

# **Brushless Synchronous Machines—500 kVA and Larger**

API STANDARD 546  
FOURTH EDITION

POST 4<sup>TH</sup> BALLOT CHANGES

VENDOR DATA CHANGES AS SUGGETED BY API

# Brushless Synchronous Machines—500 kVA and Larger

## 1 General

### 1.1 Scope

**1.1.1** This standard covers the minimum requirements for form-wound and bar-wound brushless synchronous machines 500 kVA and larger for use in petroleum, chemical and other industrial applications. This standard includes synchronous motors and generators with two different rotor designs:

- a) salient-pole type rotors with solid or laminated poles;
- b) cylindrical type rotors with solid or laminated construction.

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

Some paragraphs have intentionally been left blank to align paragraph numbers with API 541.

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 or Annex B); 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** The purchaser specifies machine details and features by completing the associated sections of the datasheets in Annex A or Annex B.

NOTE Guidance for completion of the datasheets is provided in Annex D and Annex E.

**1.1.3** The vendor completes the details and features in the vendor section of the Annex A or Annex B datasheets. (See Section 8.)

**1.1.4** Within this Standard, the term "motor" addresses synchronous motors as well as synchronous motor-generators that are subjected to an asynchronous start. The term "machine" addresses the three types of machines: motors, generators, and motor-generators.

**1.1.5** Super synchronous motor applications are addressed in Annex I.

### 1.2 Alternative Designs

The vendor may offer alternative designs in accordance with 8.1.49.

### 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. If 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 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 546 standard, and
- 5) referenced publications

## 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 Recommended Practice 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*

API Recommended Practice 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1 and Zone 2*

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

API Recommended Practice 684, *Tutorial on the API Standard Paragraphs Covering Rotor Dynamics and Balance (An Introduction to Lateral Critical and Train Torsional Analysis and Rotor Balancing)*

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

ABMA 9, *Load Ratings and Fatigue Life for Ball Bearings*

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<sup>1</sup> American Bearing Manufacturers Association, 2025 M Street, NW, Suite 800, Washington, DC 20036, [www.americanbearings.org](http://www.americanbearings.org).

ABMA 11, *Load Ratings and Fatigue Life for Roller Bearings*

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

AGMA 9002–B04 <sup>2</sup>, *Bores and Keyways for Flexible Couplings (Inch Series)*

AISI <sup>3</sup>, *Material Properties of Stainless Steel*

ANSI S12.54, *Acoustics—Determination of Sound Power Levels of Noise Sources Using Sound Pressure—Engineering Method in an Essentially Free Field Over A Reflecting Plane*

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

ASME *Boiler and Pressure Vessel Code* <sup>4</sup>, Section V—*Nondestructive Examination*; Section VIII—*Rules for Construction of 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, (Class 25, 125, 250)*

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

ASME B16.11, *Forged Steel 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*

ASTM A278 <sup>5</sup>, *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 A469, *Standard Specification for Vacuum-Treated Steel Forgings for Generator Rotors*

ASTM A515, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A536, *Standard Specification for Ductile Iron Castings*

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

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<sup>2</sup> American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314, [www.agma.org](http://www.agma.org).

<sup>3</sup> American Iron and Steel Institute, 1540 Connecticut Avenue, N.W., Suite 705, Washington, D.C. 20036, [www.steel.org](http://www.steel.org).

<sup>4</sup> ASME International, 3 Park Avenue, New York, New York 10016, [www.asme.org](http://www.asme.org).

<sup>5</sup> ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, [www.astm.org](http://www.astm.org).

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

ASTM E94, *Standard Guide for Radiographic Testing*

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

ASTM E709, *Standard Guide for Magnetic Particle Examination*

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

AWS D1.1 <sup>6</sup>, *Structural Welding Code—Steel*

CENELEC EN10250 <sup>7</sup>, *Open Die Steel Forgings for General Engineering Purposes, Part 1—General Requirements*

CSA W47.1-09, *Certification of companies for fusion welding of steel*

IEC 60034-1<sup>8</sup>, *Rotating Electrical Machines, Part 1—Rating and Performance*

IEC 60034-2, *Rotating Electrical Machines, Part 2—Methods for Determining Losses and Efficiency or Rotating Electrical Machinery from Tests [Excluding Machines for Traction Vehicles]*

IEC 60034-4, *Rotating Electrical Machines, Part 4—Methods of Determining Synchronous Machine Quantities from Tests*

IEC 60034-5, *Rotating Electrical Machines, Part 5—Degrees of Protection Provided by the Integral Design of Rotating Electrical Machines (IP Code)—Classification*

IEC 60034-6, *Rotating Electrical Machines, Part 6—Methods of Cooling (IC Code)*

IEC 60034-8, *Rotating Electrical Machines, Part 8—Terminal Markings and Direction of Rotation*

IEC 60034-15, *Rotating Electrical Machines, Part 15—Impulse Voltage Withstand Levels Of Rotating A.C. Machines With Form-wound Stator Coils*

IEC 60034-18, *Rotating Electrical Machines, Part 18—Functional Evaluation of Insulation Systems*

IEC TS 60034-27, *Rotating Electrical Machines, Part 27—Off-Line Partial Discharge Measurements on the Stator Winding Insulation of Rotating Electrical Machines*

IEC 60038, *IEC Standard Voltages*

IEC 60072, *Dimensions and Output Series for Rotating Electrical Machines*

IEC 60079, *Electrical Apparatus for Explosive Gas Atmospheres*

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<sup>6</sup> American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, [www.aws.org](http://www.aws.org).

<sup>7</sup> European Committee for Electrotechnical Standardization, 35 Rue de Stassartstraat, B-1050 Brussels, Belgium, [www.cenelec.eu/Cenelec/Homepage.htm](http://www.cenelec.eu/Cenelec/Homepage.htm).

<sup>8</sup> International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, [www.iec.ch](http://www.iec.ch).

IEC 60270, *High Voltage Test Techniques—Partial Discharge Measurements*

IEC 60404-1-1, *Magnetic Materials—Classification—Surface Insulations of Electrical Steel Sheet, Strip and Laminations*

IEC 60529, *Degrees of Protection Provided by Enclosures (IP Code)*

IEEE C50.13, *Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above*

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

IEEE 115, *Test Procedures for Synchronous Machines*

IEEE 286, *Measurement of Power Factor Tip-up of Electric Machinery Stator Coil Insulation*

IEEE 522, *Guide for Testing Turn Insulation on Form-wound Stator Coils for Alternating-current Electric Machines*

IEEE 841, *Standard for Petroleum and Chemical Industry—Severe Duty Totally-enclosed Fan-cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 Kw (500 Hp)*

ISO 15 , *Rolling Bearings—Radial Bearings—Boundary Dimensions, General Plan*

ISO 68 , *ISO General Purpose Screw Threads*

ISO 261, *ISO General Purpose Metric Screw Threads—General Plan*

ISO 286-1, *ISO System of Limits and Fits—Bases of Tolerances, Deviations and Fits*

ISO 286-2, *Geometrical product specifications (GPS) — ISO code system for tolerances on linear sizes — Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts*

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

ISO 1680, *Acoustics - Test Code for the Measurement of Airborne Noise Emitted by Rotating Electrical Machines*

ISO 1940-1, *Mechanical Vibration—Balance Quality Requirements for Rotors in a Constant (Rigid) State, Part 1— Specification and Verification of Balance Tolerances*

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

ISO 3452, *Non-Destructive Testing—Penetrant Inspection—General Principles*

ISO 3453, *Non-Destructive Testing—Liquid Penetrant*

ISO 3506, *Mechanical Properties of Corrosion Resistant Stainless-steel Fasteners*

*ISO 4386-1, Plain Bearings - Metallic Multilayer Plain Bearings - Part 1: Non-Destructive Ultrasonic Testing Of Bond Of Thickness Greater Than Or Equal To 0,5 Mm*

ISO 5579, *Non-destructive Testing—Radiographic Examination Of Metallic Materials By X- and Gamma-rays—Basic Rules*

ISO 5753, *Rolling Bearings—Radial Internal Clearance*

ISO 7005, *Metallic Flanges*

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 9606, *Qualification testing of welders*

ISO 10721-1, *Steel Structure, Part 1—Materials and Design*

ISO 17025, *General Requirements for Competence of Calibration and Test Labs*

NEMA MG1 <sup>9</sup>, *Motors and Generators*

NFPA 70 <sup>10</sup>, *National Electrical Code*

### **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 (VSD), adjustable frequency drive (AFD), and variable frequency drive (VFD); however, use of these terms is discouraged.

#### **3.3**

##### **amortisseur winding**

An amortisseur winding is a permanently short-circuited winding consisting of conductors embedded in the pole shoes of a synchronous machine and connected together at the ends of the poles, but not necessarily connected between poles. An amortisseur winding is often used for starting purposes and used in both

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<sup>9</sup> National Electrical Manufacturers Association, 1300 North 17<sup>th</sup> Street, Suite 1752, Rosslyn, Virginia 22209, [www.nema.org](http://www.nema.org).

<sup>10</sup> National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, [www.nfpa.org](http://www.nfpa.org).

motors and generators to dampen mechanical oscillations. On machines with solid pole shoes, the pole shoes act as the amortisseur winding.

### **3.4**

#### **anchor bolt**

Bolts used to attach the equipment to the support structure (concrete foundation or steel structure).

### **3.5**

#### **balance weight**

Balance weight is any mass added to a rotating component with the purpose of reducing unbalance to the required level in the balance device and not defined as a trim balance weight.

Note: balance weight can also be defined as a correction mass.

### **3.6**

#### **cold point**

The cold point of a vibration test is the point at which the bearing temperature has stabilized (change of not more than 1 °C in 30 min) at the no load condition, ignoring transient conditions associated with field application.

### **3.7**

#### **cold start**

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

### **3.8**

#### **in-frame balance**

In-frame balance is the process of balancing the rotor assembly in its own bearings and support structure (e.g. frame, brackets, pedestal) rather than in a balance device.

### **3.9**

#### **hold down bolts**

#### **mounting bolts**

Bolts holding the equipment to the mounting plate.

### **3.10**

#### **hot start**

A hot start is any start that occurs when the rotor and/or stator are above rated ambient temperature.

### **3.11**

#### **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 values but are critical speeds confirmed by test-stand data. Critical speeds above the maximum test speed are calculated damped values.

### **3.12**

#### **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.

### **3.13**

#### **owner**

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

### **3.14**

#### **power factor**

##### **PF**

Power factor is the ratio of kilowatt input to kilovolt-ampere input for a motor or the ratio of kilowatt output to kilovolt-ampere output for a generator.

### **3.15**

Types of externally circulated lubrication:

#### **flood lubrication**

Flood lubricated hydrodynamic bearings utilize an external source to continuously apply low pressure lubricant to the bearing loading surfaces. This source is typically a common lubrication system that supplies oil to the multiple bearings of rotating equipment included in an equipment train. Oil is supplied to the electrical machine at an elevated pressure and reduced to a slightly higher than atmospheric value by a flow regulating device near the bearing housing(s). Oil flows between the babbitt material and shaft for lubrication and cooling, then collects in the bearing housing sump and returns to the system through a properly sized drain. See API 614.

#### **pressure lubrication**

Pressure lubricated hydrodynamic bearings utilize an external source to continuously apply high pressure lubricant to the bearing loading surfaces where an over-riding force exists. For example external thrust on plate bearings. This source is typically a common lubrication system that supplies pressurized oil to the multiple bearings of rotating equipment included in an equipment train. Oil is supplied to the electrical machine at an elevated pressure then regulated near the bearing housing(s). Oil flows between the babbitt material and stationary surface or shaft for lubrication and cooling, then collected in the bearing housing sump and returned to the system through a properly sized drain. See API 614.

