

General Purpose Form-wound Squirrel Cage Induction Motors—185 kW (250 hp) through 2240 kW (3000 hp)

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General Purpose Form-wound Squirrel Cage Induction Motors— 185 kW (250 hp) through 2240 kW (3000 hp)

1 Scope

1.1 General

1.1.1 This standard covers the requirements for form-wound induction motors for use in general purpose petroleum, chemical and other industrial severe duty applications and with the following characteristics:

- a) rated 185 kW [250 horsepower (hp)] through 2240 kW (3000 hp) for four-, six-, and eight-pole speeds;
- b) rated less than 600 kW (800 hp) for two-pole (3000 or 3600 RPM) motors of totally enclosed construction;
- c) rated less than 930 kW (1250 hp) for two-pole motors of WP-II type enclosures;
- d) rated less than 375 kW (500 hp) for vertical motors;
- e) drive centrifugal loads;
- f) drive loads having inertia values not exceeding those listed in NEMA MG 1 Part 20; and
- g) operated as motors, not induction generators.

NOTE Motors larger than that covered above and motors in other applications should be specified in accordance with API 541.

1.1.2 Application of the API Monogram—If the product is manufactured at a facility licensed by API and it is intended to be supplied bearing the API Monogram, the requirements of Annex A apply.

1.1.3 A datasheet is provided in Annex B. The purchaser is not required to complete and provide the datasheet for pre-configured or catalog based motors manufactured with standard features. However, the purchaser shall provide the completed datasheet to specify motor requirements for a specific application and/or with options and features beyond the above description. A datasheet guide, which provides detailed information to assist with completion of the datasheet, is provided in Annex C.

1.2 Usual Service Conditions

Unless otherwise specified, motors conforming to this standard shall be suitable for operation within their rating under the following service conditions:

- a) exposure to an ambient temperature in the range of -18°C to 40°C (0°F to 104°F);
- b) exposure to a maximum altitude of 1000 m (3300 ft) above sea level;
- c) indoor or outdoor severe duty applications, such as humid, chemical (corrosive), or salty atmospheres;
- d) horizontal foot mounted;
- e) installation in a Class I, Zone 2 or Division 2 hazardous (classified) location;
- f) constant frequency sinusoidal input power;
- g) not subject to frequent transient overvoltages (e.g. switching surges, lightning surges); and
- h) direct coupled without a gear, fluid coupling, or other speed modification device.

1.3 Unusual Service Conditions

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

- a) exposure to:
 - 1) combustible, explosive, abrasive, or conductive dust;
 - 2) dirty operating conditions where the accumulation of dirt will interfere with normal ventilation;
 - 3) nuclear radiation;
 - 4) abnormal shock, vibrations, or mechanical loading from external sources;
 - 5) abnormal axial or side thrust imposed on the motor shaft;
 - 6) altitude or ambient temperature outside the range covered in 1.2;
 - 7) reciprocating or positive displacement loads; and
 - 8) offshore applications;
- b) conditions under which the variation from rated voltage or frequency, or both, exceeds the limits given in NEMA MG 1 (or IEC 60034-1);
- c) conditions under which the AC supply voltage is unbalanced by more than the limits given in NEMA MG 1 (or IEC 60034-1);
- d) operation at speeds other than rated speed;
- e) operation on an adjustable speed drive;
- f) load inertia greater than and/or starting conditions more severe than given in NEMA MG 1;
- g) orientation of a foot-mounted motor in any position other than horizontal;
- h) vertical flange-mounted motors;
- i) coupled through a belt, gear, fluid coupling or other speed modification device; and
- j) requirements for enclosure purging or pre-start ventilation.

NOTE A 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 should be indicated on the datasheets (see Annex B); otherwise it should be stated in the quotation request or in the order.

1.4 Dimensions and Standards

- **1.4.1** Both the SI and U.S. customary 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.

