shall be removed from the operating speed frequency and other significant exciting frequencies (see 3.23) by at least 15 %.

- ♦ **4.4.6.1.2** Machines intended for continuous operation on ASDs shall meet the requirement of 4.4.6.1.1 over the specified speed range. If it is not practical to avoid lateral natural frequencies by at least 15 % in an ASD application,

it shall be stated in the proposal and a well damped resonance [see 6.3.5.3 e) and Annex F] may be permitted with purchaser approval.

- **4.4.6.1.3** If the machine is to be supported in the field by a structure other than a massive foundation, the purchaser shall specify this on the datasheets, and the machine vendor shall supply the following data (as a minimum) to the purchaser so that a system dynamic analysis can be made and an adequate foundation designed:
 - a) a detailed shaft section model with masses, mass elastic data including mass and rotational inertia (Wk^2), shaft section lengths, and inner and outer diameters;
 - b) for the minimum and maximum design bearing clearances plus minimum and maximum oil operating temperature, an eight-coefficient bearing model with damping and spring constants;
 - c) horizontal and vertical bearing housing stiffness; and
 - d) foundation dynamic stiffness requirements.

NOTE 1 The rigidity of a foundation is a relative quantity. It should be compared with the rigidity of the machine bearing system. The ratio of bearing housing vibration to foundation vibration is a characteristic quantity for the evaluation of foundation flexibility influences. One indication that a foundation is massive is if the vibration amplitudes of the foundation (in any direction) near the machine feet or base frame are less than 30 % of the amplitudes that could be measured at the adjacent bearing housing in any direction.

NOTE 2 A massive foundation is recommended. See 4.4.2.1 for information on the foundation natural frequencies.

4.4.6.2 Dynamic Analysis

- **4.4.6.2.1** When specified, the vendor shall provide a lateral critical speed analysis of the machine to assure acceptable amplitudes of vibration at any speed from zero to maximum operating speed. The vendor shall identify the foundation data required from the purchaser to perform this analysis. When the vendor provides a machine modal analysis model that is utilized in the system and train analysis, the accuracy of that model shall be confirmed during final test. If the first critical speed identified by the vendor model differs from the test results by more than $\pm 5\%$, then the vendor model shall be updated as necessary. (This only applies if the first critical speed is identified by test to be below the specified maximum overspeed.)

4.4.6.2.1.1 The damped unbalance response analysis shall include but shall not be limited to the following considerations.

- a) Foundation stiffness and damping.
- b) Support (base, frame, bearing housing, and bearing tilting pad or shell) stiffness, mass, and damping characteristics, including effects of rotational speed variation. The vendor shall state the assumed support system values and the basis for these values (e.g. tests of identical rotor support systems and assumed values).
- c) Bearing lubricant film stiffness and damping characteristics including changes due to speed, load, preload, oil temperatures, accumulated assembly tolerances, and maximum to minimum clearances.
- d) Starting conditions, operating speed ranges (including agreed-upon test conditions if different from those specified), trip speed, and coastdown conditions. The analysis of the starting and coastdown conditions shall allow for any resonance to fully evolve. If the acceleration and deceleration of the shaft string is taken into consideration to limit the evolution of any resonance, this shall be clearly stated and presented in addition to the above results.
- e) Rotor masses including the stiffness and damping effects (e.g. accumulated fit tolerances).
- f) Mass moment of the coupling half (including mass moment of coupling spacer).

- g) Asymmetrical loading (e.g. eccentric clearances).
- h) For machines equipped with antifriction bearings, the vendor shall state the bearing stiffness and damping values used for the analysis and either the basis for these values or the assumptions made in calculating the values.
- i) The location and orientation of the radial vibration probes which shall be the same in the analysis as in the machine.
- j) Unbalanced magnetic pull.

4.4.6.2.1.2 In the case of a nonmassive foundation, dynamic foundation stiffness shall be mutually agreed by the vendor of the electrical machine and the vendor who has responsibility for the train. In this case, an adequate model of the machine shall be given to the vendor who has the responsibility for the train.

4.4.6.2.1.3 Separate damped unbalanced response analysis shall be conducted for each critical speed within the speed range of zero to the next mode occurring above the maximum operating speed. Unbalance shall analytically be placed at the locations that have been determined by the undamped analysis to affect the particular mode most adversely. The mode shapes predicted by the undamped response analysis shall be compared to the examples shown in Figure 1 and the analytic weights attached accordingly. For the translatory modes as shown in the three left-hand side examples of Figure 1, the unbalance shall be applied at the location of maximum displacement. The magnitude of the unbalance shall be four times the value of U as calculated by Equation (3) or Equation (4). The unbalance shall be based on the total static bearing load in the case of major deflection between the bearings or the overhung mass in the case of major deflection outboard of the bearings. For conical modes as illustrated in the three right-hand side examples of Figure 1, the unbalances shall be added at the location of maximum displacement nearest to each journal bearing. These unbalances shall be 180° out of phase and of magnitude four times the value of U as calculated by Equation (3) or Equation (4), based on the static load on the bearing adjacent to the unbalance placement.

In SI units:

$$U = 6350W/N \text{ g-mm} \quad (3)$$

In USC units:

$$U = 4W/N \text{ oz-in.} \quad (4)$$

where

U is the input unbalance for the rotor dynamic response analysis in g-mm (oz-in.);

N is the operating speed nearest to the critical speed of concern, in revolutions per minute; and

W is the journal static load in kg (lb) or for bending modes where the maximum deflection occurs at the shaft ends, the overhung mass (e.g. the mass of the rotor outboard of the bearing) in kg (lb) (see Figure 1).

NOTE For machines rated at less than or equal to 1800 rpm, it may be necessary to increase the weight of the added unbalance weights to get a sufficient unbalance response.

4.4.6.2.1.4 If an unbalance response analysis has been performed and the foundation data used in the unbalanced response analysis are significantly different from the test floor conditions, additional analyses shall be made for use with the verification test specified in 6.3.5.3. The location of the unbalance shall be determined by the vendor. Any test stand parameters that influence the results of the analysis shall be included.