#### **hydrostatic jacking**

Hydrostatic jacking applies to machines which require that the shaft be lifted, or raised, from the bearing surface(s) prior to rotation to ensure separation or the development of an oil film. This source is typically located close to the bearing(s) requiring jacking oil. Oil is injected at an elevated pressure in specific areas of the shaft-bearing interface to produce separation. It is possible that not all bearings in an equipment train require jacking oil. Hydrostatic jacking is also used to aid in maintenance where the rotor or train components are spun or indexed at slow rpm by an external source.

### **3.16**

#### **pull-in torque**

Pull-in torque is the maximum constant torque of a synchronous motor under which the motor will pull the connected load inertia into synchronism at the rated voltage and frequency when rated field excitation is applied.

### **3.17**

#### **pull-out torque**

Pull-out torque is the maximum sustained torque of a synchronous motor that the motor will develop at synchronous speed with the rated voltage, frequency, and excitation applied.

### **3.18**

#### **pulsating torque**

Pulsating torque is the single amplitude oscillatory torque of a synchronous motor that is superimposed on the mean uniform starting torque developed by the motor during an asynchronous start. The frequency of this

torque oscillation is twice the rotor-slip frequency and thus decreases linearly (at the usual rated frequencies of 50 Hz or 60 Hz) from 100 Hz or 120 Hz to 0 Hz as the speed increases from zero to synchronous speed.

### **3.19**

#### **purchaser**

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

### **3.20**

#### **removable link**

Removable links are insulated copper bus bars that are installed in the main machine terminal box and located such that the removal of the bus bars isolates each phase winding from the line side power connections and any terminal box auxiliary devices.

### **3.21**

#### **self-lubrication**

Self-lubricated hydrodynamic bearings utilize rotation of the shaft to continuously apply lubricant to the bearing surfaces from 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.

### **3.22**

#### **service factor**

Service factor is a multiplier applied to the rated power of an AC motor, which indicates an increased power loading that may be carried under the conditioning specified for the service factor (see NEMA MG1).

NOTE For service factors above 1.0, the motor will run at an increased temperature and insulation life will be adversely affected.

### **3.23**

#### **special tool**

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

### **3.24**

#### **stator shift**

Stator shift is where the stator assembly is axially re-located on the soleplate or base without bearing removal. This exposes the rotor poles to facilitate maintenance or removal.

### **3.25**

#### **torsional critical speeds**

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

NOTE The first torsional natural frequency of synchronous-motor/driven-equipment combinations normally lies between twice the line frequency and zero frequency and could be excited from the motor or driven equipment. This means that at least the first torsional critical speed is traversed each time such a drive train is started. 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 the torque oscillations, the torque oscillation could 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.

### **3.26**

#### **trim balance (trim balance weight)**

Adding, modifying, or removing any mass from the completed rotor assembly after it has been balanced in the balancing device.

### **3.27**

#### **trip speed**

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

### 3.28

#### **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.

### 3.29

#### **vendor**

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

### 3.30

#### **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 system 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 motor load or generator driver;~~
- ~~i) short-circuits (faults) and other transient conditions on the electrical system;~~
- ~~j) ASDs; and~~
- ~~k) ——— electrical exciting pulsating torque with double slip frequency.~~

## **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 flood lubrication system for the bearings is typically installed if a five year continuous uninterrupted operation is required.~~  
**4.1.1 Equipment Reliability**

- **4.1.1.1** Only equipment that is field proven is acceptable. The purchaser shall specify the TRL level from API 691 for qualified equipment.

~~NOTE 1 Purchasers can use their engineering judgment in determining what equipment is field proven. Typically, motors and generators covered by this standard are of a field proven design consistent with a TRL level of 7.~~

- **4.1.1.2** If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

**4.1.1.3** In the event no such equipment is available, the vendor shall submit an explanation of how their proposed equipment can be considered field proven.

~~NOTE A possible explanation can be that all components comprising the assembled machine satisfy the field proven definition.~~

- **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 or Annex B). 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 machine shall not exceed 85 dBA at a reference distance of 1 m (3 ft) with the machine 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).

**4.1.3.1** For machines that utilize sound insulation, a supplementary mechanical means shall be incorporated to prevent pieces of the insulation from coming loose and blocking cooling passages.

- ◆◆ **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. For concerns around increased motor sound levels due to the ASD application, the Purchaser should address these issues with the ASD and motor suppliers and reach agreement on resolution.

NOTE Some ASDs could 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.

- ◆◆ **4.1.5** All equipment shall be designed to be mechanically stable at the overspeed and duration specified in the applicable standard (e.g., NEMA MG 1, IEEE C50.13, or 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, (including the rotating elements of the exciter and synchronizing controls as applicable) shall be ~~subject to approval by 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 for easy removal of covers for maintenance and inspection
- d) elimination of air pockets and traps; and
- e) complete drainage through low points without disassembly of piping.

- **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 maintenance and inspection of coil end turns, the exciter, synchronizing controls, and rotor windings as applicable. Easily removable covers shall be provided for the inspection of the air gap in at least three places at each end of the stator, each separated by 90° as specified in 4.4.7.2.4.

The manufacturer shall bring to the attention of the purchaser any and all cases where the above requirements cannot be met.

Note: Inspection covers are possible in all situations such as cast frames, smaller fabricated frames, TEAAC air path, etc.

- ~~**4.1.11**~~ If special tools or fixtures are required to disassemble, assemble or maintain the equipment, they shall be included in the quotation and furnished as part of the initial supply of the equipment. ~~For multiple-unit installations, the requirements for quantities of special tools and fixtures shall be agreed between purchaser and vendor.~~ These special tools shall be used, and their use demonstrated, during shop assembly and post-test disassembly of the equipment.

Note: For multiple-unit installations, the quantity of special tools or fixtures can be adjusted as agreed between purchaser and vendor.

~~**4.1.12**~~ **4.1.24.4** If special tools are provided, each tool shall be labeled using metal stamps or have a permanently attached stainless steel tag to indicate its intended use. Tools which do not exceed 1 meter in length, width or height and that weigh less than 40 kg shall be packaged in one or more rugged metal boxes and shall be marked "special tools for (tag/item number), box x of x". Larger tools do not need to be boxed but shall have a stainless steel tag permanently attached to indicate both the intended use and the tag/item number of the equipment for which they are intended.

~~**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 equipment (including auxiliaries) covered by this standard shall be suitable for the specified operating conditions and shall be designed and constructed for 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 flood lubrication system for the bearings is typically installed if a five year continuous uninterrupted operation is required.

~~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.~~

**4.1.15** Oil reservoirs and housings that enclose moving lubricated parts such as bearings, shaft seals, highly polished parts, instruments, and control elements, shall be designed to meet the requirements of IP 55 as a minimum to reduce contamination by moisture, dust, and other foreign matter.

## **4.2 Electrical Design**

### **4.2.1 Rating and Voltage**

- **4.2.1.1** Unless otherwise specified, motors shall use standard power ratings per the standards referenced in Table 0. If the required rating falls between two listed ratings, the larger listed rating shall be selected. Generators shall be rated to meet or exceed the prime mover capability throughout the defined operating range. Machine kVA ratings shall correspond to the specified power and power factor.

**Table 04.2.1.1 – Power Ratings**

	<b>Power Rating Units</b>	<b>Applicable Standard</b>
<b>Motors, US customary data sheets</b>	hp	<b>NEMA MG1 Part 21</b>
<b>Generators, US customary data sheets</b>	kW	<b>NEMA MG1 Part 32</b>
<b>Motors and Generators, SI data sheets</b>	kW	<b>IEC 60072-2, R40 series</b>

- **4.2.1.2** Unless otherwise specified, machines shall be rated for the bus voltage.

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

**Table 1—Voltage Ratings for Three Phase 60 Hz Systems**

Horsepower or kVA	Machine and System Voltage
500–4,000	2,400
500–7,000	4,160
1,000–12,000	6,900
3,500–Above	13,800

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

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

kW	Machine and System Voltage
500 – 4,000	3,300
500 – 12,000	6,600
4,000 – Above	11,000

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

kW	Machine and System Voltage
500 – 4,000	3,000
500 – 12,000	6,000
4,000 – Above	10,000

NOTE 1 Nonstandard supply voltages would lead to other 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. While ASD output voltage harmonics and voltage to frequency ratio typically match motor design parameters (voltage and flux), the vendor should be informed by the purchaser of any deviations and appropriate design accommodations should be mutually agreed between purchaser and vendor.
- **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  $\pm 10\%$ .

**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, power factor, 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. the heat produced by operating above the rated power may still be within the insulation rating). This higher temperature operation negatively impacts the life of the insulation and other components of the machine. Therefore, machines are sized and selected based upon a standard 1.0 service factor rating (see datasheet guide for nameplate rating information).

**4.2.1.5** Maximum momentary overload capability for synchronous machines shall be per NEMA MG 1, ~~IEEE C50.12~~, IEEE C50.13, or IEC 60034-1.

## 4.2.2 Motor 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 21. When the loads have characteristics other than those listed in NEMA MG 1, Part 21, 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 could 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 21 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).

To obtain  $Wk^2$  [lb-ft<sup>2</sup>], multiply  $J$  [kg-m<sup>2</sup>] by 23.73.

$$J = 0.25GD^2$$

$$D = 2R$$

where

$J$  is the polar mass moment of inertia (kg-m<sup>2</sup>);

$G$  is the rotating mass (kg);

$D$  is the diameter (m);

$R$  is the radius of gyration (m);

$W$  is the rotating mass (lb); and

$k$  is the radius of gyration (ft).

### 4.2.3 Motor 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 4.2.3.1 or 4.2.3.2 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 pull-in torque point.

NOTE Some ASDs could limit motor accelerating torque at reduced speeds due to insufficient flux (V/Hz) levels or limitations in the drive's momentary current capacity. If this is a concern, the purchaser could work with the motor supplier to implement a special motor design.

**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** ~~(This paragraph intentionally left blank.)~~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 66 % 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 could 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 Motor Starting Capabilities

- **4.2.4.1** Unless otherwise specified, the motor shall be designed and constructed for a minimum of 5,000 full voltage starts. Fixed-speed motors shall also have the starting capabilities in Table 4. Starting capabilities for motors different from those shown in Table 4 shall be jointly developed between the purchaser and the vendor (see Note 2 following 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 or below rated ambient temperature (cold start)	3
Motor at a temperature above rated 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, the number of starts could be reduced 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 could be increased to allow maximum starting flexibility for the operation.

**4.2.4.2** The motor vendor shall provide motor thermal capacity data (per 4.2.4.3) necessary 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:

a) thermal limit curves (per IEEE 620) with the motor initially at ambient temperature;

Note: Although intended for induction machines, IEEE 620 gives useful information on developing thermal limit curves that could be used for synchronous motors.

b) thermal limit curves (per IEEE 620) with the motor initially at rated temperature;

c) acceleration time curves with the defined shaft load at rated voltage and at the starting voltage conditions specified in 4.2.3;

d) required wait time prior to another start after exhausting the defined number of starts, with the motor running at rated load;

e) required wait time prior to another start after exhausting the defined number of starts, with the motor stopped; and

f) after exhausting the defined number of starts, required wait time for the motor to return to ambient conditions with the motor stopped.

- **4.2.4.3** The minimum safe hot stall (locked rotor) time shall be the greatest 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. The minimum safe stall (locked rotor) time shall be clearly identified on the thermal limit curves.

**4.2.4.4** With rated voltage and frequency applied, motors 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 not exceed 500 % of the full-load current.

b) The minimum locked-rotor, pull-in, and pull-out torques shall not be less than the values listed in NEMA MG 1 Part 21 or IEC 60034-1.