- **1.4.2** This document recognizes two different systems of standards for the manufacturing and testing of electrical motors: 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. The selection of which system of standards to be utilized shall depend upon the motor's application and site location.

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

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 541, *Form-wound Squirrel Cage Induction Motors—375 kW (500 Horsepower) and Larger*

API Standard 670, *Machinery Protection Systems*

ABMA Standard 20 ¹, *Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types—Metric Design*

AISI ², *Standards of the American Iron and Steel Institute*

ANSI/ASA S12.54 ³, *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*

ASTM A976 ⁴, *Standard Classification of Insulating Coatings for Electrical Steels by Composition, Relative Insulating Ability and Application*

ASTM D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials*

CENELEC EN 60751 ⁵, *Industrial platinum resistance thermometers and platinum temperature sensors*

IEC 60034 (all parts) ⁶, *Rotating electrical machines*

IEC 60072 (all parts), *Dimensions and output series for rotating electrical machines*

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

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

IEEE 43 ⁷, *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*

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

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

² American Iron and Steel Institute, 1540 Connecticut Avenue, NW, Suite 705, Washington, DC 20036, www.steel.org.

³ Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, NY 11747-4300, www.acousticalsociety.org.

⁴ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁵ European Committee for Standardization (CEN-CENELEC), Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.

⁶ International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.

⁷ Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, New Jersey 08854, www.ieee.org.

IEEE 303, *IEEE Recommended Practice for Auxiliary Devices for Rotating Electrical Machines in Class I, Division 2 and Zone 2 Locations*

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

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

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 15⁸, *Rolling bearings—Radial bearings—Boundary dimensions, general plan*

ISO 68-1 (DIN/ISO 68-1), *ISO General purpose screw threads—Basic profile—Part 1 Metric screw threads*

ISO 178, *Plastics—Determination of flexural properties*

ISO 492, *Rolling bearings—Radial bearings—Geometrical product specifications (GPS) and tolerance values*

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

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

NEMA MG 1⁹, *Motors and Generators*

NFPA 70¹⁰, *National Electrical Code*

3 Terms and Definitions

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

3.1

accelerating torque

Accelerating torque of a motor is the difference between the input torque to the rotor 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 (VSD), adjustable frequency drive (AFD), and variable frequency drive (VFD); however, use of these terms is discouraged.

⁸ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

⁹ National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.

¹⁰ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

3.3**breakdown torque**

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

3.4**dN factor**

The product of bearing bore size, as measured in millimeters, and rated speed, in revolutions per minute.

3.5**lateral critical speed**

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.

3.6**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.

3.7**observed**

The purchaser shall be notified of the timing of the inspection or test. However, the inspection or test shall be performed as scheduled, and if the purchaser or his or her representative is not present, the vendor shall proceed to the next step.

3.8**power factor**

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

3.9**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.

3.10**purchaser**

The agency that issues the order and specification to the vendor.

3.11**reed frequency**

Term used to designate the cantilevered bending mode (lateral frequency) about a fixed base.

3.12**service factor**

Service factor of a motor is a multiplier which is applied to the rated power to indicate a permissible power loading that may be carried under the conditions specified for the service factor (see NEMA MG 1).

NOTE IEC standards do not recognize service factor.

3.13

static deflection

Static deflection of a motor is the distance the center of gravity of a vertical motor would be displaced downward from its original position if the motor were horizontally mounted. This value assumes that the motor uses its normal mounting and fastening means but that the foundation to which it is fastened does not deflect.

NOTE See NEMA MG 1 Part 20.

3.14

stiff-shaft motor

A motor that operates below its first mechanical rotor-system resonant speed, as excited by a rotor unbalance.

NOTE Other terms commonly used are stiff-rotor motor, rigid-rotor motor, and rigid-shaft motor.

3.15

vendor

The agency that supplies the equipment.

NOTE Supplier is also used interchangeably with vendor in this standard.