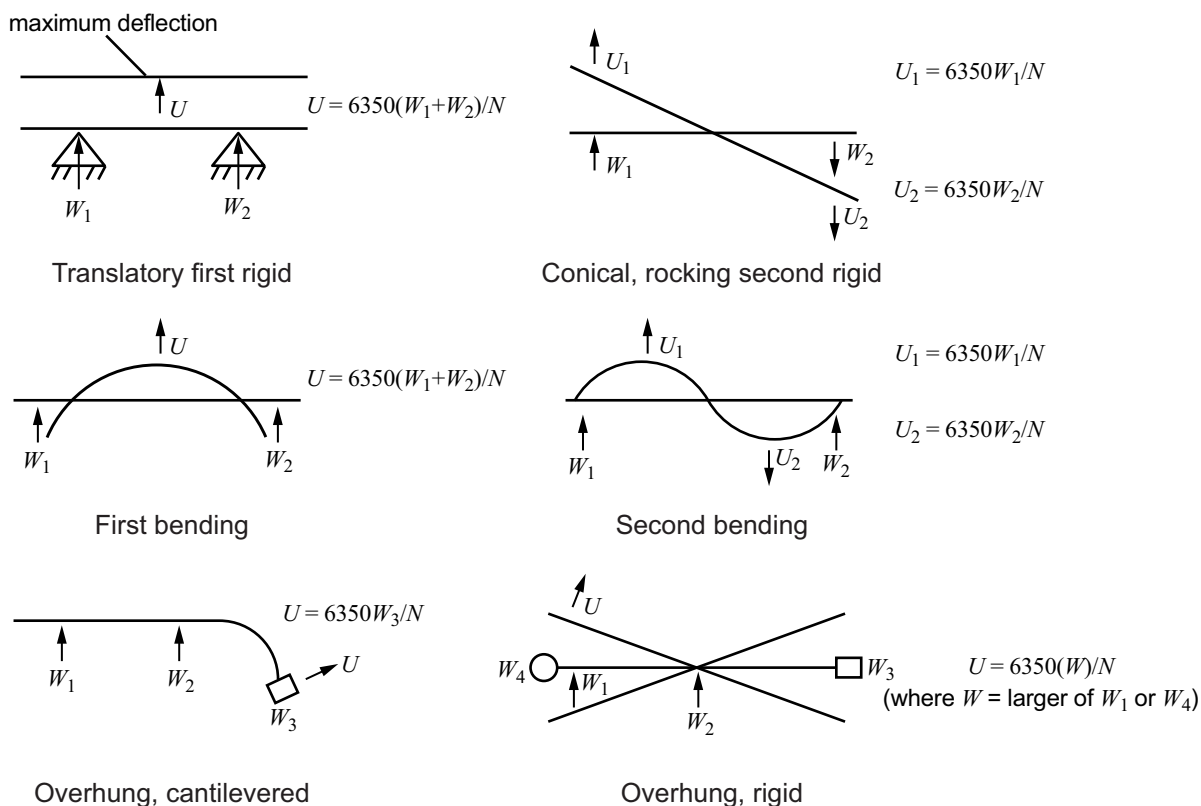


Figure 1—Typical Rotor Mode Shapes

4.4.6.2.1.5 As a minimum, the unbalanced response analysis shall produce the following:

- identification of the frequency of each critical speed in the range from zero to the next mode occurring above the maximum operating speed;
 - frequency, phase, and response amplitude data (Bode plots) at the vibration probe locations through the range of each critical speed resulting from the unbalance specified in 4.4.6.2.1.3;
 - the plot of the deflected rotor shape for each critical speed resulting from the unbalances specified in 4.4.6.2.1.3 showing the major-axis amplitude at each coupling, the centerlines of each bearing, the locations of each radial probe, and at each seal throughout the machine as appropriate; the minimum design diametral running clearance of the seals shall also be indicated; and
 - additional Bode plots that compare absolute shaft motion with shaft motion relative to the bearing housing for machines where the support stiffness is less than 3.5 times the oil film stiffness.
- 4.4.6.2.2** When specified, the vendor(s) with unit responsibility shall perform a steady-state and transient torsional and stress analysis of the complete mechanical train including gears, pumps, compressors, fans, shaft driven auxiliaries, and the effects of the electrical system including ASDs (if applicable). The equipment vendors shall be responsible for providing the data required for the torsional analysis to the purchaser or the party responsible for the analysis as specified to allow for any system modifications that may be necessary to meet the requirements of 4.4.6.2.2.3, 4.4.6.2.2.4, 4.4.6.2.2.5, and 4.4.6.2.2.6.

4.4.6.2.2.1 Excitation of torsional natural frequencies may come from many sources, which may or may not be a function of running speed and should be considered in the analysis. These sources shall include but are not limited to the following:

- a) gear characteristics (e.g. unbalance, pitch line runout, and cumulative pitch error);
- b) cyclic process impulses;
- c) torsional transients (e.g. phase-to-phase, three phase, and if applicable, phase-to-ground faults);
- d) torsional excitation resulting from reciprocating equipment and rotary type positive displacement machines;
- e) control loop resonances from hydraulic governors, electronic governors, or adjustable speed drives;
- f) one and two times line frequency;
- g) running speed or speeds;
- h) harmonic frequencies from an ASD; and
- i) torsional excitation caused during motor starting, including both rated voltage and minimum starting voltage conditions.

4.4.6.2.2.2 The torsional analysis shall include but not be limited to the following:

- a) a complete description of the method used to complete the analysis;
- b) a graphic display of the mass-elastic system;
- c) a tabulation identifying the polar mass moment of inertia and torsional stiffness for each component identified in the mass-elastic system;
- d) a graphic display or expression of any torsional excitation versus speed or time; and
- e) a graphic display of torsional critical speeds and deflections (a mode shape diagram).

4.4.6.2.2.3 The torsional natural frequencies of the complete train shall be at least 10 % above or 10 % below any possible excitation frequency within the specified operating speed range (from minimum to maximum continuous speed).

4.4.6.2.2.4 Torsional natural frequencies at two or more times running speeds shall preferably be avoided, or in systems in which corresponding excitation frequencies occur, shall be shown to have no adverse effect.

- ◆ **4.4.6.2.2.5** For ASDs, the torsional analysis shall also verify that the calculated shaft torque at any resonance point up to the maximum operating speed does not result in shaft torsional stresses that exceed the allowed maximum for the shaft design. Any design changes required to achieve this shall be agreed by the vendor with unit responsibility, purchaser, ASD supplier and motor vendor.

4.4.6.2.2.6 When torsional resonances are calculated to fall within the margin specified in 4.4.6.2.2.3 (and the purchaser and the vendor have agreed that all efforts to remove the critical from within the limiting frequency range have been exhausted), a stress analysis shall be performed to demonstrate that the resonances have no adverse effect on the complete train. The assumptions made in this analysis regarding the magnitude of excitation and the degree of damping shall be clearly stated. The acceptance criteria for this analysis shall be mutually agreed upon by the purchaser and the vendor.

4.4.6.2.2.7 For machines that drive a load where torsional oscillations occur (e.g. a reciprocating compressor), the torsional study shall include an analysis of the rotor bar and end ring structure plus the fan design and any attachments to confirm that the components will have infinite fatigue life. The stress in the rotor bar-ring interface as well as fan stresses shall be analyzed in relation to the fundamental through 6th harmonic of the compressor torque pulsation frequency.

As a minimum the analysis shall consider:

- a) the applied forces on the components and systems under all normal operating conditions;
- b) the resonant frequencies of the systems;
- c) the metallurgy of the materials involved; and
- d) stress concentration factors.

4.4.6.3 Balancing

4.4.6.3.1 All rotors shall be dynamically balanced in two or more planes. Rotors operating at speeds in excess of the first lateral critical bending mode shall be balanced in at least three planes, including a center plane at or near the axial geometric center of the rotor assembly. If a center balance plane is not practical, the vendor shall propose an alternate balancing arrangement that shall satisfy the requirements of 6.3.3.12 for purchaser approval. When a keyway is provided for a coupling hub, the rotor shall be balanced with the keyway fitted with a crowned half-key or its dynamic equivalent. Where rotor mounted fan(s) are utilized on two, four, and six pole machines, the complete rotor assembly shall also be balanced prior to mounting the fan(s) except where the fan contains a main rotor balance plane. Individual fans which do not contain a main rotor balance plane shall be dynamically balanced independently.