- ◆● **4.2.4.5** When the motor is only started by an ASD, 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 could lead to higher rotor and stator temperatures due to harmonic currents, which could be a concern for Division 2 and Zone 2 applications. In addition, the “displaced neutral” effect of some drive topologies could lead to the shaft being at an elevated voltage to ground, which creates the possibility of electric discharge across the bearings and consequent ignition of a flammable mixture.

NOTE 2 Torsional oscillations could be caused by the drive harmonics, leading to the need for a torsional study.

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

NOTE 4 Refer to IEEE 1349 and IEC 60079-0 for incendive energy calculation methods.

## 4.2.5 Generator Start/Stop Cycling Capabilities

- **4.2.5.1** Unless otherwise specified, the generator shall be designed and constructed to withstand the thermal cycling and mechanical fatigue of at least 10,000 start/stop cycles.

## 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) Main 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, IEEE C50.13~~2~~, 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.

When a VPI insulation system is not available, an alternative insulation system meeting the performance criteria of this— standard requires the approval of the Owner.

- b) The allowable temperature rise above ambient, ~~normally 40 °C (104 °F)~~ unless otherwise specified, shall not exceed that listed for Class B insulation in NEMA MG 1 Part 21, IEEE C50.13 or IEC 60034-1 as appropriate. 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 for Class B insulation.
- c) Generators driven by combustion gas turbines shall meet or exceed the turbine output over the specified range of ambient conditions without exceeding Class B total temperature limits. Unless otherwise specified, the generator nameplate and performance data shall be shown based on 40 °C cooling air.
- ♦♦ **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. The purchaser shall provide the motor supplier with necessary harmonic data. 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 the motor vendor with these parameters.

- ◆◆ **4.3.1.2.1** The purchaser shall provide the motor vendor with drive output voltage amplitude and rise time characteristics at the motor terminals so that the insulation system can be designed 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.

**4.3.1.3** Machine field coil turn insulation shall be maintained during forming, winding, and curing. Rotor coils made from rectangular wire or edgewound strips shall be adequately insulated and securely braced. Additional ground insulation and blocking shall be used as required to maintain the integrity of insulation. To improve the cooling effect, individual turns of the windings may project on particular sides or all around the pole to form cooling fins. Adequate creepage paths, distances, and clearances shall be provided on all current-carrying conductors. The complete rotor winding system shall withstand the mechanical and electrical stresses that occur during starting and normal operating, surge, overspeed, and short-circuit conditions, as well as during shutdown and all tests specified. The rotor insulation system shall be suitably rated for induced overvoltage conditions or be provided with over voltage protection via by-pass thyristors, varistors or a discharge resistor.

The insulation on field windings shall maintain its integrity while withstanding the centrifugal forces and thermal stresses at Class F temperature without damage and per 4.3.1.1 b). Special attention shall be given to adequate support of both coil-to-coil connections and coil-to-main-field-lead connections.

**4.3.1.4** The exciter rotor and stator insulation shall be Class F and per 4.3.1.1 b), using a highly moisture and chemical resistant, cured material. The conductor strands shall be individually insulated by an enamel coating, a glass weave, or a combination of these that is saturated with varnish to provide turn-to-turn insulation.

- **4.3.1.5** When specified, the exciter rotor and stator windings shall have a sealed insulation system, as defined by NEMA MG 1 Part 1.

**4.3.2** The insulation system of multi-turn stator windings 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. Sheared exposed edges of insulation parts shall be sealed. 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** Machines 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 one or more terminal box(es). Owner shall specify the location of the terminal box/boxes and conduit or cable entry in the note section of the datasheet.

**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 machine frame and terminal box. If used, electrical grade fiberglass shall 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** Magnetic stator slot wedges shall not be used.

**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) [intentionally left blank]
- 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 machine 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 NFPA 496, IEEE 303, IEEE 1349, and IEC 60079 for 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 Machine Enclosures and Corresponding NEMA or IEC 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 6.4 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 will drain from the machine.
- c) When abrasive dust conditions have been specified, 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** Dripproof 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 could result in reduced reliability (see 4.1.1 and Table 5).

**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 <sup>a</sup> IP Code	Method of Cooling <sup>b</sup>
Dripproof 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 <sup>c</sup> IC86W <sup>d</sup>
Air to air cooled	TEAAC	1.26.8	IP44/54	IC511 <sup>c</sup> IC516 <sup>d</sup> IC611 <sup>c</sup> IC616 <sup>d</sup> IC666 <sup>e</sup>
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.
- e) Auxiliary primary and secondary fans.

**4.4.1.2.3** Totally enclosed machines (~~TEFC~~, TEPV, TEWAC and TEAAC or the IEC equivalents) 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 (<sup>1</sup>/<sub>8</sub> 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.
- 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 (<sup>1</sup>/<sub>8</sub> in.).
- c) 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.
- d) Requirements for heat exchanger tube materials are is outlined in 4.4.10.8.
- e) 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 or the IEC equivalents) machines shall be designed for the following conditions.

- a) Unless otherwise specified, cooling water system or systems shall be designed on the water side for the following conditions. The vendor shall notify the purchaser if a 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 of the specified concentration.

Water 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)	700 kPa (7 bar)	100 psig
Test pressure ( $\geq 1.5$ MAWP)	$\geq 1050$ kPa (10.5 bar)	$\geq 150$ psig
Maximum pressure drop	100 kPa (1 bar)	15 psig
Maximum inlet temperature	30 °C	90 °F
Maximum outlet temperature	50 °C	120 °F
Maximum temperature rise	20 K	30 °F
Minimum temperature rise	10 K	20 °F
Water side fouling factor	0.35 m <sup>2</sup> K/kW	0.002 hr-ft <sup>2</sup> -°F/Btu
Corrosion allowance for carbon steel shells	3 mm	<sup>1</sup> / <sub>8</sub> in.

Note 1: 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.

Note 2: When using this table, the column appropriate to the system of units specified applies (see 1.3.1).

- 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) When specified, a flow-sensing device shall be provided for mounting in the water supply piping to each cooler.
- h) When 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, terminal boxes, 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):

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

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

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 1 The reason for requiring margin from the 2X multiple as well as 1X, is that electric machines can have a significant electrical vibration component at the 2X multiple. Margin requirements are based upon percentage of rated operating frequency. For example, 15% minimum margin from two times the electric operating frequency on a 60 Hz system means that natural frequencies do not occur between 111 Hz and 129 Hz [e.g. for 2 x 60 Hz electric operating frequency,  $N = (2 \times 60) \pm (0.15 \times 60) = 111 \text{ Hz or } 129 \text{ Hz}$ ].

NOTE 2 Transfer of vibration from surrounding equipment is avoided by proper layout of the foundation, which is the responsibility of the purchaser. For guidance, 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 or ISO 10721-1 at the maximum operating temperature. For cast materials, the factors specified in Section VIII, Division I of the ANSI/ASME BPVC or ISO 10721-1 shall be applied. The conditions evaluated shall include short circuits, out-of-phase synchronism, 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 (<sup>5</sup>/<sub>8</sub> 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 (<sup>5</sup>/<sub>8</sub> 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. Soleplates 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 jackbolt 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 (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 at least M16 ISO 68 (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  $\mu\text{m}$  (250  $\mu\text{in.}$ ) arithmetic average roughness ( $R_a$ ) or better.
- b) To prevent a soft foot, they shall be in the same horizontal plane within 125  $\mu\text{m}$  (0.005 in.).
- c) Each mounting surface shall be machined within a flatness of 40  $\mu\text{m}$  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).

Note: During manufacturing, it is typically possible to verify this tolerance with applicable component level measurements (e.g., from the frame centerline or other frame feature) to the mounting planes.

f) The upper machined or spot faced surface shall be parallel to the mounting surface.

g) Anchor or 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 anchor or 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. Unmachined or uneven top surfaces shall be spot faced to a diameter three times that of the hole diameter.

**4.4.2.9** The mounting surface on a vertical machine shall be machined perpendicular to the machine'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** (This paragraph intentionally left blank.)

**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 considered necessary based on the vendor's experience, the vendor shall submit methods used to keep the frame free of unacceptable internal stresses for approval by the purchaser.

- **4.4.2.16** When specified, axial stator shift shall be provided for machines with a single pedestal bearing.

#### **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, bus ducting, 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 1/4 in., 2 1/2 in., 3 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 ASME 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 and threading 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 (3/4 in.) nominal pipe size. Oil inlet lines shall be not less than 12 mm (1/2 in.). All pipe connections shall be flanged. Where flanged openings are impractical, threaded openings in sizes through 40 mm (1 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 1/2 times the major diameter of the stud. The first 1 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** (This paragraph intentionally left blank.)

**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) components (such as keys, fan hubs, thrust collars, etc.) shall have a minimum chamfer equal to or greater than the adjacent radii.
- c) welded shaft, bar shaft, and spider constructions ~~are shall not be allowed used~~ for two pole machines; and
- d) shaft straightening techniques are ~~not permitted shall not be used~~ during or after fabrication of the rotor.

**4.4.5.1.3** Shafts shall be heat-treated forged steel.

**4.4.5.1.4** (This paragraph intentionally left blank.)

**4.4.5.1.5** ~~Heat-treated forged steel s~~ Shafts shall be AISI 4000 series and comply with ASTM A668 or equivalent in EN 10250 or EN 10083. ~~Any inclusions in the forging shall be limited to a value that shall not have any adverse impact on the finished shaft.~~ Two and four pole solid cylindrical rotor shafts shall meet ASTM A469 ~~with suitable grade/class for the application.~~

**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 4.1.1 and 4.2.4.

NOTE For single bearing motors driving reciprocating compressors, additional coordination could be needed between the compressor vendor and motor vendor to minimize the risk of excessive motor vibration. This could include incorporating the compressor drive end bearing characteristics (such as clearance, oil viscosity, and the housing or frame stiffness) as well as any lateral loads associated with piston rod forces in the motor design model.

**4.4.5.1.7** When radial shaft displacement and/or 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 displacement 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  $\mu\text{m}$  (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  $\mu\text{m}$  (0.25 mils), whichever is greater; and
- b) for areas to be observed by axial-position probes, 12.7  $\mu\text{m}$  (0.5 mils).

- **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 μin.)  $R_a$  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.

**4.4.5.1.10** For rotating exciter assemblies that are mated axially to the main shaft with a flanged connection, the connection shall withstand torques greater than those arising from normal operation, including forces experienced during starting and two- and three-phase fault conditions at the machine terminals.

#### **4.4.5.2 Assembly**

**4.4.5.2.1** On laminated poles, laminated pole shoes, exciter rotor laminations, and laminated cylindrical rotors, the 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**

Machines with fabricated-bar amortisseur windings shall be furnished with copper or copper alloy bars and shorting connections.

**4.4.5.2.3** Where retaining rings are used, the vendor shall advise the purchaser in the proposal. They shall be without circumferential joints and of a material not susceptible to stress cracking due to exposure to moisture, chlorides or other airborne contaminants.

**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 amortisseur windings shall be maintained centered (e.g. swaged, center locked or pinned) to prevent uneven axial movement.

**4.4.5.2.5** The method by which the bars are attached to the current-carrying 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 (i.e. it shall be free from phosphorus). Outward bending of the ends of the rotor bars and articulation of the current-carrying 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 IEEE C50.13 or IEC 60034-1 shall be specified by the purchaser where required.

**4.4.5.2.8** The end ring and bars shall be replaceable without damage to air passages or laminations.

**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.~~ All fans shall be indexed such that they can be removed and reinstalled without changing the rotor balance beyond the allowable residual unbalance limit.