3.16

witnessed

Means that a hold shall be applied to the production schedule and the inspection or test shall be carried out with the purchaser or his or her representative in attendance. For vibration, unbalance response, and heat run tests, this requires confirmation of the successful completion of a preliminary test.

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, except for required bearing maintenance, at least five 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.

4.1.2 Motors shall have a 1.0 service factor rating. Motors shall be capable of continuous operation at rated load and temperature rise in accordance with 4.3.1 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 and to provide adequate torque capacity.

- **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 meter (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 ANSI S12.54 or ISO 3744.
- **4.1.4** The motor 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.

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

4.2 Electrical Design

4.2.1 General

Unless otherwise specified, motor electrical performance and characteristics shall be in accordance with NEMA MG 1.

4.2.2 Voltage and Frequency

The standard three phase voltage ratings are:

- a) 60 Hz: 2300 V, 4000 V, and 6600 V;
- b) 50 Hz: 3000 V, 3300 V, 6000 V, and 6600 V.

Dual voltage motors are acceptable only for 2300/4000 V ratings.

NOTE When motors supplied under this standard are to be applied on a non-sinusoidal source and/or an adjustable speed application, the vendor should be consulted to determine if the motor will operate successfully over the required speed range. Refer to NEMA MG 1 Part 30 or IEC 60034-17. Proper selection of the motor and drive is required to avoid the following conditions:

- 1) motor RMS (root mean square) current exceeding the continuous sinusoidal nameplate rating due to excessive voltage harmonics or improper volt/hertz levels;
- 2) excessive winding temperature due to insufficient cooling, excessive torque levels, improper volt/hertz levels, or increased losses due to harmonics;
- 3) insufficient motor accelerating torque at reduced speeds due to insufficient volt/hertz levels or limitations in the drive's short-time current capacity;
- 4) increased noise levels due to increased fan noise (above base speed), excitation of mechanical resonances, or magnetic noise caused by supply source harmonics;
- 5) mechanical failure of the motor or coupling due to torque pulsations, operation at or near mechanical resonances, or excess speed;
- 6) winding failures due to repetitive high-amplitude voltage spikes created by the drive's carrier frequency and motor feeder cable system;
- 7) damage to the motor and drive due to improper application of power factor correction capacitors or harmonic filters;
- 8) higher motor temperatures that may limit application in Zone 2 or Division 2 hazardous (classified) locations;
- 9) shaft-to-bearing voltages/currents resulting from common mode currents flowing through stray system capacitances to ground via the bearings (these currents are induced from the ASD's high rate of change (dv/dt) of output voltage); and
- 10) extended operation at slow speed causing insufficient cooling or lubrication.

4.2.3 Motor Design and Starting Characteristics

4.2.3.1 Motors with power/speed ratings defined per NEMA MG 1 Part 12 [which covers up to 375 kW (500 hp), depending on speed] shall meet the requirements for Design B torque and current characteristics. Where applicable, the torque and current characteristics shall meet the requirements of IEC 60034-12 Design N.

4.2.3.2 Motor ratings above those defined for NEMA Design B shall meet, as a minimum, the standard torque characteristics defined in NEMA MG 1 Part 20. Where applicable, the torque characteristics shall meet the requirements of IEC 60034-12 Design N.

4.2.3.3 Motors shall be capable of accelerating a load with 80 % of rated voltage at the motor terminals where the load torque requirement varies with the square of the speed and the full-load torque requirement is equal to or less than the rated full-load torque of the motor. The load inertia for this condition shall be less than or equal to the

maximum inertia given within NEMA MG 1 for four-pole and slower motors, and less than or equal to one half the inertia listed for two-pole motors.

4.2.3.4 When the motor speed-torque curve at the conditions specified in 4.2.3.3 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.

- **4.2.3.5** When specified and when the purchaser provides particular load torque and inertia data, the motor vendor shall validate with the proposal that the 10 % minimum accelerating torque is maintained at 80 % rated voltage.