4.4.6.3.2 Balance weights and fasteners added to the final assembly shall be readily removable and replaceable and made of AISI 300 series (or ISO 3506) stainless steel or a purchaser-approved corrosion-resistant material. If parent metal is to be removed to achieve balance, it shall be removed only from an area designed for that purpose. The material shall be removed by drilling in a manner that maintains the structural integrity of that component and does not cause harmful or distortive hot spots during operation. Chiseling, grinding, sawing, or torch burning is not permitted. The use of solder or similar deposits for balancing purposes is not acceptable. Balance corrections shall not be made to the fan blades.

4.4.6.3.3 For the final balancing of the rotor in the balancing device, the maximum allowable residual unbalance in the correction plane (per journal) shall be calculated from the following equation:

In SI units:

$$U_B = 6350 W_r / N_{mc} \quad (5)$$

In USC units:

$$U_B = 4 W_r / N_{mc} \quad (6)$$

where

U_B is the residual unbalance in g-mm (oz-in.);

W_r is the journal static loading determined from the mass distribution in the rotor in kilograms (pounds) (typically one-half rotor mass); and

N_{mc} is the maximum continuous speed in revolutions per minute.

4.4.6.3.3.1 Where a rotor is unsymmetrical or the correction planes are unsymmetrically located, the allocation of residual unbalance between the correction planes by reference to journal static loading may not be appropriate. In this case, the proportionate allocation of residual unbalance to the correction planes should be determined by reference to ISO 1940-1. However, the total residual unbalance shall be less than $6350 W/N_{mc}$ ($4W/N_{mc}$), where W is the rotor mass and not the ISO 1940-1 balance grade.

- **4.4.6.3.4** When specified, the residual unbalance of the rotor shall be determined in accordance with 4.4.6.3.3 and Annex D.

NOTE Annex D provides a method of determining the residual unbalance remaining in the completely assembled rotor and balancing machine sensitivity check.

4.4.6.3.5 A balancing device is either a conventional balancing machine or the actual machine frame assembly with the rotor installed. When the machine frame is used as a balance device, the residual unbalance of the rotor shall be determined in accordance with 4.4.6.3.3 and Annex D.

4.4.6.4 Vibration

Machines shall be designed so that they meet the acceptance criteria stated in 6.3.3. Machine design shall consider all applicable vibration forcing phenomena (see 3.23).

4.4.7 Bearings, Bearing Housings, and Seals

4.4.7.1 Bearings

- **4.4.7.1.1** Unless otherwise specified, hydrodynamic radial bearings (e.g. sleeve or tilting pad) shall be provided on all horizontal machines.

NOTE To limit bearing babbitt wear, bearings and lubrication should be evaluated for application of hydraulic jacking means when applying hydrodynamic bearings in motors that require multiple starts per day or are supplied from an ASD and may operate at very slow speeds.

4.4.7.1.2 Hydrodynamic radial bearings shall be split for ease of assembly, precision bored, and of the sleeve or pad type with steel-backed or bronze-backed, babbitted replaceable liners, pads, or shells. These bearings shall be equipped with anti-rotation pins and shall be positively secured in the axial direction. The bearing design shall suppress hydrodynamic instabilities and provide sufficient damping to limit rotor vibration to the maximum specified amplitudes while the machine is operating loaded or unloaded at specified operating speeds, including operation at any critical frequency if that frequency is a normal operating speed. The bearings on each end of horizontal machines shall be identical.

The design of the bearing housing shall not require removal of the lower half of end bells or plates, ductwork, or the coupling hub to permit replacement of the bearing liners, pads, or shells. Bearing temperatures measured with bearing metal temperature detectors shall not exceed 93 °C (200 °F) at rated operating conditions.

- **4.4.7.1.3** When specified, antifriction bearings shall be used for horizontal machines provided that the following conditions are met.
 - a) The dN factor is less than 300,000. [The dN factor is the product of bearing size (bore) in millimeters and the rated speed in revolutions per minute.]
 - b) Antifriction bearings meet an ABMA L_{10} rating life of either 100,000 hours with continuous operation at rated conditions or 50,000 hours at maximum axial and radial loads and rated speed. (The L_{10} rating life is the number of hours at rated bearing load and speed that 90 % of a group of identical bearings shall complete or exceed before the first evidence of failure. See ABMA Standard 9 or ABMA Standard 11 as applicable or ISO 281 or ISO 76.)

4.4.7.1.4 Antifriction guide bearings may be used for vertical machines provided the conditions of 4.4.7.1.3 a) and 4.4.7.1.3 b) are satisfied.

4.4.7.1.5 Antifriction thrust bearings may be used for vertical machines provided that the following conditions are met.

- a) Thrust bearings for vertical motors shall be on top.
- b) Multiple bearings to accommodate thrust in the same direction shall not be permitted.
- c) The thrust bearings for vertical machines shall be rated for ABMA L_{10} life of at least 5000 hours with continuous operation at 200 % of the maximum up and down thrust that may be developed during starting, stopping, or while operating at any capacity on the rated performance curve. Vendor shall notify the purchaser if testing is affected by the presence of bearing springs or the reorientation of mounting position during testing.

NOTE Spherical roller bearings often have springs designed to compress with the down thrust, and if the thrust is less than design, the rotor rides higher than normal and there may be increased vibration during no load testing.

4.4.7.1.6 Antifriction bearings shall be retained on the shaft and fitted into housings in accordance with the requirements of ABMA Standard 7 or ISO 286-1 or ISO 286-2; however, the device used to lock ball thrust bearings to the shaft shall be restricted by a nut with a tongue-type lock washer (e.g. Series W per ABMA Standard 8.2).

4.4.7.1.7 Except for the angular-contact bearings and lower guide bearings in vertical machines, antifriction bearings shall have an internal clearance fit equivalent to ABMA Symbol 3 as defined in ABMA Standard 20 or ISO 15, ISO 492, or ISO 5753. Single-row or double-row bearings shall be of the deep-groove (Conrad) type. Filling-slot (maximum-load) antifriction bearings shall not be used. Bearings shall be commercially available from more than one bearing vendor.

4.4.7.1.8 Bearings shall be electrically insulated. A shorting device shall be provided in the bearing housing on the drive end. For double-end drivers, the coupling on one end also shall be electrically insulated and the bearing housing shorting device provided on the opposite end.

- ◆ **4.4.7.1.9** For ASD applications where it is determined that the bearing currents may be noncharacteristic or where the rotor may become electrically charged, special measures may be required and shall be proposed by the vendor. These measures may involve special isolation procedures, shaft grounding brushes, or winding connection design modifications. If grounding brushes are used, they shall be redundant and replaceable without shutting down the machine. When specified, there shall be a monitoring system installed to annunciate the need for brush replacement.

4.4.7.1.10 Hydrodynamic thrust bearings for vertical machines shall be of the babbitted multiple-segment type. Tilting-pad bearings shall incorporate a self-leveling feature that assures that each segment carries an equal share of the thrust load. With minor variation in pad thickness, each pad shall be designed and manufactured with dimensional precision (thickness variation) that shall allow interchange of individual pads. The thrust collar shall be replaceable. Fretting and axial movement shall be prevented. The thrust faces of the collar shall have a surface finish of not more than $0.4\text{ }\mu\text{m}$ (16 $\mu\text{in.}$) R_a , and the total indicated axial runout of either thrust face shall not exceed $12\text{ }\mu\text{m}$ (500 $\mu\text{in.}$). Split thrust collars are not acceptable.