**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).

**4.4.5.2.11** Internal fans shall be mounted on all machine rotors by one of the following methods:

- a) split hub on shaft
- b) shrink fit hub on shaft
- c) directly bolted to shaft
- d) bolted to a retaining ring

On rotors below 1000 rpm, the following methods are also acceptable:

- e) bolted to the spider
- f) bolted to the rotor hub (field winding support) structure

**4.4.5.2.12** Rotors with removable solid pole heads shall have ~~easily~~ removable field coils. The bolts that retain the laminated or solid pole heads shall be secured by a method that allows easy removal of the bolts.

**4.4.5.2.13** If field-winding braces are installed in interpolar spaces of salient-pole machines, ~~to avoid excessive hot spots,~~ they shall be located so that the fan can draw ~~adequate~~ cooling air through the interpolar spaces.

**4.4.5.2.14** Bolt-on field poles shall be mounted and secured in a manner to prevent undue stresses on mounting bolts which can result in premature failure. Bolt hole diameters and bolt clearances shall be sized to ensure that the bolts remain properly centered under all conditions of installation and operation.

## **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 3.11) 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 H] 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 and frame stiffness; and

d) foundation dynamic stiffness requirements.

NOTE 1 The rigidity of a foundation is a relative quantity, to 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.

- **4.4.6.1.4** When specified, for offshore applications, the machine and auxiliary components shall conform to the motion criteria noted on the datasheet.

**4.4.6.1.5** Resonances of structural support systems that are within the vendor's scope of supply shall not occur within the specified operating speed range or the specified separation margins.

#### **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 testing. 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, o~~Operating speed ranges (including agreed-upon test conditions if different from those specified), trip speed, and coast-down conditions. ~~The analysis of the starting and coast down 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 ~~other than a~~~~of a non~~ massive foundation, dynamic foundation stiffness shall be mutually agreed by the vendor of the 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 ~~critical speed~~~~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 bearing adjacent to the unbalance placement.

In SI units:

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

In USC units:

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

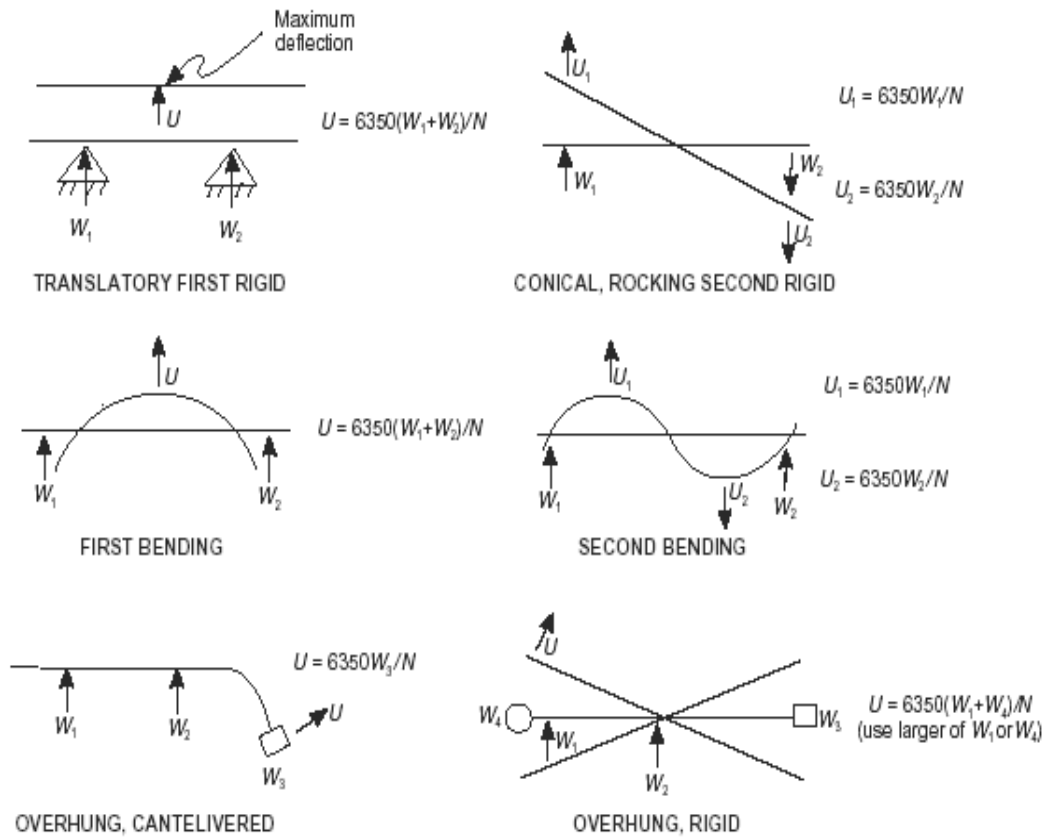
where

$U$  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).



**Figure 1 - Typical Rotor Mode Shapes**

**NOTE** For some machines, it could be necessary to increase the mass of the added unbalance weights to get a sufficient unbalance response to identify the location of the expected critical speed(s).

**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.

**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;

- c) 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
- d) 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.

Note: See API RP 684 for further information.

**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. startup of synchronous electric motors and 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;

e) for the starting torsional study, the motor speed torque curve and the twice slip frequency pulsating torque curve shall be furnished for both rated voltage at an infinite bus and the minimum starting conditions; and

f) 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.

**4.4.6.2.2.4.1** For motors driving reciprocating compressors, torsional natural frequencies of the complete driver-compressor system (including couplings and any gear unit) shall not be within 10 % of any operating shaft speed and within 5 % of any multiple of operating shaft speed in the rotating system up to and including the tenth multiple. The torsional stiffness and inertia of all rotating parts shall provide at least a 20 % difference between any inherent exciting frequency of the compressor and the torsional frequency of the motor rotor oscillation with respect to the rotating magnetic field.

Note: See API 618.

- ◆ **4.4.6.2.2.5** For ASDs, the torsional analysis shall 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** Unless otherwise specified, machines in a service where torsional oscillations occur (e.g. a reciprocating compressor or an engine driven generator) shall be designed to withstand both a and b:

a) a mean torque equal to the transmitted torque at nameplate conditions.

b) a continuous alternating torque of  $\pm 200\%$  of the mean torque for motor applications or  $\pm 25\%$  of mean torque in the range of 95% to 110% of rated speed for generator applications.

**4.4.6.2.2.7.1** The design of the machine shall include evaluation of rotor shafting and rotor mounted components such as, but not limited to, amortisseur winding, fans, brushless exciter and its associated components.

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.

When the equipment vendor cannot meet this requirement or when the torsional vibration analysis indicates higher values need to be considered, alternative values shall be mutually agreed upon by the purchaser and the vendor.

Note 1: This clause is intended to enable the electric machine vendor to proceed with their shaft and rotor component design without waiting for completion of the full train torsional analysis.

Note 2: The alternating torque for reciprocating compressors with more than 4 throws is likely to be considerably reduced from the values stated in 4.4.6.2.2.7 b).

#### **4.4.6.3 Balancing**

**4.4.6.3.1** All rotors 600 rpm and above shall be dynamically balanced in two or more planes as complete assemblies. 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 paragraph 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. If the exciter is not component balanced, means shall be taken to allow for reassembly in the original position.

**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. For machines less than 600 rpm requiring balance weights in excess of 500 g (1.1 lbs), the weights may be carbon steel and welded in position provided they are mounted on the inside diameter of a substantial steel component. 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:

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

In USC units:

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

where

$UB$  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 asymmetrical, or the correction planes are asymmetrically 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 21940-11. 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 21940-11 balance grade.

**4.4.6.3.3.2** For rotors operating above the first bending mode and balanced at operational speed(s), the residual unbalance verification check is not required. For these machines, the 1X component shall not exceed 80% of the unfiltered vibration limits given in 6.3.3.12.1 and 6.3.3.12.5.

Note See API RP 684 for additional information.

- **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 F.

NOTE Annex F 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 F.

#### 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 3.30)~~. Potential excitations to be considered in the design of the system 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 motor load or generator driver;
- i) short-circuits (faults) and other transient conditions on the electrical system;
- j) ASDs; and
- k) electrical exciting pulsating torque with double slip frequency.

#### 4.4.7 Bearings, Bearing Housings, and Seals

##### 4.4.7.1 Bearings

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

**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.

Note Under certain circumstances it ~~may could~~ be impractical to supply identical bearings, e.g., lateral critical speed or torsional resonance considerations, or three bearing machines. ~~For those cases, the vendor shall propose alternative solutions for approval by the purchaser.~~

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.

- **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<sub>10</sub> 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<sub>10</sub> 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 machines 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<sub>10</sub> 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 1 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.

~~NOTE 2 Condensation can be avoided if the minimum inlet water temperature to water-cooled bearing housings is kept above the ambient air temperature.~~

**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 are high enough to cause damage, special measures may be required and shall be proposed by the vendor and approved by the purchaser. These measures may involve special isolation procedures, alternative ASD designs, or winding connection design modifications. Grounding brushes shall only be considered after other methods have been evaluated and determined to be unacceptable. If grounding brushes are necessary, the brushes or their enclosure shall be certified for the specified area classification. Brushes shall have a minimum continuous service life of 5 years or be redundant- and capable of being swapped during operation to achieve a minimum of 5 years of continuous machine operation. 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  $0.4\ \mu\text{m}$  ( $16\ \mu\text{in.}$ )  $R_a$  and the total indicated axial runout of either thrust face shall not exceed  $12\ \mu\text{m}$  ( $500\ \mu\text{in.}$ ). Split thrust collars are not acceptable.

**4.4.7.1.11** Hydrodynamic thrust bearings for vertical machines, and where applicable for horizontal machines, shall be selected such that under any operating condition the thrust 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 maximum 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** Where applicable, external thrust force data shall be provided by the entity having train responsibility.

**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 flood lubrication systems with an oil ~~outlet-inlet~~ 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 1 Condensation can be avoided if the minimum inlet water temperature to water cooled bearing housings is kept above the ambient air temperature.

NOTE 2 For ambient conditions which exceed 40 °C (104 °F) or when the inlet oil temperature exceeds 50 °C (122 °F), bearing design, oil flow, and allowable temperature rise could be affected.

**4.4.7.1.15** (This paragraph intentionally left blank.)

- **4.4.7.1.16** When specified, bearing oil temperature indicators shall be provided on the bearing housing of self-lubricated bearings or in the drain lines of flood lubricated 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 flood 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** Bearings utilizing oil rings 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 could discuss a 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 when specified 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 could 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 (1/4 in.) above the lower edge of the bore of the oil ring.

The vendor shall notify the purchaser when oil rings are not provided so that adequate provision can be made for lubrication during loss of oil supply.

Note: Oil rings are not practical when the shaft circumferential speed exceeds the limits for their use, for certain bearing designs, or when the machine may be subjected to excess inclination.

**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 of self-lubricated bearings. 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 flood 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. 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.

NOTE 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.

- **4.4.8.6** When specified, oil systems shall conform to the requirements of API 614.
- 4.4.8.7** In machines that require multiple starts per day or are supplied from an ASD and may operate at very slow speeds, bearings and lubrication should be evaluated for application of hydrostatic jacking means to limit bearing babbitt wear.
- 4.4.8.8** 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).
- **4.4.8.9** The purchaser shall specify on the datasheet the type of oil used for the application. When the use of synthetic lubricants is specified, the purchaser shall inform the vendor of the specific type and brand used.

Note The use of synthetic lubricants for machine bearings requires a special design.

#### **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 (1/2 in.). The design of the machine 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 (1/2 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 (<sup>3</sup>/<sub>16</sub> 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 machine vendor shall install the machine 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.