4.2.3.6 The motor shall be designed for a lifetime minimum of 5000 full voltage starts. Design features outlined in 4.3 shall be demonstrated in the stator construction and/or documented as part of the design. The rotor design shall have proven field service and shall be demonstrated or documented to include features of 4.4.5.

4.2.3.7 With rated voltage and frequency applied, the motor locked-rotor current shall not be less than 450 % of the full-load current. Additionally, the locked-rotor current shall not exceed the values given in NEMA MG 1 Part 12, where applicable. For motors larger than those listed in NEMA MG 1 Part 12, the locked-rotor current shall not exceed 650 % of the full-load current, including any tolerances in the calculations and uncertainties in the test methods.

4.3 Winding and Insulation Systems

4.3.1 Stator windings shall have an epoxy based, vacuum pressure impregnated, nonhygroscopic insulation system, including lead and coil connections. If bus bars are used as interface connections, they shall have the same insulation properties as would 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 60034-18-31, as applicable. The allowable temperature rise above ambient, 40 °C (104 °F) shall not exceed that listed for Class B insulation. For ambient temperatures above 40 °C (104 °F), the allowable temperature rise shall be reduced by the amount equal to the temperature above 40 °C (104 °F), so as not to exceed the total temperature limits (ambient, rise and hot spot) for Class B insulation. For windings operating at 6000 V (line-line) or greater, the use of partial discharge suppressant materials is required.

4.3.2 The insulation system shall be capable of withstanding the surge test specified in 6.1.4.

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 60034-18-31, as applicable.

4.3.4 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. The sealed insulation system shall be a proven design with temperature classification per IEEE 1776 or IEC 60034-18-31, as applicable. This standard shall not be interpreted to require a sealed winding conformance test unless specified by the purchaser.

4.3.5 The entire stator winding insulation system including winding connections and terminal leads shall be sufficiently secured to prevent insulation cracking and fatigue as a result of motion and vibrations during starting, operation and electrical transient conditions which produce electromechanical forces in the stator windings. The windings shall withstand electromagnetic and mechanical forces under normal operating conditions, the starting requirements specified in 4.2.3.3 and 4.2.3.6, and the forces associated with phase-to-phase and three phase short circuits with 110 % of rated voltage.

4.3.6 The insulation system, including leads, shall be compatible with mineral oil based lubricants. Type test and/or design information shall be supplied when requested on identical lead insulating material to verify this requirement has been satisfied.

4.3.7 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 number of these stator conductors shall be the

fewest practical to minimize the number of connection points. These conductors shall have Class F (minimum) insulation and in total be sized for a minimum of 125 % of rated current while not exceeding 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 bracing purposes, it shall be vacuum pressure impregnated so as to be made nonhygroscopic.

4.3.8 The type of slot wedges used (magnetic or non-magnetic) shall be indicated on the vendor's datasheet. If a magnetic wedge system is used, it shall comply with all of the following.

- a) The magnetic slot wedge material shall be of the amorphous or composite design, be Class F insulation as a minimum, and have a minimum flexural strength at 120 °C of 150 MPa (22,000 psi) as measured using ISO 178 or ASTM D790.
- b) The magnetic slot wedge design shall be a system that includes rigid slot wedge material and a global vacuum pressure impregnation (VPI) system.
- c) The wedge-to-slot interface shall be a tight fit that will support the wedge.
- d) The wedge shall fit tight up against the coil so that the stick will bond to the coil but still permit the wedge to be properly inserted into the slot without damage.

NOTE Magnetic slot wedges may improve the efficiency and temperature rise performance of machines, but there have been wedge failures in some cases due to poor fit, weak materials, and inadequate impregnation. For machines that use magnetic wedges, the purchaser may evaluate the vendor's experience with the wedge system used.