4.4.7.1.11 Hydrodynamic thrust bearings for vertical machines shall be selected such that under any operating condition the load does not exceed 50 % of the bearing vendor's ultimate load rating. The ultimate load rating is the load that produces the minimum acceptable oil film thickness without inducing failure during continuous service or the load that does not exceed the creep-initiation yield strength of the babbitt at the location of maximum temperature on the pad, whichever load is less. In sizing thrust bearings, consideration shall be given to the following for each specific application:

- a) the thrust loads from the driven equipment under all operating conditions (see 4.4.7.1.12 and 4.4.7.1.13);

- b) the shaft speed;
- c) the temperature of the bearing babbitt;
- d) the deflection of the bearing pad;
- e) the minimum oil film thickness;
- f) the feed rate, viscosity, and supply temperature of the oil;
- g) the design configuration of the bearing;
- h) the babbitt alloy; and
- i) the turbulence of the oil film.

The sizing of hydrodynamic thrust bearings shall be reviewed and approved by the purchaser.

4.4.7.1.12 If a nonaxially locating gear-type or spline-type coupling (nonlimited end-float type where sliding may take place at the tooth mesh) is considered, the transmitted external axial force shall be calculated from Equation (7) and Equation (8).

In SI units:

$$F = 19095 \mu P_r / N_r d \quad (7)$$

In USC units:

$$F = 12600 \mu P_r / N_r d \quad (8)$$

where

F is the external force, in kilo-Newtons (pounds);

P_r is the rated power, in kilowatts (horsepower);

N_r is the rated speed, in revolutions per minute;

d is the gear tooth pitch circle diameter (CD) in mm (in.),

(use $d = 2$ times the shaft diameter if coupling details are unknown); and

μ is the coefficient of friction at the gear teeth,

(use $\mu = 0.25$ unless a definite value is available).

4.4.7.1.13 Thrust loads for diaphragm-type and disk-type couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling vendor.

4.4.7.1.14 Sufficient cooling (including an allowance for fouling) shall be provided to maintain oil and bearing temperatures as follows, based on the specified operating conditions and an ambient temperature of 40 °C (104 °F).

- a) For pressurized systems (i.e. pressure lubrication) with an oil outlet temperature of 50 °C (122 °F) or below, the oil passing through the bearing during shop testing and in operation shall not exceed a temperature rise of 20 °C (36 °F) and the maximum bearing metal temperature shall not exceed 93 °C (200 °F).
- b) For ring-oiled or splash systems (i.e. self lubrication), oil sump temperature shall not exceed 80 °C (176 °F) on test and in operation. Bearing metal temperature on test and in operation shall not exceed 93 °C (200 °F).

NOTE To avoid condensation, the minimum inlet water temperature to water cooled bearing housings should preferably be above the ambient air temperature.

4.4.7.1.15 For ambient conditions which exceed 40 °C (104 °F) or when the inlet oil temperature exceeds 50 °C (122 °F), special consideration shall be given to bearing design, oil flow, and allowable temperature rise.

- **4.4.7.1.16** When specified, bearing oil temperature indicators shall be provided on the bearing housing of non-pressure-fed bearings or in the drain lines of pressure-fed bearings. The sensor shall be removable without loss of oil.

4.4.7.1.17 At ambient temperature, the fit between the outside of the bearing shell and the bearing housing shall be zero clearance to an interference fit.

4.4.7.2 Bearing Housings

4.4.7.2.1 Bearing housings for pressure-lubricated hydrodynamic bearings shall be arranged to minimize foaming. The drain system shall be adequate to maintain the oil and foam level below shaft end seals and to allow a sufficient oil level for operation.

- **4.4.7.2.2** On horizontal machines, bearing housings for self-lubricated, oil bearings shall have oil reservoirs of sufficient depth to serve as settling chambers. The housings shall be provided with tapped and plugged fill and drain openings at least DN 15 (1/2 in. NPT). A permanent indication of the proper oil level shall be accurately located and clearly marked on the outside of the bearing housing with permanent metal tags, marks inscribed in the castings, or other durable means. If the oil-level indicator breaks, the resulting drop in oil level shall not result in loss of bearing lubrication (e.g. reduction of the oil level below the level required for oil-ring operation). When specified, the housings shall be equipped with constant-level oilers at least 0.25 liter (8 fluid ounces) in size, with a positive level positioner (not a set screw), clear glass containers, protective wire cages, and supplemental support in addition to the piping.

4.4.7.2.3 Housings for ring-oil-lubricated bearings shall be provided with plugged ports positioned to allow visual inspection of the oil rings while the equipment is running.

4.4.7.2.4 Bearing housings shall be positively located by cylindrical precision dowels and/or rabbeted fits. Bearing housings and support structures shall be designed so that upon assembly, none of the air-gap measurements taken in at least three positions (spaced 90° apart) at each end of the stator deviates from the limit given below as defined by the following equation:

$$D = [(H - L) / A] * 100 \quad (9)$$

where

D is the percentage deviation;

H is the highest of the readings at one end of the stator;

L is the lowest of the readings at the same end of the stator; and

A is the average of the readings at the same end of the stator.

The air gap between the exterior of the rotor and the interior of the stator shall be measured at both ends of the stator. Measurements should be taken at the same positions on both ends. The percentage deviation (D) shall not exceed 10 %. This data shall be recorded and made part of the final report. To allow for accurate measurement, stator and rotor surfaces at the measuring positions shall be free from resin buildup.

NOTE Air gap measurements are not possible on many vertical and some horizontal machines. For those cases, the vendor and purchaser should mutually agree on the process for addressing the air gap. Typically, this is by review of tolerances on the mating surfaces, rotor diameter, and stator inner diameters.

4.4.7.2.5 Bearing housings shall be machined for mounting vibration detectors as described in 5.8.1

4.4.7.3 Shaft Seals

Shaft seals shall conform to the following.

- a) Enclosure or housing shaft seals shall be made from nonsparking materials and centerable about the shaft. Where aluminum is used, it shall have a copper content of less than 0.2 %. Split type seals shall be provided to allow replacement without shaft or coupling removal. Where end-shield supported bearings are used, the inner seal shall be maintained at atmospheric pressure. Pressure balancing from the cooling fan shall be by use of copper or steel tubing, unless other materials are approved by the purchaser. Seals shall be designed to minimize the entry of fumes, dirt, and other foreign material into the stator enclosure. When specified, seals shall be constructed so that a purge gas can be introduced. If possible, self-aligning seals shall be used.
- b) When specified, the shaft seals shall be fabricated from electrically nonconducting materials.
- c) Bearing housings for horizontal machines shall be equipped with split labyrinth-type end seals and deflectors where the shaft passes through the enclosure. Lip-type seals shall not be used. The sealing system shall meet the requirements of IP55. If replaceable shaft seals are used to achieve this degree of protection, they shall be the noncontact or noncontacting while rotating type with a minimum expected seal life of five years under usual service conditions. No oil shall leak past the seals during both stationary and operating conditions, while circulating lube oil.

4.4.7.4 Oil Mist Provisions

- **4.4.7.4.1** The requirements of 4.4.7.4.2 through 4.4.7.4.6 apply when oil mist lubrication is specified.

4.4.7.4.2 A threaded 6 mm ($1/4$ NPT) oil mist inlet connection shall be provided in the top half of the bearing housing. The pure oil or purge oil mist fitting connections shall be located so that oil mist shall flow through antifriction bearings. On pure mist systems, there shall be no internal passages to short circuit oil mist from inlet to vent.