- **4.4.10.1.5** External bolts, studs, and other fastening devices up through M12 (1/2 in.) size shall be AISI 300 series or ISO 3506 stainless steel. When the machine is specified to be installed offshore on a production platform or similar marine installation, or when specified, AISI 316 material shall be supplied. The use of non-stainless steel fastening devices for structural reasons may be permitted if approved by the owner.

**4.4.10.1.6** Internal fastening devices shall use locknuts, lock washers, locking plates, or tie wires. Use of non-mechanical thread-locking means (e.g. anaerobic adhesive or similar epoxy bonding agents) is not permitted.

#### **4.4.10.2 Castings**

**4.4.10.2.1** The vendor shall specify the material grade of castings on the datasheets. 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, stitching, 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 ASME BPVC IX, AWS D1.1, CSA 47.1, or ISO 9606. 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 post weld stress relieved prior to finish machining.

#### **4.4.10.4 Low Temperature Service**

To avoid brittle fractures, 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 If vendor furnished steel pressure retaining parts could be subjected to temperatures below the ductile-brittle transition temperature, this could influence fabrication methods, welding procedures, and materials used. 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. This is typically a concern for materials intended for services below  $-30^{\circ}\text{C}$  ( $-22^{\circ}\text{F}$ ).

#### **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 6.4 mm (0.25 in.). On enclosures equipped with filters, the screens downstream of the filters may have a maximum mesh of 12.7 mm (1/2 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 non-sparking 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 other shaft mounted components shall be designed and constructed so that they will not resonate at any frequency that can be excited 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 machine enclosure or may be on the inlet ducting in the case of TEPC machines. 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 Lamination**

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  $400^{\circ}\text{C}$  ( $750^{\circ}\text{F}$ ) 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 for offshore application, AISI 316 shall be used ~~for all offshore applications~~.
- b) Water-to-air heat exchanger tubes shall be not less than 15 mm (5/8 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 machine's nameplate(s):

- a) Manufacturer's name;
- b) serial number;
- c) horsepower, kW, or kVA;
- d) voltages;
- e) phase;
- f) rated 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) (for motors);
- l) full-load speed, in revolutions per minute;
- m) rated main field current;
- n) rated main field voltage;

- o) rated exciter current;
- p) rated exciter voltage;
- q) time rating;
- r) temperature rise, in degrees Celsius; the maximum ambient or cooling-air temperature for which the machine was designed and the insulation system's designation;
- s) service factor (for motors);
- t) starting limitations;
- u) 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);
- v) for machines installed in Class I or Class II, Division 2 or Zone 2 locations, labeling or marking requirements as required in NFPA 70 or IEC 60079-10;

NOTE The "T Code" designations of the two systems are not identical.

- w) enclosure type;
- x) total machine mass and rotor mass;
- y) year of manufacture;
- z) location of manufacture;
- ◆ aa) the frequency and speed range;
- ◆ ab) 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
- ◆ ac) type of inverter for which the motor is intended to be used.

**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 (when provided); and

- ◆ h) connection diagram for tachometer (when provided).

- i) Oil heater (when provided)

- j) Exciter (polarity)

- **4.4.11.4** When specified, the purchaser's identification information shall be stamped on a separate nameplate.

## **4.5 Excitation System**

### **4.5.1 General Requirements**

**4.5.1.1** All components of the excitation system shall comply with the requirements of 4.1.1.

**4.5.1.2** The excitation control system shall provide supervisory functions to maintain the excitation system within the machine operating limits. The excitation control system may also provide additional protection functions (such as overexcitation, loss of field, component failure, exciter phase unbalance, etc.). The excitation control and protection system functionalities shall be mutually agreed upon by the owner and manufacturer.

NOTE 1 See IEEE 421.4, IEEE C37.102, and IEEE 3004.8 for information on the supervisory and protective functions that are typically implemented.

NOTE 2 Consideration is needed to determine which protection functions will be performed by the excitation control system and which protection functions are more critical and will be performed by an independent protective device(s).

- **4.5.1.3** When specified for motors, the system shall be capable of automatically controlling either power factor or VAR export of the motor and allow for "bumpless" transfer from one mode to another.

**4.5.1.4** For generators, the system shall be capable of automatically controlling the voltage and either the power factor or VAR export of the generator and allow for "bumpless" transfer from one mode to another.

- **4.5.1.5** When specified for motors the exciter shall be supplied from a constant voltage transformer, a phase controlled rectifier, or other approved means to maintain 95 % of rated voltage or better for at least two seconds when the primary supply voltage drops to as low as 50 % of normal voltage.
- **4.5.1.6** When specified, excitation protection shall be provided with the motor.

Note 1 This is separate from the excitation controls mentioned in 4.5.1.2.

Note 2 Where excitation system control components that are sensitive to voltage disturbances are supplied (e.g. a programmable logic controller, power factor controller) the method of supplying a secure voltage source for these components is typically jointly developed between the vendor and the purchaser.

- **4.5.1.7** Field forcing capability of the excitation system for generators and all rotor-mounted components shall be provided. Unless otherwise specified, field forcing shall maintain a minimum of 300 % rated stator current for at least ten seconds.

Note This is for the purpose of maintaining sufficient short circuit current to allow protective relays to operate and/or for starting a relatively large motor.

**4.5.1.8** Excitation control system wiring shall meet the requirements of sections 5.1.17 and 5.1.18.

## **4.5.2 Stationary Section**

**4.5.2.1** The exciter stator winding shall meet the requirements of 4.3.1.4 and if applicable, 4.3.1.5. It shall be sufficiently insulated to tolerate the voltage transients and common mode voltages from the selected excitation control power module. If the excitation control power module is not included in the machine manufacturer's scope of supply and no transient voltage levels are otherwise defined, the following voltage levels shall apply. The exciter stator windings shall be sufficiently insulated to tolerate input from a solid state supply with 0.1  $\mu$ s voltage rise times and common mode voltages equal to two times the line-to-line voltage.

**4.5.2.2** The exciter stator windings shall be rated for the fundamental and harmonic currents produced by the selected excitation control power module.

**4.5.2.3** Panel mounted surge protection shall be applied on the power input of the exciter control panel to protect components from lightning and switching transients.

## **4.5.3 Rotating Section**

**4.5.3.1** Conductors shall be fixed firmly to withstand centrifugal forces at the overspeed condition specified in 4.1.5.

**4.5.3.2** Exciter rotor windings shall be insulated sufficiently to withstand any transients arising from the recovery of the diodes in the rotating rectifier.

- **4.5.3.3** When specified, rotating element mounted electronic components (including finished circuit boards, diodes, thyristors, etc.) shall be "burned in" for at least 48 hours. During this "burn-in" period, the boards and modules shall be cycled through their normal function and application rating for four consecutive timed intervals of 12 hours each (48 hours total). Each interval shall provide one ambient and one 60 °C temperature cycle of 6 hours each. Boards and modules shall be power cycled at an interval of 45 min "ON" and 15 min "OFF" for the entire 48 hours. The test chamber shall maintain the desired temperature levels within  $\pm 3$  °C throughout the chamber. Components rated for intermittent duty are not required to operate continuously during this test but should function within their normal duty cycle rating.

**4.5.3.4** Rotating rectifier commutation spikes shall be limited to less than  $4 \times$  the average output voltage. The rotating rectifier may be equipped with fast recovery diodes, R-C snubber circuits, or other means to limit commutation spikes to the required level.

**4.5.3.5** The rotating rectifier shall be equipped with an overvoltage protection circuit (varistor or voltage gated thyristor) to discharge the full field current in the case of a pull out or other transient.

**4.5.3.6** Rotating rectifier diodes shall have a voltage rating of at least 1200 volts, or twice the peak value of the maximum rotor induced voltage (at maximum speed and maximum exciter stator voltage), whichever is greater.

NOTE The rotor induced voltage used to satisfy this requirement can be limited by overvoltage suppression devices.

**4.5.3.7** Rotating rectifier diodes shall be current rated and provided with heat sinks such that their junction temperature does not exceed 125 °C when the machine is at its maximum temperature (rated torque and maximum ambient) and the lowest operating speed.

- **4.5.3.8** When specified, the manufacturer shall provide a test device and means to easily connect to all rotating electronic devices that will test and simulate the action of all rotating field application and control devices.

**4.5.3.9** Connections shall either be soldered or tightened and positively locked in position.

- **4.5.3.10** When specified, the vendor shall supply an online rotor monitoring system to provide data on rotating section thermal and electric parameters. With the proposal, the vendor shall provide a list of what parameters are monitored.

**4.5.3.11** When utilized, the field discharge resistor or starting resistor shall be adequately braced to withstand the mechanical stresses caused by electromagnetic forces and rapid thermal expansion during start-up and the centrifugal forces under normal operating conditions. The selection of materials shall be based on the effects of high thermal stresses during the start-up conditions specified in 4.2.4, and the resistor surface temperature shall not exceed the temperature limit of its insulating components during these starting conditions. The resistor thermal capacity shall meet any starting capability requirements that are defined for repeated starts and margins in excess of expected acceleration times specified in 4.2.4. The resistor shall be waterproof to protect against corrosion.

- **4.5.3.12** When specified on fixed speed applications, rotating diode failure detection shall be supplied.
- **4.5.3.13** When specified, a permanent magnet generator (PMG) shall be provided for the generator exciter power supply.

**4.5.3.14** The rotating rectifier assembly shall be replaceable without removal of the rotor or any bearing.

Note: A split rotating rectifier assembly is often used where the exciter is mounted inboard of the bearing(s).

## **5 Accessories**

### **5.1 Terminal Boxes**

- **5.1.1** Main power lead terminal box(es) shall be constructed of steel plate with a minimum thickness of 3 mm (1/8 in). Minimum dimensions and usable volumes shall not be less than those specified in NEMA MG1 Part 21 Type II. 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 machine full load current. Stand-off 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** Main power lead terminal box(es) shall be capable of withstanding the pressure build-up resulting from a three phase fault of the specified MVA (one-half cycle after fault inception) for a duration of 0.5 sec. If a rupture device is used to relieve pressure build-up, 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.

Note Energy will still be supplied to a fault after the machine is separated from the system, due to excitation being maintained or due to the field decay time constant.

- **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 and space heaters located in the main terminal box are permitted to terminate in the 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 at least 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 machine will be installed offshore on a production platform or similar marine installation, or when specified, AISI 316 material shall be supplied. 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 mm<sup>2</sup>

(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 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 machine enclosure.~~ Except as noted in 5.1.12, all accessory wiring outside the machine 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 bus.

**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. The removable links shall be copper bus bars sized in accordance with 5.1.1 and have a minimum two-hole connection on each end. The bus bar used for removable links shall be insulated when the option for insulated terminations has been specified per paragraph 5.1.6 m. All removable link connection hardware shall be consistent with the internal current path hardware for the machine terminal box.

**5.1.17** There shall be a maximum of two wires under any control or auxiliary wiring terminal. If a two-wire lug is used the lug shall have the appropriate size range for the conductors and be approved (labeled or listed)

for the service. Where connections are made to box type compression terminals and wire sizes are 0.9 mm<sup>2</sup> (# 18 AWG) and smaller, crimp type pin terminals shall be used.

**5.1.18** Analog signal wires shall be twisted pairs and routed or shielded to minimize interference from power conductors. All other classes of service shall be grouped together by service and voltage and physically isolated from each other.

## 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  $\Omega$  at 0 °C (32 °F). These elements shall have tetrafluoroethylene-insulated, stranded, tinned copper wire leads with cross sections at least equal to 0.4 mm<sup>2</sup> (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 in accordance with NEMA MG 1, Part 21. When specified, one lead of each of these elements shall be grounded in the RTD 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.