4.4 Mechanical Design

4.4.1 Enclosures

4.4.1.1 General requirements include the following.

- a) Enclosure parts shall be made of cast or nodular iron, cast steel, or steel plate.
- b) 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.).
- c) Designs in which the stator laminations form a part of the external enclosure are not acceptable.
- d) The motor shall be totally enclosed fan-cooled (TEFC/IC411, minimum IP44) or weather-protected Type II (WP-II/IC01, minimum IP24W) as defined in 4.4.1.2 and 4.4.1.3.

4.4.1.2 Totally enclosed fan-cooled (TEFC) motors shall meet the following criteria.

- a) 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.). The air intake opening shall be guarded by a grill or a metal screen. Protective grills or metal screens shall be fabricated from not less than 1.25 mm (0.049 in.) AISI 300 series stainless steel [or European Standard (EN) equivalent] with a maximum mesh of 6.4 mm (¹/₄ in.). Where the motor will be installed offshore, AISI 316 (or EN equivalent) material shall be supplied.
- b) 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.).
- c) Corrosion-resistant, replaceable automatic drainage fittings shall be provided and located as close as practical to the lowest point of the motor enclosure. These fittings shall be shown on the outline drawing.

4.4.1.3 Weather-protected Type II (WP-II) enclosures shall meet the following criteria.

- a) Ventilation openings shall be limited to a maximum size of 6.4 mm ($1/4$ in.) by design or by the use of metal screens. The screens shall be fabricated from not less than 1.25 mm (0.049 in.) AISI 300 series stainless steel (or EN equivalent) with a maximum mesh of 6.4 mm ($1/4$ in.). Where the motor will be installed offshore, AISI 316 material (or EN equivalent) shall be supplied.
- b) Motors shall be constructed so that any accumulation of water will drain from the motor.
- c) Airflow inlet filters of standard types and sizes shall be furnished. Air filters shall be designed to permit easy removal and replacement while the motor is running.
- d) Filters shall be of the reusable, cleanable type and 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 (or EN equivalent). The screens downstream of the filters shall have a maximum mesh of 13 mm ($1/2$ in.).
- e) Threaded connections shall be furnished for the future connection of an instrument to measure the pressure drop across the filters.
- f) When specified, a switch, gauge, or transmitter to measure the pressure drop across the filters shall be provided.

4.4.2 Frame and Mounting Plates

4.4.2.1 TEFC frames shall be of cast iron construction. WP-II frames shall be of cast or nodular iron, cast steel, or welded steel plate construction. The frame shall be provided with removable end brackets or end plates to permit removal of the rotor and facilitate replacement of stator coils.

4.4.2.2 Horizontal foot mounted motors shall be equipped with vertical jackscrews located at each foot to facilitate alignment.

- **4.4.2.3** Mounting plates (baseplates or soleplates), when specified, shall be machined steel plate and supplied with horizontal jackscrews (for motor 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.

4.4.2.4 The horizontal and vertical jackscrews shall be M16 ISO 68 ($5/8$ in. with UNC threads) minimum diameter.

4.4.2.5 The frame support or supports shall be provided with two pilot holes for dowels. The holes shall be within 45 degrees of vertical (as near the vertical as practical) and shall be located to provide adequate space for field drilling, reaming, and placement of dowels.

4.4.2.6 Lifting lugs, through holes, or eyebolts shall be provided for lifting major components and the assembled motor.

4.4.2.7 Mounting surfaces shall meet the following criteria.

- a) They shall be machined to a finish of 6 micrometers (250 micro-in.) arithmetic average roughness (Ra) or better.
- b) To prevent a soft foot, they shall be in the same horizontal plane within 125 micrometers (0.005 in.).
- c) Each mounting surface shall be machined within a flatness of 40 micrometers per linear meter (0.0005 in. per linear ft) of mounting surface.