4.4.7.4.3 A threaded 6 mm ($1/4$ NPT) vent connection shall be provided on the housing or end cover for each of the spaces between the antifriction bearings and the housing shaft closures. Alternatively, where oil mist connections are between each housing shaft closure and the bearings, one vent central to the housing shall be supplied. Housings with only sleeve type bearings shall have the vent located near the end of the housing.

4.4.7.4.4 Shielded or sealed bearings shall not be used.

- **4.4.7.4.5** When pure oil mist lubrication is specified, oil rings or flingers (if any) and constant level oilers shall not be provided and a mark indicating the oil level is not required. When purge oil mist lubrication is specified, these items shall be provided and the oiler shall be piped so that the oiler is maintained at the internal pressure of the bearing housing.

NOTE At process operating temperatures above 300 °C (570 °F), bearing housings with pure oil mist lubrication may require special features to reduce heating of the bearing races by heat transfer. Typical features are:

- a) heat sink type flingers;
- b) stainless steel shafts having low thermal conductivity;
- c) thermal barriers;
- d) fan cooling; and
- e) purge oil mist lubrication (in place of pure oil mist) with oil (sump) cooling.

4.4.7.4.6 The oil mist supply and drain fittings shall be provided by the purchaser.

4.4.8 Lubrication

- **4.4.8.1** Unless otherwise specified, hydrodynamic bearings shall use hydrocarbon oil and shall be arranged for ring-type lubrication in accordance with the bearing vendor's recommendations. Oil rings shall have a minimum submergence of 6 mm (0.25 in.) above the lower edge of the bore of the oil ring. If oil rings are not practical, as with tilting pad bearings, the vendor shall advise and obtain approval from the purchaser. Where the shaft circumferential speed exceeds the limits for the use of oil rings, a pressure lubricated (see 3.11) (forced) oil system shall be used.

The vendor shall notify the purchaser when oil rings are not provided with the bearings so that adequate provision can be made for lubrication during loss of oil pressure emergency coastdown situations.

4.4.8.2 Oil slingers shall have mounting hubs to maintain concentricity and shall be positively secured to the shaft.

- **4.4.8.3** When specified, thermostatically controlled heating devices shall be provided in the bearing housings. The heating devices shall have sufficient capacity to heat the oil in the bearing housing from the specified minimum site ambient temperature to the vendor's minimum required temperature in four hours. The thermostatic enclosure shall be compatible with the area classification requirements.
- **4.4.8.4** Where a pressure lubricated or circulating lubrication system is required by the driven equipment, the electrical machine bearing oil may be supplied from that system when specified. The purchaser will specify the supplier of the complete lubrication system.
- **4.4.8.5** Where oil is supplied from a common system to two or more machines (e.g. a compressor, a gear, and a motor), the oil's characteristics shall be specified on the datasheets by the purchaser on the basis of mutual agreement with all vendors supplying equipment served by the common oil system.

NOTE 1 The usual lubricant employed in a common oil system is a hydrocarbon-based oil that corresponds to ISO Grade 32, as specified in ISO 3448.

NOTE 2 If flammable or combustible materials are handled in some part of the equipment train, means should be taken to ensure that these materials cannot enter the electrical machine through a common lube oil system. In some cases, this may require a separate lube oil system for the electrical machine.

- **4.4.8.6** When specified, pressurized oil systems shall conform to the requirements of API 614.

4.4.8.7 When supplied with the machine, oil piping (inlet and drains), orifices, and throttle valves shall be AISI 300 series stainless steel (see 4.4.3.4 for additional lube oil piping requirements).

- **4.4.8.8** The purchaser shall specify on the datasheet the type of oil used for the application.

NOTE The use of synthetic lubricants for machine bearings requires special design. When the use of synthetic lubricants is specified, it is important that the purchaser inform the vendor of the specific type and brand used.

4.4.9 End Play and Couplings

4.4.9.1 Horizontal hydrodynamic radial bearing machines shall have a total end play of at least 13 mm (0.5 in.). The design of the motor shall ensure that the magnetic center shall be within 20 % of the total end float from the center of the end float limit indicators [e.g. 2.6 mm (0.1 in.) for a 13 mm (0.5 in.) total end float]. Running at this position provides sufficient clearances between the rotor journal shoulders and the bearing and seal faces under all operating conditions when a limited end float coupling is used (see 4.4.9.2).

4.4.9.2 Flexible couplings used with horizontal hydrodynamic radial bearing machines shall be of the limited-end-float-type. The total end float shall be limited to 4.8 mm ($3/16$ in.).

4.4.9.3 When horizontal hydrodynamic bearings are provided, the machine shall have a permanent indicator to show the actual limits of total rotor end float and magnetic center. The indicator shall be durable and shall be adjacent to the drive end shaft shoulder.

- **4.4.9.4** When specified, the electrical machine vendor shall install the motor coupling hub (plus mass moment simulator, if applicable) and perform the vibration test in 6.3.1.5.

4.4.10 Materials

4.4.10.1 General

4.4.10.1.1 All components used for the purchaser interface shall be in accordance with applicable local standards, as specified on the datasheet (e.g. ANSI standard threads in the United States).

- **4.4.10.1.2** The purchaser shall specify any corrosive agents present in the environment including constituents that may cause stress corrosion cracking.

4.4.10.1.3 Where mating parts (e.g. studs and nuts) of 18-8 stainless steel or materials having similar galling tendencies are used, they shall be lubricated with a suitable anti-seizure compound.

4.4.10.1.4 Unless specifically approved by the purchaser, no component shall be repaired by plating, plasma spray, metal spray, impregnation, or similar methods.

4.4.10.2 Castings

4.4.10.2.1 Castings shall be sound and free from porosity, hot tears, shrink holes, blow holes, cracks, scale, blisters, and similar injurious defects. Surfaces of castings shall be cleaned by sandblasting or chemical methods. Any other cleaning method requires approval by the purchaser. Mold-parting fins and remains of gates and risers shall be chipped, filed, or ground flush.

4.4.10.2.2 Ferrous castings shall not be repaired by welding, peening, plugging, burning in, or impregnating, except as specified in 4.4.10.2.2.1 and 4.4.10.2.2.2.

4.4.10.2.2.1 Weldable grades of steel castings may be repaired by welding using a qualified welding procedure based on the requirements of Section IX of the ANSI/ASME BPVC (ISO 9013).

4.4.10.2.2.2 Cast gray iron or nodular iron may be repaired by plugging within the limits specified in ASTM A278/A278M, ASTM A395, or ASTM A536. The holes drilled for plugs shall be carefully examined using liquid penetrant to ensure that all defective material has been removed. All necessary repairs not covered by ASTM specifications shall be subject to the purchaser's approval.

4.4.10.2.3 Fully enclosed cored voids including voids closed by plugging are prohibited.

4.4.10.3 Welding

4.4.10.3.1 Structural welding including weld repairs shall be performed by operators and procedures qualified in accordance with AWS D1.1 and ISO Catalog 25.160.10 through ISO Catalog 25.160.50. Other welding codes may be used if specifically approved by the purchaser.

4.4.10.3.2 The vendor shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat treated and nondestructively examined for soundness and compliance with applicable qualified procedures.