**5.2.3** RTD wiring shall not compromise winding end turn stress control arrangements.

## 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  $\Omega$  at 0 °C (32 °F). These elements shall have tetrafluoroethylene-insulated, stranded, tinned copper wire leads with cross sections at least equal to 0.4 mm<sup>2</sup> (22 AWG) in size. The leads shall meet the requirements of NFPA 70 or IEC 60079. When redundant temperature detectors are specified, separate detectors shall be provided. Where separate detectors cannot be provided, dual element sensors may be used with purchaser's approval.
- **5.3.2** When specified, bearing temperature sensors shall be provided in accordance with API 670.

NOTE 1 In certain bearing designs, API 670 requires temperature measurement in two locations (axially colinear) 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 could be considered.~~

## 5.4 Space Heaters

**5.4.1** 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 suitable for the environment specified on the datasheet. 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 and exciter windings as possible. The heaters shall maintain the temperature of the machine windings at approximately 5 °C (9 °F) above the ambient temperature.

Note Based on enclosure and exciter construction, this could result in separate space heaters for the exciter.

## **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 open 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 or if specified. Filter requirements shall be in accordance with 5.5.4.
- **5.5.4** When filters are specified~~provided~~, 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 an external sensing device 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 Machine 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 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. Where applied to ASD driven motors, surge capacitors shall not be specified.

- **5.6.2.2** When specified, metal-oxide surge arresters shall be furnished and shall be installed in the terminal box. Where applied to ASD driven motors, surge arresters shall not be specified.
- **5.6.2.3** The connection leads to the capacitors and arresters shall be at least 107 mm<sup>2</sup> (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 D, "Datasheet Guide" or Annex E, "Generator 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 manufacturer 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 partial discharge 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 mm<sup>2</sup> (#6 AWG) or larger copper wire and shall meet the requirements of 5.1.5 of this standard.

### **5.6.5 Synchronizing and Control Devices**

**5.6.5.1** The method of field application and synchronization shall be described by the vendor in the proposal and shall be jointly agreed upon by the purchaser and the vendor.

- **5.6.5.2** When specified, a freestanding control panel shall be supplied for mounting the control and protective devices listed on the controls section of the data sheet. As an alternative to this, individual components shall be supplied as indicated on the section of the datasheet for mounting and wiring by others.

## 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 minimum 12.0 mm (1/2 in. NC) thread bolt.

## 5.8 Vibration Detectors

- **5.8.1** Hydrodynamic bearing machines intended to operate at 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 machine 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  $-35^{\circ}\text{C}$  to  $65^{\circ}\text{C}$  ( $-30^{\circ}\text{F}$  to  $150^{\circ}\text{F}$ );

2) resonances are avoided and minimal vibration is imparted; and

3) ease of access, best routing of cabling, optimization of conduit fittings, and the minimum amount of exposed surplus cabling are facilitated.

- **5.8.2** When specified, machines with hydrodynamic bearings shall have provisions for the mounting of four radial-vibration probes in each bearing housing.

- **5.8.3** When specified, four probes at each bearing shall be installed.

Note: Four probes (or provisions) can be specified when the probes cannot be accessed during operation and the machine cannot be stopped conveniently to change defective probes.. Typically, two of the probes are connected to the oscillator-demodulators and the other two probes have their leads run to the oscillator-demodulator terminal box and are not connected, but held as spares.

**5.8.4** Where hydrodynamic thrust bearings are provided, they shall have provisions for two axial position probes at the thrust end.

- **5.8.5** When specified, seismic vibration sensors, or provisions for such shall be supplied in accordance with API 670.

NOTE 1 Axial position probes are normally applied to monitor thrust loading and hydrodynamic thrust-bearing conditions in vertical machines. Axial probes are occasionally used to monitor a rotor's axial vibration. On horizontal machines, axial probes are generally not applied because no thrust bearing is present and because axial probes used as vibration sensors will not generally accommodate the rotor's relatively large amount of axial motion. Noncontacting vibration systems are generally used on machines operating at speeds greater than or equal to 1200 rpm with hydrodynamic radial bearings, and accelerometer systems are generally used on units with antifriction bearings, that have high transmissibility of shaft-to-bearing force.

NOTE 2 Non contacting vibration detectors are typically not used on machines 514 rpm and slower. Acceleration or velocity sensing devices can be considered for slower speed applications where vibration monitoring is required.

## **6 Inspection, Testing, and Preparation for Shipment**

### **6.1 General**

- **6.1.1** Whenever the specification or purchase order calls for shop inspections and tests to be witnessed, observed, or performed by a purchaser's representative, the vendor shall provide sufficient advance notice to the purchaser before each inspection or test, including a list of tests to be performed with associated procedures and acceptance criteria. If inspections or tests are rescheduled, the vendor shall provide similar advance notice. At all other times the purchaser's representative, upon providing similar advance notice to the vendor, shall have access to all vendor and sub-vendor plants where work on or testing of the equipment is in progress. In each instance, the actual number of working days considered to be sufficient advance notice shall be established by mutual agreement between the purchaser and the vendor but shall not be less than five working days.

**6.1.2** The vendor shall notify all sub-vendors of the purchaser's inspection and testing requirements.

- **6.1.3** The purchaser will specify the extent of his/her participation in the inspection and testing.

**6.1.3.1** *Witnessed* means that a hold shall be applied to the production schedule and that the inspection or test shall be carried out with the purchaser or his/her representative in attendance. For vibration, unbalance response, and heat run tests, this requires confirmation of the successful completion of a preliminary test. Preliminary test data shall be supplied to the attending observer within 24 hours after the testing is completed. Completed documentation of testing shall be supplied within three business days after the testing.

**6.1.3.2** *Observed* means that 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/her representative is not present, the vendor shall proceed to the next step.

**6.1.3.2.1** If the purchaser or his/her representative is present for the observed testing, then the observance of that notified testing is allowed but not the authority to delay progression of manufacturing. Preliminary test data shall be supplied to the attending observer within 24 hours after the testing is completed. Completed documentation of that test shall be supplied for informational purpose within three business days after the testing.

**6.1.3.3** *Required* means that the paragraph in question applies or that certified documentation shall be recorded for the purchaser.

- **6.1.4** Unless otherwise specified, all required test and inspection equipment shall be provided by the vendor.

### **6.2 Inspection**

#### **6.2.1 General**

**6.2.1.1** The vendor shall keep the following data available for at least five years for examination by the purchaser or his/her representative upon request:

- a) certification of materials (e.g. mill test reports on shafts, forgings, and major castings);
- b) purchase specifications for all items on bills of materials;

- c) test data to verify that the requirements of the specification have been met;
  - d) results of all quality-control tests and inspections; and
  - e) when specified, final assembly clearances of rotating parts (e.g. air gap, bearing and seal clearances).
- 6.2.1.2** Pressure-containing parts shall not be painted until the specified inspection and testing of the parts are complete.

- **6.2.2 Material Inspection**

**6.2.2.1 General**

When radiographic, ultrasonic, magnetic particle or liquid penetrant inspection of welds or materials is required or specified, the criteria in 6.2.2.2 through 6.2.2.5 shall apply unless other corresponding procedures and acceptance criteria have been specified. Cast iron may be inspected in accordance with 6.2.2.4 and 6.2.2.5. Welds, cast steel, and wrought material may be inspected only in accordance with 6.2.2.2 through 6.2.2.5. Regardless of the generalized limits in 6.2.2, it shall be the vendor's responsibility to review the design limits of the equipment in the event that requirements that are more stringent are necessary. Defects that exceed the limits imposed in 6.2.2 shall be removed to meet the quality standards cited as determined by the inspection method specified.

**6.2.2.2 Radiography**

**6.2.2.2.1** Radiography shall be in accordance with ASTM E94 or ISO 5579 or ISO 19232.

**6.2.2.2.2** The acceptance standard used for welded fabrications shall be Section VIII, Division 1, UW-51 (continuous weld) and UW-52 (spot weld) of the ANSI/ASME BPVC. The acceptance standard used for castings shall be Section VIII, Division 1, Annex 7 of the ANSI/ASME BPVC.

**6.2.2.3 Ultrasonic Inspection**

**6.2.2.3.1** Ultrasonic inspection shall be in accordance with Section V, Article 5 and Article 23 of the ANSI/ASME BPVC or EN 10228-3 (for forgings) or ISO 17640 (for welded fabrications).

**6.2.2.3.2** The acceptance standard used for welded fabrications shall be Section VIII, Division 1, UW-51 (continuous weld) and UW-52 (spot weld) of the ANSI/ASME BPVC. The acceptance standard used for castings shall be Section VIII, Division 1, Annex 7 of the ANSI/ASME BPVC.

**6.2.2.4 Magnetic Particle Inspection**

**6.2.2.4.1** Both wet and dry methods of magnetic particle inspection shall be in accordance with ASTM E709.

**6.2.2.4.2** The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Annex 6 and Section V, Article 25 of the ANSI/ASME BPVC. The acceptability of defects in castings shall be based on a comparison with the photographs in ASTM E125. For each type of defect, the degree of severity shall not exceed the limits specified in Table 6.

**Table 6—Maximum Severity of Defects in Castings**

Type	Defect	Degree
I	Linear discontinuities	1

II	Shrinkage	2
III	Inclusions	2
IV	Chills and chaplets	1
V	Porosity	1
VI	Welds	1

### 6.2.2.5 Liquid Penetrant Inspection

**6.2.2.5.1** Liquid penetrant inspection shall be in accordance with Section V, Article 6 of the ANSI/ASME BPVC or ISO 3452 and ISO 3453.

**6.2.2.5.2** The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Annex 8 and Section V, Article 24 of the ANSI/ASME BPVC.

### 6.2.2.6 Hydrostatic Testing

**6.2.2.6.1** Pressure containing parts of water cooling circuits (including auxiliaries) shall be tested hydrostatically with liquid at a minimum of 1 1/2 times the maximum allowable working pressure but not less than 138 kilopascals (20 lb per square in.) gauge.

**6.2.2.6.2** The test liquid shall be at a higher temperature than the nil-ductility transition temperature of the material being tested. The hydrostatic test shall be considered satisfactory when neither leaks nor seepage is observed for a minimum of 30 minutes.

### 6.2.3 Inspection

**6.2.3.1** During assembly of the lubrication system and before testing, each component (including cast-in passages) and all piping and appurtenances shall be inspected to ensure they have been cleaned and are free of foreign materials, corrosion products and mill scale.

- **6.2.3.2** When specified for machines having externally circulated ~~eding pressure~~ oil systems (e.g., flood lubrication, pressure lubrication, and hydrostatic jacking) with a rated pump capacity of 19 liters (5 gallons) per minute or more, the oil system furnished shall meet the cleanliness requirements of API 614.
- **6.2.3.3** When specified, the purchaser may inspect the equipment and all piping and appurtenances furnished by or through the vendor for cleanliness before final assembly.

**6.2.3.4** The purchaser's representative shall have access to the vendor's quality program for review.

## 6.3 Final Testing

### 6.3.1 General

**6.3.1.1** During a witness or observed test, the purchaser shall have the right to observe any dismantling, inspection, and reassembly of a machine due to expected or unexpected parts of the test.

**6.3.1.2** The vendor shall provide calculated data from final witnessed testing immediately upon completion of testing. The final results of critical parameters shall be determined prior to the inspector leaving the test facility.

**6.3.1.3** Tests shall be made on the fully assembled machine, using contract components, instrumentation, and accessories.

**6.3.1.4** The vendor shall notify the purchaser not less than 5 working days before the date that the equipment will be ready for testing. If the testing is rescheduled, the vendor shall notify the purchaser not less than 5 working days before the new test date.