- d) Different mounting planes shall be parallel to each other within 170 micrometers per meter (0.002 in. per ft).
- e) The upper machined or spot faced surface shall be parallel to the mounting surface.
- f) Hold-down bolt holes shall be drilled perpendicular to the mounting surface or surfaces, shall be machined or spot faced to a diameter two times that of the hole and, to allow for equipment alignment, shall be 13 mm ($\frac{1}{2}$ in.) larger in diameter than the hold down bolt.

4.4.3 Fans

Fan systems, blades, and housings shall be designed to prevent sparking as a result of mechanical contact or static discharge. Bi-directional fans are preferred. If a unidirectional fan is used, the rotation of the fan shall be indicated by a rotation arrow in accordance with 4.4.11 mounted on the motor.

4.4.4 Hardware

All the enclosure's bolts, studs, and other fastening devices up through M12 ($\frac{1}{2}$ in.) size, shall be AISI 300 series (or EN equivalent) stainless steel. Where the motor will be installed offshore AISI 316 material (or EN equivalent) shall be supplied.

4.4.5 Rotating Element

4.4.5.1 General

4.4.5.1.1 No shaft-straightening technique is permitted during or after fabrication of the rotor.

- 4.4.5.1.2 When non-contacting eddy current vibration probes are specified, the probe-mounting and shaft preparation requirements of API 541 shall apply.

4.4.5.2 Rotor Cage Material

Die cast aluminum rotor cages are acceptable for motors rated up to 750 kW (1000 hp). For motors rated above 750 kW (1000 hp), the cage construction shall be of fabricated copper or copper alloy. All brazing materials shall be phosphorous free to prevent hydrogen sulfide attack.

4.4.6 Dynamics

A stiff-shaft motor determined with the motor mounted on a massive foundation as described in API 541 shall be provided. Lateral natural frequencies, which can lead to resonance amplification of vibration amplitudes, shall be above the maximum normal operating speed frequency by at least 15 %. The motor shall be capable of demonstrating a minimum 15 % separation margin during an unbalance response (coast down) test.

4.4.7 Bearings, Bearing Housings, and Seals

4.4.7.1 Bearings

4.4.7.1.1 Hydrodynamic radial bearings with oil ring lubrication shall be provided for horizontal motors unless otherwise specified in 4.4.7.1.6.

4.4.7.1.2 Hydrodynamic radial bearings shall be split for ease of assembly. The bearings on each end of the motor shall be identical.

4.4.7.1.3 The design of the hydrodynamic bearing housing shall not require removal of the lower half of the end bell or plates, ductwork, or coupling hub to permit replacement of shaft seals or bearing liners, pads, or shells.

4.4.7.1.4 Hydrodynamic bearing temperatures shall not exceed 93 °C (200 °F) as measured by resistance temperature detectors (RTDs) with the motor operating at rated output and at the maximum rated ambient temperature indicated on the datasheet.

4.4.7.1.5 The fit between the outside of the bearing shell and the bearing housing of hydrodynamic bearings shall be zero clearance to an interference fit at ambient temperature.

- **4.4.7.1.6** When specified, antifriction bearings may be supplied for horizontal motors. The following conditions shall be met.

- a) The dN factor shall be less than 300,000.
- b) Bearings shall have an ABMA or ISO L10 life of at least 100,000 hours in direct coupled applications with continuous operation at rated conditions.
- c) Ball and roller bearing manufacturing tolerance limits shall be ABEC 1 in accordance with ABMA 20 or ISO Normal in accordance with ISO 492. Ball bearings shall have internal clearances in accordance with ABMA 20 or ISO 5753-1, Group 3 (C/3 clearance) or Group 4 (C/4 clearance). Bearing dimensions shall be in accordance with ABMA 20 or ISO 15.