4.4.10.3.3 All butt welds shall be continuous full-penetration welds.

4.4.10.3.4 Intermittent welds, stitch welds, and tack welds are not permitted on any structural part of the machine. If specifically approved by the purchaser, intermittent welds may be used where significant problem-free operating experience exists and well-established design procedures are available.

4.4.10.3.5 Welding of or to shafts is not acceptable for balancing purposes on finished shafts or on two pole machines. Any shafts or spiders subjected to welding shall be postweld stress relieved prior to finish machining.

4.4.10.4 Low Temperature Service

To avoid brittle failures, materials and construction for low temperature service shall be suitable for the minimum design metal temperature in accordance with the codes and other requirements specified. The purchaser and the vendor shall agree on any special precautions necessary with regard to conditions that may occur during operation, maintenance, transportation, erection, commissioning, and testing.

NOTE Good design practice should be followed in the selection of fabrication methods, welding procedures, and materials for vendor furnished steel pressure retaining parts that may be subject to temperatures below the ductile-brittle transition temperature. The published design-allowable stresses for many materials in internationally recognized standards (e.g. the ANSI/ASME BPVC and ANSI standards) are based on minimum tensile properties. Some standards do not differentiate between rimmed, semi-killed, fully killed hot-rolled, and normalized material, nor do they take into account whether materials were produced under fine-grain or coarse-grain practices. The vendor should exercise caution in the selection of materials intended for services below -30°C (-22°F).

4.4.10.5 Protective Grills or Metal Screens

Protective grills or metal screens shall be fabricated from not less than 1.25 mm (0.049 in.) AISI 300 series stainless steel with a maximum mesh of 6.0 mm (0.25 in.). On enclosures equipped with filters, the screens downstream of the filters may have a maximum mesh of 12.7 mm (0.5 in.).

4.4.10.6 Fans

- **4.4.10.6.1** Fan systems, blades, and housings shall be designed to prevent sparking as a result of mechanical contact or static discharge. Fans shall be constructed to minimize failure from corrosion or fatigue. When specified, the vendor shall demonstrate to the purchaser's satisfaction that the nonsparking qualities and durability required are provided by the fan system.

NOTE Materials that are typically used are: aluminum (with a copper content of less than 0.2 %), bronze, reinforced thermosetting conductive plastic (to bleed off static charges) or epoxy coated steel fans.

4.4.10.6.2 Shaft mounted cooling fans and any other similar shaft mounted components shall be designed and constructed so that they will not resonate at any frequency within the defined operating speed range.

• 4.4.10.6.3 Auxiliary Motor Driven Fans

When specified on the datasheets, cooling shall be provided by redundant motor driven auxiliary fans. Fans shall be directly mounted on the motor enclosure or may be on the inlet ducting in the case of TEPC motors. In all cases, the fan motor assembly shall be designed for easy access and replacement. Fan assemblies shall meet the requirements of 4.4.10.6.1. Motors shall be in accordance with IEEE 841 and externally accessible for lubrication.

4.4.10.7 Stator Laminations

Stator laminations shall be produced from magnetic steel per ASTM A345 (IEC 60404-1) utilizing methods that will produce a core structure capable of passing the interlaminar insulation integrity test described in 6.3.4.1 and shall have burr heights not exceeding 0.076 mm (0.003 in.). The insulation applied to the laminations shall be of at least C-5 quality per ASTM A976 (IEC 60404-1-1). The stator core assembly shall be capable of withstanding a burnout temperature of 400 °C (750 °F) without damage or loosening.

4.4.10.8 Heat Exchangers

Heat exchangers shall conform to the following.

- a) Air to air exchanger tubes shall be made of copper, copper-based alloy, aluminum, aluminum alloy containing no more than 0.2 % copper, or AISI 300 series stainless steel. If stainless steel is specified, AISI 316 shall be used for all offshore applications.
- b) Water to air heat exchanger tubes shall be not less than 15 mm (0.625 in.) outside diameter and 1.25 mm (0.049 in.) wall thickness made of 90-10 Cu-Ni material. Purchaser has the responsibility to provide the cooling water chemistry to be checked for material compatibility.
- c) On double tube water to air coolers, the water-side tubes shall conform to 4.4.10.8 b) above. The air side outer tube material shall be copper or copper based alloy and have a minimum wall thickness of 0.7 mm (0.028 in.).

4.4.11 Nameplates and Rotation Arrows

4.4.11.1 All nameplates and rotation arrows shall be of AISI 300 series stainless steel, securely fastened by pins of similar material and attached at readily visible locations. All information (including title fields) shall be permanently inscribed, embossed, or engraved. Nameplates shall be provided on the machine and on or adjacent to each auxiliary device or junction box.

4.4.11.2 As a minimum, the data listed below shall be clearly stamped on the motor's nameplate(s):

- a) vendor's name;
- b) serial number;
- c) horsepower or kW;
- d) voltages;
- e) phase;
- f) full load power factor and efficiency;
- g) frequency (in Hz);
- h) for antifriction bearings, the vendor and model number;

- i) for bearings with an external oil supply, the oil flow rate in liters (gallons) per minute and the oil pressure required in kilopascals (pounds per square inch) gauge;
- j) full-load current (amps);
- k) locked-rotor amperes (amps);
- l) full-load speed in revolutions per minute;
- m) time rating;
- n) temperature rise in degrees Celsius, the maximum ambient or cooling-air temperature for which the motor was designed, and the insulation system's designation;
- o) service factor (not applicable to IEC motors);
- p) starting limitations;
- q) location of the magnetic center per 4.4.9.3 in mm (in.) (from the drive end bearing housing on a horizontal machine with a sleeve bearing);
- r) enclosure type;
- s) total motor mass and rotor mass;
- t) year of manufacture;
- ♦ u) the frequency and speed range for ASD driven units;
- ♦ v) type of torque and speed characteristic for which the motor is designed [e.g. VT (variable torque) or CT (constant torque)] down to a specified speed; and
- ♦ w) type of inverter for which the motor is intended.

4.4.11.3 Separate connection diagrams or data nameplates shall be located near the appropriate connection box (or device location if there is no box) for the following:

- a) machines with more than three power leads;
- b) space heater operating voltage and wattage, and maximum surface temperature or class (T-Code, see IEC 60079-0, NFPA 70, or CSA C22.1 as applicable) for Class I or II, Division 2 or Zone 2 locations when applicable;
- c) temperature detectors (resistance, in ohms, or junction type);
- d) vibration and position detectors (vendor and model number);
- e) connections for proper rotation (including bidirectional);
- f) current transformer secondary leads (when provided) with polarity marks;
- g) lube oil supply orifice size; and
- ♦ h) connection diagram for tachometer (when provided).
- **4.4.11.4** When specified, the purchaser's identification information shall be stamped on a separate nameplate.

5 Accessories

5.1 Terminal Boxes

- **5.1.1** Main terminal boxes shall be constructed of steel plate with a minimum thickness of 3 mm (0.125 in.). Minimum dimensions and usable volumes shall not be less than those specified in NEMA MG 1, Part 20 for Type II terminal housings. Copper bus bars and standoff insulators shall be supplied and sized so that the bus does not exceed 90 °C (194 °F) total temperature at 125 % of motor full load current. Standoff insulators shall be either porcelain or cycloaliphatic resin material. Electrical insulating materials shall be nonhygroscopic. When specified, larger boxes shall be provided for shielded or special cable terminations, increased cable bending radius allowance, or auxiliary devices.
- **5.1.2** The terminal box for the main power lead terminations shall be capable of withstanding the pressure buildup resulting from a three phase fault of the specified MVA (one-half cycle after fault inception) for a duration of 0.1 sec. If a rupture disc is used to relieve pressure buildup, it shall not compromise the environmental rating of the box and the discharge from the pressure release shall be directed away from locations where personnel may be normally present.
- **5.1.2.1** For motors fed from fused motor starters, the terminal box withstand capability shall be coordinated with the I^2t (ampere-squared sec.) let-through energy specified on the datasheet.