- **6.3.1.4.1** When specified, at least six weeks before the first scheduled test, the vendor shall submit to the purchaser, for his/her review and comment, detailed procedures for all tests including acceptance criteria for all monitored parameters. The following items (when applicable) shall be included in the test procedures.
  - a) Types of tests (electrical or mechanical).
  - b) Testing sequence.
  - c) Detailed testing schedule.
  - d) Guarantee limits (e.g. overall and filtered vibration levels, frequency and amplification factors of critical speeds, efficiency, noise levels, and stator temperature rise).
  - e) Data measurements to confirm guarantee limits and proper operation of equipment components including but not limited to the following:
    - 1) power, voltage, current, power factor, full load speed, and torque;
    - 2) shaft and bearing vibration, unfiltered and filtered, and 1X phase angle for each probe;
    - 3) journal bearing temperatures;
    - 4) stator winding temperatures;
    - 5) cooling water flow and temperature;
    - 6) temperature on air inlets and discharges;
    - 7) lube oil flows, pressures, and inlet and drain temperatures for each bearing; and
    - 8) all instrumentation and data points that are to be monitored in the field.
  - f) Calculated lateral critical speed analysis.
  - g) A complete set of test datasheets which are to be used during the testing.
  - h) A listing of all alarm and shutdown levels.
  - i) Calibration sheets for all switches, vibration probes, and oscillator-demodulators.
  - j) General arrangement drawings.
  - k) Residual rotor unbalance worksheet.
  - l) List of the test equipment and data acquisition systems, including vibration measuring equipment, that will be used during the testing and how and when it was calibrated (or the calibration schedule).

- ◆ m) When a motor is tested in the factory with the project ASD or one of equivalent design, the following test conditions shall be included:

- 1) the speeds and loads at which the tests are performed; and
- 2) measurement of the harmonic contents of the machine input voltage and current waveforms.

- **6.3.1.5** When the half-coupling assembly (including any mass moment simulator, if applicable) is installed in accordance with 4.4.9.4, the following vibration check shall be made. Without the half coupling mounted, the machine shall be properly installed on a massive foundation and run at a voltage suitable to maintain magnetic center until the bearing temperatures stabilize and a complete set of vibration data recorded. With the coupling mounted, the test shall be repeated. All data shall be within the limits given in Figure 2, Figure 3, Figure 4, and Figure 5. The magnitude of the vectoral change in the 1X vibration on the shaft and bearing housings shall not exceed 10 % of the vibration limits given in Figure 2, Figure 3, Figure 4, and Figure 5. If the vibration change or amplitude exceeds the allowable limits, the vendor and purchaser shall mutually agree on the appropriate corrective action.

NOTE 1: Excessive radial shaft runout can cause high vibration after a balanced coupling has been mounted on the rotor. Shaft extension radial runout is typically checked against the vendor's drawings prior to making any corrections.

NOTE 2: Annex K provides guidance and an alternate procedure if the purchaser and electric machine vendor agree to its use.

**6.3.1.6** Where applicable, all oil pressures, flow rates, and temperatures shall be measured and maintained within the range of operating values recommended in the vendor's operating instructions for the specific unit being tested. The lube oil used during testing shall be as specified on the datasheet.

**6.3.1.7** During the mechanical running tests (where vibration data is being collected), the lube oil inlet temperature shall be adjusted to the maximum specified operating temperature.

**6.3.1.8** Test stand oil filtration shall not exceed 10  $\mu\text{m}$  (0.0004 in.) nominal. Oil system components downstream of the filters shall meet the cleanliness requirements of API 614 before any test is started.

**6.3.1.9** All detection, protective, and control devices except current transformers, voltage transformers, surge capacitors, lightning arresters, and partial discharge couplers shall be tested to verify satisfactory performance. Devices not tested by the motor vendor as permitted in this clause shall have satisfactory test reports available from the device supplier.

**6.3.1.10** During the running tests, the mechanical operation of all equipment being tested and the operation of the test and purchased instrumentation shall be satisfactory.

**6.3.1.11** If replacement or modification of bearings or seals or dismantling to replace or modify other parts is required to correct mechanical performance deficiencies, the mechanical vibration and unbalance response tests shall be repeated after these replacements or corrections are made.

**6.3.1.12** Internal or external oil leakage from the machine or contract components shall not occur during the tests. Any violation of this condition requires termination of the test until the necessary correction is made. Additional testing sufficient to verify that the oil leak is corrected shall be performed.

**6.3.1.13** The vendor shall maintain a complete, detailed log and plots of all final tests and shall submit the required number of copies to the purchaser. This information shall include but not be limited to data for electrical performance, winding temperatures, bearing temperatures, rotor balancing, critical speeds, vibration measurements taken over the operating speed range, and the vibration spectrums. A description of the test

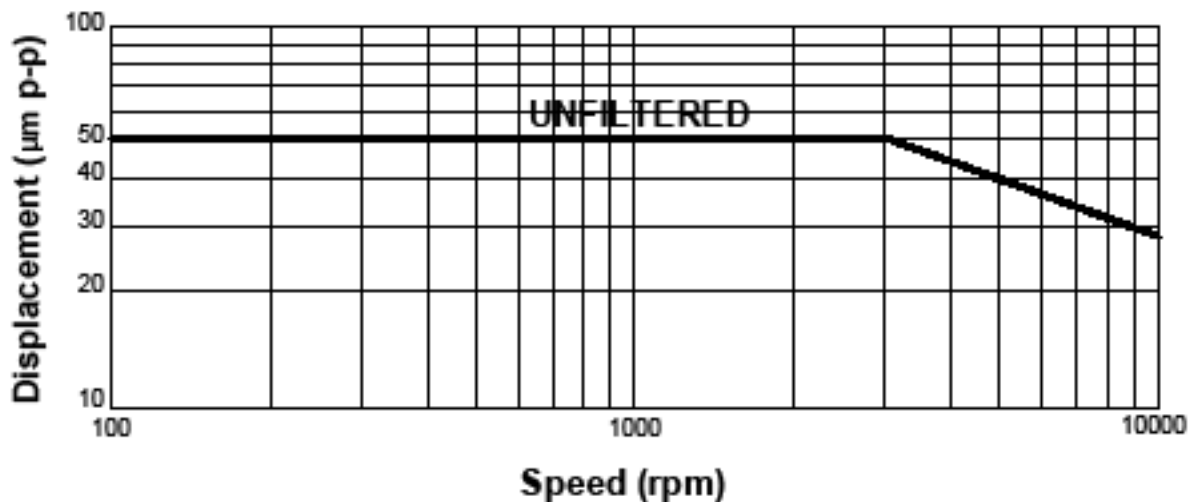
instrumentation and certified copies of the instrument calibrations shall be kept available for the purchaser's review.

**6.3.1.14** All test results shall be certified by the vendor and transmitted to the purchaser in reproducible form.

- **6.3.1.15** When specified, before the start of testing, the vendor shall demonstrate the accuracy of test equipment and automated data acquisition systems. The calibration and maximum deviation from a recognized standard at all phase angles and anticipated frequencies and harmonics shall be demonstrated. A maximum deviation of no more than 0.5 %, including all voltage transformers, current transformers, test leads, shunts, voltage dividers, transducers, analog to digital converters and computers that are part of the test set-up, shall be demonstrated. Every element of the test equipment setup shall be included in the accuracy demonstration.

**6.3.1.16** Prior to any mechanical running test, a check for “soft feet” shall be made. After the machine has been aligned, shimmed, and firmly secured to the test base, a dial indicator micrometer oriented in the vertical direction shall be attached at the mounting foot to be checked. The micrometer is then zeroed, the mounting bolt or bolts loosened at the foot and the change in micrometer reading noted. If the micrometer reading exceeds 0.025 mm (0.001 in.), the mounting requires cleaning or re-shimming. This soft foot check shall be performed at each mounting foot with the other feet secured until all micrometer change readings are less than 0.025 mm (0.001 in.). If there are intermediate bases, this check shall be performed at each interface between the machine and the test floor.

**6.3.1.17** During the shop running test of the assembled machine, vibration measurements shall be made with the machine properly shimmed and securely fastened to a massive foundation (see Note 1 to 4.4.6.1.3) or test floor stand. Elastic mounts are not permitted.



**Figure 2—Shaft Vibration Limits (Metric Units, Relative to Bearing Housing Using Non-contact Vibration Probes) for All Hydrodynamic Sleeve Bearing Machines with the Machine Securely Fastened to a Massive Foundation**

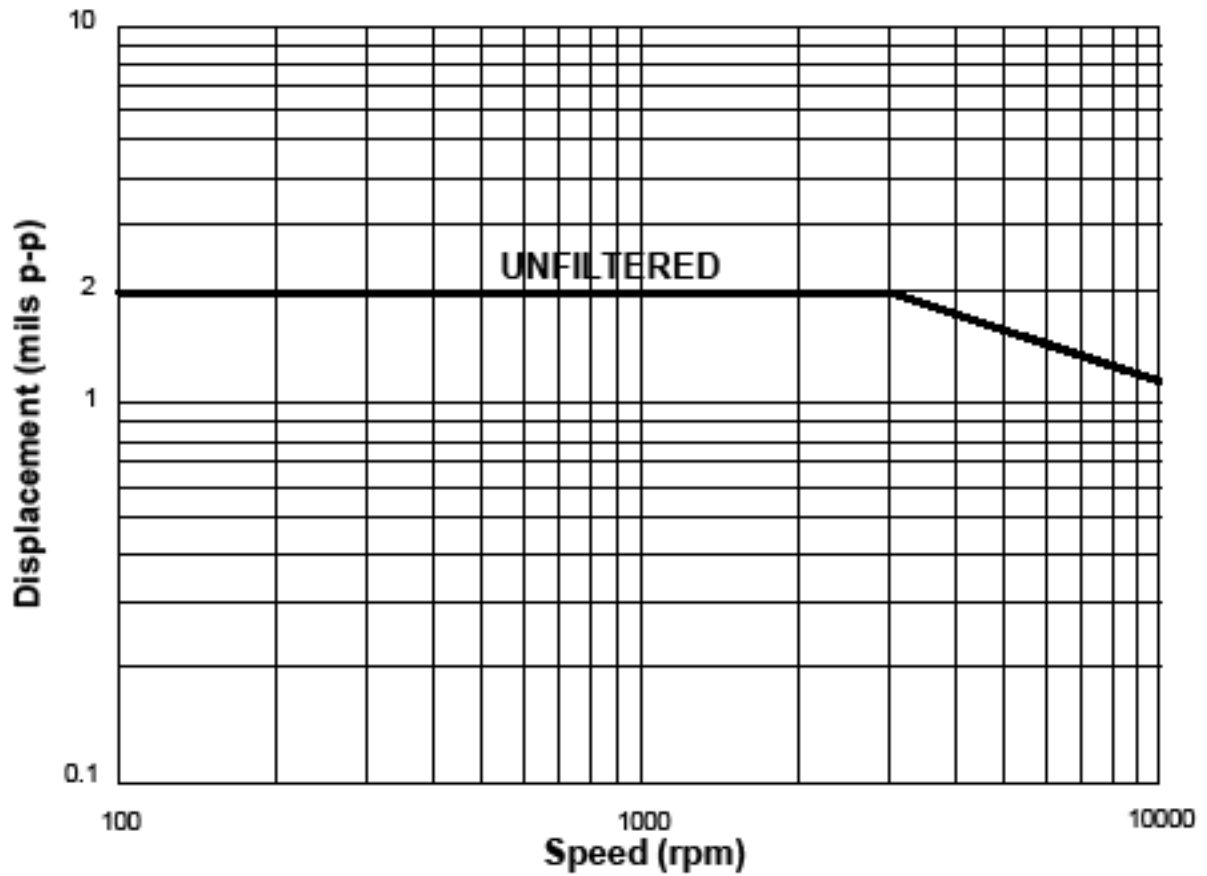


Figure 3—Shaft Vibration Limits (US Customary Units, Relative to Bearing Housing Using Non-contact Vibration Probes) for All Hydrodynamic Sleeve Bearing Machines with the Machine Securely Fastened to a Massive Foundation