4.4.7.1.7 Antifriction bearings shall be used on vertical motors and shall meet the following requirements.

- a) The dN factor shall be less than 300,000.
- b) Bearings shall be rated for ABMA or ISO L10 life of at least 50,000 hours at rated conditions with the continuous maximum radial and thrust loads applied to motor.
- c) Thrust bearings shall be rated for at least 5000 hours with continuous operation at 200 % of maximum up or down thrust load, whichever is greater.
- d) All bearings designed to handle axial loads shall be located on the non-drive end.
- e) Tandem or duplex antifriction bearings shall be permitted when required to handle the thrust load and shall be oil lubricated. In no case shall more than two bearings be stacked.
- f) Grease lubricated bearings shall be regreasable. Fittings for grease lubricated bearings shall be arranged for safe and easy access to provide lubrication while the motor is in operation without removal of external covers.
- g) When oil lubricated bearings are provided, the bearing lubrication shall be made with an internal lubricant recirculating system. The purchaser shall be advised if an external cooler is required. All oil lubricated bearings shall be furnished with oil level indicators.
- h) Vertical motors designed for no external thrust loads shall have either ball or single row angular contact bearings that are mounted on top in either grease or oil lubrication.
- i) Except for the angular-contact bearings and spherical roller thrust bearings, single- or double-row bearings shall be of deep groove (Conrad) type and shall have an internal clearance equivalent to ABMA 20 and ISO 5753-1, Group 3 (C/3 clearance). Filling slot (maximum-load) bearings shall not be used. Bearings shall be commercially available from more than one bearing manufacturer. Bearing dimensions shall be in accordance with ABMA 20 or ISO 15.

4.4.7.2 Bearing Housings

4.4.7.2.1 Bearing housings and shaft seals shall be designed to meet the requirements of IP55 per NEMA MG 1 or IEC 60034 as a minimum.

4.4.7.2.2 A permanent indication of the proper oil level to within 1 mm (0.04 in.) of the actual operating oil level shall be clearly marked on the outside of the bearing housing with metal tags, marks inscribed in the castings, or other durable means. If the oil level indicator breaks, any resulting drop in oil level shall not result in the loss of bearing lubrication, that is, reduction of the oil level below the level required for oil ring operation.

4.4.7.2.3 Hydrodynamic bearing housings on horizontal motors shall be equipped with constant level sight feed oilers, which are at least 0.25 liters (8 oz) in size and include a positive level positioner (not a set screw), glass container, protective wire cage, and supplemental support in addition to the piping.

4.4.7.2.4 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.

4.4.7.2.5 Bearing housings shall be located by cylindrical precision dowels and/or rabbet fits.

4.4.7.3 Shaft Seals

4.4.7.3.1 Shaft seals for hydrodynamic radial bearings shall conform to the following.

- a) Primary bearing housing/enclosure seals (both inboard and outboard) shall be made from a non-sparking material and shall be split labyrinth type.
- b) The seals shall have a minimum life expectancy of five years under usual service conditions. Lip type seals shall not be used.
- c) Oil shall not leak past the seals when the rotor is stationary or when operating within rated conditions.

4.4.7.3.2 Shaft Seals for antifriction bearings shall conform to the following.

- a) All antifriction bearings shall have replaceable labyrinth shaft seals of the non-contact or non-contacting-while-rotating type with a minimum expected seal life of five years under usual service conditions.
- b) Cast iron inner bearing caps shall be provided to minimize grease or oil migration to the motor interior.

4.4.7.4 Bearing Insulation

4.4.7.4.1 Both bearings shall be electrically insulated. A shorting device shall be provided in the bearing housing on the drive end.

4.4.7.4.2 The bearing insulation shall be permanent and non-deteriorating during assembly and disassembly of the bearing for the service life of the motor. The bearing insulation resistance shall be at least 10 megohms at a test voltage of 50 V DC minimum.

4.4.8 Lubrication

4.4.8.1 Hydrodynamic bearings shall use mineral oil and shall be arranged for ring-type lubrication in accordance with the bearing manufacturer's recommendations.

4.4.8.2 Oil lubricated antifriction bearings shall use mineral oil and be arranged for the type of lubricant circulation and cooling in accordance with the bearing manufacturer's recommendations for the application.