5.1.3 For machines rated at 601 V and higher, accessory leads shall terminate in a terminal box or boxes separate from the machine's main power terminal box. However, secondary connections for current and voltage transformers located in the main terminal box are permitted to terminate in the main terminal box if they are separated from power leads or buses by a suitable physical barrier to prevent accidental contact and are accessible without removal of the main terminal box door or cover. For machines rated at 600 V and lower, the termination of leads of accessory items that normally operate at 50 V root mean square (rms) or less shall be separated from other leads by a suitable physical barrier to prevent accidental contact or shall be terminated in a separate box.

5.1.4 Terminal Box and Auxiliary Equipment Enclosure Construction

- **5.1.4.1** Terminal boxes and auxiliary equipment enclosures shall be constructed per IP55 (NEMA 250, Type 4) and be suitable for the area classification shown on the datasheets. When specified, auxiliary equipment enclosures shall be ISO 3506 or AISI 300 series stainless steel. Where the motor will be installed offshore on a production platform or similar marine installation, AISI 316 material shall be supplied in lieu of the 300 series material. Terminal boxes shall be arranged and be suitable for conductor entry as specified on the datasheets. Each terminal box shall be equipped with a breather and drain fitting. All auxiliary device wires shall be terminated on 600 V rated moisture resistant terminal blocks.
- **5.1.4.2** Each terminal box shall have a bolted, gasketed cover that is arranged for convenient front access. If explosion-proof boxes are used, they shall conform to NEMA 250, Type 7R or IEC 60079 requirements. All vertical covers or doors having gasketed surfaces shall be provided with a drip shield at the top. The gasket material shall be impervious to attack by the specified lube oil or other chemicals noted on the datasheet.

5.1.5 Grounding for field wiring inside the terminal box shall conform to the requirements of NEMA MG 1, Part 4 or IEC 60072.

- **5.1.6** When specified, the main terminal box shall be supplied with the following items as detailed on the purchaser datasheet:
 - a) thermal insulation on the interior top side;
 - b) space heaters in accordance with 5.4.2;
 - c) provisions for purging;

- d) removable links;
- e) adequate space for termination of shielded cables;
- f) quick disconnect type bushings or receptacles;
- g) arresters and surge capacitors (not applicable with ASDs);
- h) differential and phase current transformers;
- i) copper bus with silver or tin-plated bus connections;
- j) voltage transformers;
- k) copper ground bus;
- l) partial discharge sensors; and
- m) insulated terminations and interior jumpers.

5.1.7 When surge protection is provided in accordance with 5.6.2, a low-impedance ground path shall be provided between the surge protection and the stator core. This low-impedance path shall be provided by running a copper conductor in parallel with the machine leads. The minimum conductor size shall be 107 mm² (4/0 AWG). This wire shall be as short as possible and have only gradual bends with a minimum bending radius greater than 10 cable diameters (where practical), and bond the stator core to the terminal box by means of compression fittings at the ground point as specified in 5.1.5.

5.1.8 When differential current transformers are provided in accordance with 5.6.3, the secondary leads shall be routed (in a workmanlike manner) away from high-voltage motor leads and protected by a physical barrier to prevent accidental contact. These leads shall be terminated at an appropriate shorting and grounding terminal block housed in an auxiliary box. The auxiliary box shall be accessible without removal of the main terminal box cover.

5.1.9 Wiring and terminal blocks in all terminal boxes shall be clearly identified. The method for marking the wiring shall be a stamped sleeve of the heat-shrinkable type. The terminal blocks shall be permanently and suitably labeled. Stator leads shall be identified in accordance with NEMA MG 1 or IEC 60034-8. Current transformer leads shall have polarity identification markings at the transformer and at the terminal block in the auxiliary terminal box. All wiring markings shall agree with the notations on the special nameplates required by 4.4.11.3.

5.1.10 All wiring shall have insulation that is suitable for the operating conditions specified in 4.1.2 and be impervious to the lubricating oil specified. All wiring shall be adequately supported and protected against physical damage.

- **5.1.11** Where practical, accessory wiring shall be run inside of the motor enclosure. Except as noted in 5.1.12, all accessory wiring outside the motor enclosure and junction boxes shall be run in rigid metal conduit or other purchaser approved means.

5.1.12 Liquid tight flexible metal conduit may be used as the adjacent component to connect to the auxiliary device to facilitate the installation, maintenance or removal of auxiliary devices. Where liquid tight flexible metal conduit is used, the length shall be less than 0.9 m (3 ft).

5.1.13 Conduit and cable entrances to auxiliary terminal boxes shall be in the back, bottom, or sides of the terminal boxes. The back is preferred for machine wiring, and the bottom is preferred for purchaser interface wiring. Entrances to boxes shall be through threaded openings or by use of suitable weather-tight hubs or cable glands. Low points in

conduit systems shall be equipped with drain fittings to prevent accumulation of condensation. Fittings shall be suitable for the area classification.

- **5.1.14** Terminal heads or boxes (as specified) shall be supplied for bearing temperature detectors and the bearing vibration sensing units.

5.1.15 All power connection leads shall be terminated with two-hole, long barrel compression lugs with multiple crimps that are rated for the operating voltage of the motor and suitable for the cable. The lugs shall be sized so that they shall not exceed a total temperature of 90 °C (194 °F) when connected to their cable and landed on their associated buss.

5.1.16 Where both ends of each stator winding are brought out to the terminal box as required in 4.3.6, removable links shall be provided to allow access to each end of the phase windings. Each link shall be installed so that it can be removed without disturbing other parts and connections.

5.2 Winding Temperature Detectors

5.2.1 Stator winding resistance temperature detectors (RTDs) shall be supplied.

- **5.2.1.1** Unless otherwise specified, RTD elements shall be platinum, three-wire elements with a resistance of 100 Ω at 0 °C (32 °F) in accordance with EN 60751, Class B. These elements shall have tetrafluoroethylene-insulated, stranded, tinned copper wire leads with cross sections at least equal to 0.4 mm² (22 AWG) in size. The leads shall meet the requirements of NFPA 70 or IEC 60079.
- **5.2.1.2** A minimum of three sensing elements per phase shall be installed, suitably distributed around the circumference in the stator winding slots. When specified, one lead of each of these elements shall be grounded in the terminal box.

5.2.2 To prevent damage, the leads for all detectors shall be protected during manufacture and shipment. The vendor's drawings shall show the location and number of each sensing element in the stator winding and its connection point on the terminal strip.

5.3 Bearing Temperature Detectors

- **5.3.1** Bearing temperature detectors (at least one per bearing) shall be provided in machines with hydrodynamic radial and thrust bearings. Detectors shall be installed so that they measure bearing metal temperature. Bearing temperature detectors shall be installed in such a way that they do not violate the integrity of the bearing insulation. Unless otherwise specified, RTD elements shall be platinum, three-wire elements with a resistance of 100 Ω at 0 °C (32 °F) in accordance with EN 60751, Class B. These elements shall have tetrafluoroethylene-insulated, stranded, tinned copper wire leads with cross sections at least equal to 0.4 mm² (22 AWG) in size. The leads shall meet the requirements of NFPA 70 or IEC 60079. When specified, bearing temperature sensors shall be provided in accordance with API 670.

NOTE 1 Adoption of API 670 requires two sensors per bearing for most bearings.

NOTE 2 If redundant temperature detectors are desired, separate detectors are preferred. Where space is limited, the use of dual element sensors may be considered.

5.4 Space Heaters

- **5.4.1** When specified, machines shall be equipped with completely wired space heaters brought out to a separate terminal box. Heaters with exposed elements are prohibited. The heater sheath material shall be as specified. The heaters shall be installed inside the enclosure in a location suitable for easy removal and replacement. Heaters shall be located and insulated so that they do not damage components or finish.

- **5.4.2** Space heaters shall be low power density, one or three phase with a frequency and voltage as specified, and shall have all energized parts protected against contact. Low dissipation space heaters shall be provided and wired using high temperature insulation lead material of types FEPB, NI, or SA. Unless otherwise specified, surface temperatures of an unlabeled heating element shall not exceed 160 °C (320 °F). Unless otherwise specified, labeled heating elements shall be identified with a temperature code of T3 or lower temperature. Any type of heater that contacts the surface of the stator winding is not acceptable.

5.4.3 Space heaters shall be selected and mounted to meet the life requirements of 4.1.1 and arranged so that heat is radiated from both sides to provide as equally distributed heating of the stator windings as possible. The heaters shall maintain the temperature of the machine windings at approximately 5 °C (9 °F) above the ambient temperature.

5.5 Screens and Filters

5.5.1 When airflow inlet and outlet screens are provided, see 4.4.10.5 for material requirements.

- **5.5.2** When specified, provisions for future airflow inlet filters in standard types and sizes shall be provided for dripproof guarded and weather protected type I (IP23) (WP-I) enclosures. Filter requirements shall be in accordance with 5.5.4.

5.5.3 Airflow inlet filters in standard types and sizes shall be furnished in all machines having a weather protected type II (WP-II) enclosure. Filter requirements shall be in accordance with 5.5.4.

- **5.5.4** When filters are specified, they shall be of the permanent type and shall meet the service requirements indicated on the datasheets. Filters shall be selected to remove 90 % of particulates 10 micron and larger or as specified on the datasheet. The entire filter element and assembly shall be constructed of AISI 300 series stainless steel.
- **5.5.5** When filters or provisions for future filters are provided, connections shall be furnished for a specified switch or gauge to measure the pressure drop across the filters.

5.5.6 Air filters shall be designed to permit easy removal and replacement while the machine is running.

5.6 Alarms and Control Devices for Motor Protection

5.6.1 Switches

Unless otherwise specified, alarm and control devices shall be equipped with single pole, double-throw switches with a minimum rated capacity of 10 amperes at 120 V AC and 125 V DC.

5.6.2 Surge Protection

- **5.6.2.1** When specified, surge capacitors shall be furnished. The capacitors shall be three individual single phase units. The surge capacitors shall be the last devices connected to the leads before the leads enter the stator. When partial discharge capacitive couplers are used, the couplers shall be the last device before the leads enter the stator.
- **5.6.2.2** When specified, metal-oxide surge arresters shall be furnished and shall be installed in the terminal box.
- **5.6.2.3** The connection leads to the capacitors and arresters shall be at least 107 mm² (4/0 AWG). Leads shall have only gradual bends (if any) and shall be as short as possible with the total lead length (line-side and ground-side combined) on each capacitor and arrester not to exceed 0.6 m (2 ft). The surge arresters shall be rated for the system voltage and the method of system grounding specified on the datasheets (see 5.1.7 for bonding requirements).

NOTE See Annex C, "Datasheet Guide" for assistance in determining the proper voltage ratings for surge capacitors and surge arresters.

5.6.3 Differential Current Transformers

When specified, differential protection current transformers shall be provided. The purchaser shall advise the vendor of the size, type, and source of supply of the current transformers (see 5.1.8 for installation requirements).

5.6.4 Partial Discharge Detectors

- **5.6.4.1** When specified, the vendor shall supply and install stator winding partial discharge monitoring equipment. The make and type shall be as specified by the purchaser in the datasheets. The installed system shall include sensing transducers, signal cables, interface equipment, termination devices, wiring, power supplies, and terminal boxes as required to provide a complete system. The system output shall be either raw signals, relay contacts, or processed data as appropriate to the particular system.

5.6.4.2 The sensing devices shall be mounted either in the main terminal box or in the stator windings as required by the particular system. Sensing devices that are energized at line potential shall be subjected to a minimum of 30 kV RMS for one minute for devices used on machines rated above 6.9 kV and at a minimum of 15 kV for one minute for machines rated 6.9 kV or less. Each device shall also be tested to have a partial discharge extinction voltage above 120 % of machine rated voltage with 5 pC sensitivity. The partial discharge test of the sensors shall be in accordance with ASTM D1868 or IEC 60270. All wiring from the sensors shall be routed along a conductive, grounded metal surface inside the machine and in rigid metallic conduit external to the machine.

- **5.6.4.3** The coupling system shall be installed and wired in accordance with the system vendor's recommendations and terminated in a terminal box. Unless otherwise specified, the terminal box shall be mounted at an easily accessible location on an outside vertical surface of the main terminal box. The box shall contain either the output terminals from the sensors or the output device supplied by the system vendor. Output terminals shall be permanently identified. If the system requires an external power supply, the vendor shall supply terminals in the output terminal box for that power supply. Terminal boxes shall be grounded with a separate 16 mm² (#6 AWG) or larger copper wire and shall meet the requirements of 5.1.5 of this standard.

5.7 Ground Connectors

Visible ground pads shall be provided at opposite corners of the machine frame. A ground connection point shall be provided by drilling and tapping the frame for a 12.0 mm (1/2 in. NC) thread bolt.

5.8 Vibration Detectors

- **5.8.1** Hydrodynamic bearing machines intended to operate at synchronous speeds greater than or equal to 1200 rpm, or when specified for other speeds, shall be equipped with noncontacting vibration probes and a phase-reference probe, or shall have provisions for the installation of these probes. Noncontacting vibration probes and phase-reference probes shall be installed in accordance with API 670. Shaft surface preparation in the probe area shall be in accordance with 4.4.5.1.7.
- **5.8.1.1** The leads of the noncontacting vibration probes shall be physically protected by the use of conduit or other purchaser specified means and shall be secured to prevent movement.

5.8.1.2 Oscillator-demodulators shall be located in a single dedicated terminal box attached to the machine frame. The box shall be mounted on spacers or an intermediate rigid mounting plate so that a spacing of at least 25 mm (1.0 in.) from the motor frame is provided for ventilation purposes. The spacers or mounting plate and associated hardware shall not be subject to corrosion in the specified atmosphere. The box mounting location shall be selected and arranged so that:

- 1) the oscillator-demodulators are not subject to ambient temperatures exceeding –35 °C to 65 °C (–30 °F to 150 °F);
- 2) resonances are avoided and minimal vibration is imparted; and