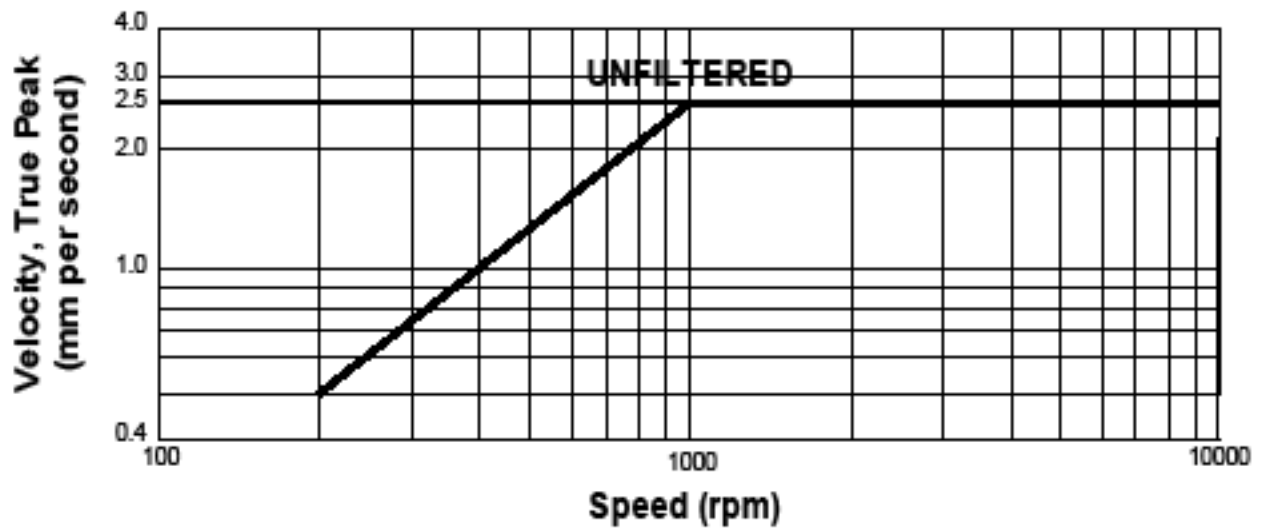
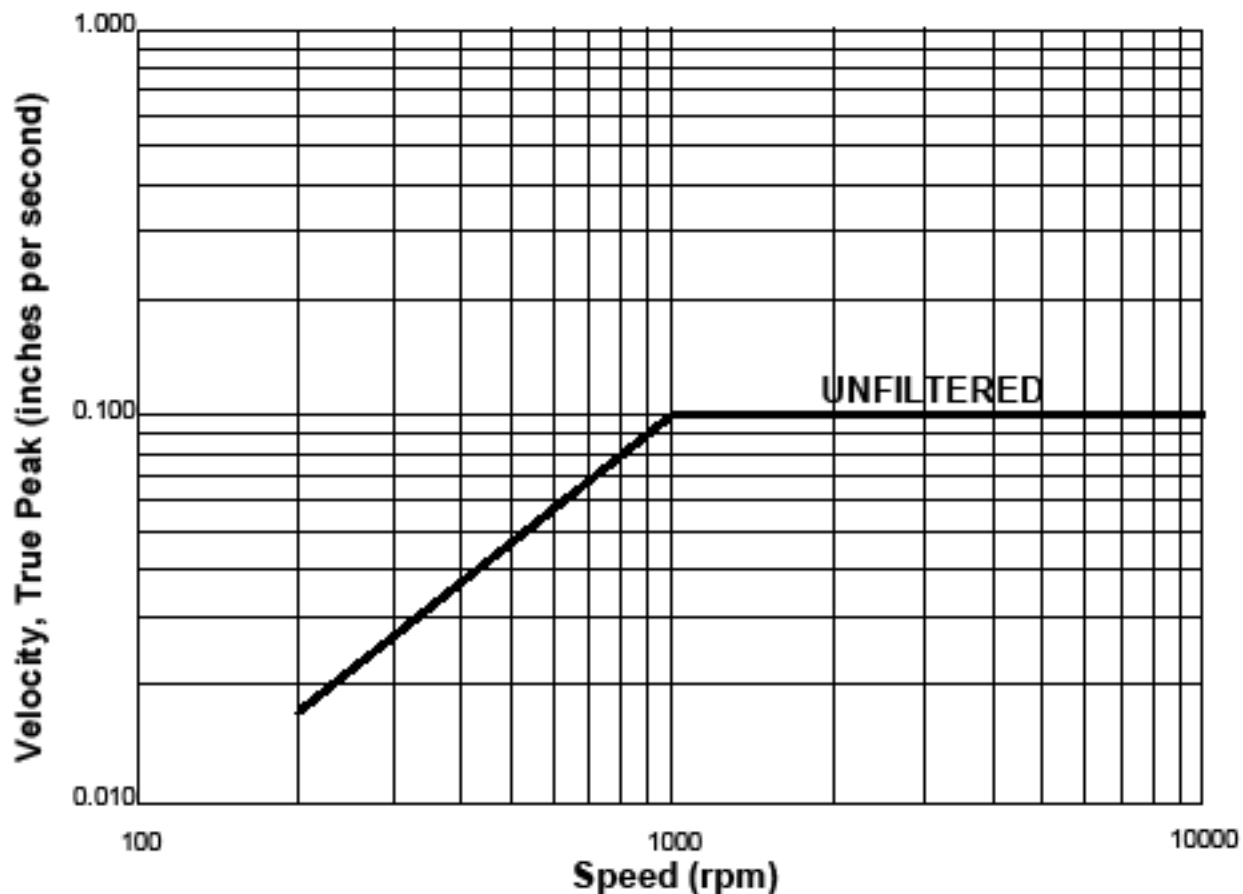


Figure 4—Bearing Housing Radial and Axial Vibration Limits (Metric Units) for Sleeve and Antifriction Bearing Machines with the Machine Securely Fastened to a Massive Foundation



**Figure 5—Bearing Housing Radial and Axial Vibration Limits (US Customary Units) for Sleeve and Antifriction Bearing Machines with the Machine Securely Fastened to a Massive Foundation**

### 6.3.2 Routine Test

**6.3.2.1** Each machine shall be given a routine test to demonstrate that it is free from mechanical and electrical defects. These tests shall be conducted in accordance with the applicable portions of NEMA MG 1, IEEE 115, IEC 60034-2, or IEC 60034-4. The tests shall include the following items.

- a) Measurement of no-load current (each phase) and exciter stator current.
- b) For motors, a determination of locked-rotor current by calculation.
- c) An AC high potential test on the stator ~~and field~~ windings, space heaters, and stator RTDs. During testing of the stator ~~and field~~ windings, each phase shall be tested separately when possible with the other phases and RTDs grounded. Leakage current in each phase, ambient temperature, and humidity shall be documented. The end windings shall be observed during the test where access is practical. After reaching the test voltage level, the voltage and current shall remain stable (without rapid fluctuations) for the duration

of the test. If an abnormality in the test occurs without an obvious failure, the vendor and purchaser shall jointly decide whether additional testing, inspection or repairs are required to demonstrate acceptable results.

d) An insulation resistance test by megohmmeter and polarization index per IEEE 43. The insulation resistance measurement and polarization index shall be performed in accordance with Table 7 and on each phase separately when possible. (The polarization index is the ratio of the 10 minute resistance value to the one minute resistance value.) The minimum acceptable value for the stator winding polarization index is 2. The stator winding polarization index values shall be determined both before and after the high-potential test of the stator winding.

NOTE If the one minute insulation resistance is above 100 GΩ, the calculated polarization index may not be meaningful. In such cases, the polarization index may be disregarded as a measure of winding condition and the minimum acceptable value of 2 may not apply.

**Table 7—DC Test Voltages for Insulation Resistance and Determination of Polarization Index**

Machine Voltage	Test Voltage
< 1000	500
1000 - 2500	1000
2501–5000	2500
> 5000	5000

e) Measurement of stator and field winding resistance, using a digital low resistance meter.

f) Measurement of vibration (see 6.3.1.5 and 6.3.3).

g) A test of the bearing insulation per 6.3.5.7.

h) A test of the bearing temperature rise. The machine shall be operated at no load for at least one hour after the bearing temperatures have stabilized. Stable temperature is defined as a change of not more than 1 °C in 30 minutes. The no load run shall demonstrate that bearing operation is without excessive noise, heating, vibration, or lubrication leaks.

i) Insulation resistance test of bearing RTDs and any other nonstator RTDs.

j) Inspection of the bearings and oil supply (when furnished). After all running tests have been completed, the shaft journals and bearings shall be inspected by completely removing both the top and bottom halves of each sleeve bearing. The contact between the shaft journal and the bearing bore shall be a minimum of 80 % of the axial length and symmetrical with no edge loading or metal transfer between the shaft and the bearing. Where the lubricant is accessible, its condition shall be visually examined after the run.

- k) When specified before the tests are run, each bearing's journal-to-bearing clearance and bearing-shell-to-bearing-cap crush and alignment shall be determined and recorded.
- l) When specified after the tests are run, each bearing's journal-to-bearing clearance shall be determined and recorded.

m) Measurements of the main machine and exciter air gaps. Allowable limits are per 4.4.7.2.4.

n) Insulation resistance ~~and~~, AC high potential testing ~~, and polarization index tests~~ on the rotor main field winding, exciter rotor and exciter stator windings, and PMG winding (if supplied).

### 6.3.3 Vibration Test

**6.3.3.1** ~~For hydrodynamic bearing machines, E~~lectrical and mechanical runout shall be determined with the rotor supported at the bearing journal centers by lubricated v-blocks, lunettes (hydrodynamic bearing segments), or other nondamaging means of support. The rotor shall be rotated through the full 360° while measuring runout with a noncontacting vibration probe and a dial indicator. Measurements shall be made at the centerline of each probe location and one probe tip diameter to either side. Alternative methods that determine out-of-roundness of the journal and track, concentricity between the journal and track, and electrical runout that achieve the above results are also acceptable. Measurements utilizing this method shall be taken at least every 10° of rotation. The acceptance criteria are specified in paragraph 4.4.5.1.7.

**6.3.3.2** ~~For hydrodynamic bearing machines, a~~Accurate records of electrical and mechanical runout for the full 360° at each probe location shall be included in the test report.

**6.3.3.3** When non-contacting vibration probes or provisions are specified for hydrodynamic bearing machines, combined electrical and mechanical runout shall also be measured in the assembled machine with the rotor at slow roll speed (200 rpm to 300 rpm). The continuous unfiltered trace of the probe output shall be recorded for a 360° shaft rotation at each probe location. The rotor shall be held at its axial magnetic center during recording. The acceptance criteria for the combined total electrical and mechanical runout in the assembled machine shall not exceed 30 % of the allowed peak-to-peak unfiltered vibration amplitude. This runout data shall be used to compensate the shaft vibration readings filtered at running speed.

**6.3.3.4** Vibration measurements shall be taken in the horizontal and vertical radial directions and the axial direction on the bearing housings. All shaft radial-vibration measurements shall be taken using noncontacting eddy-current probes when equipped with them or when provisions for noncontacting probes are specified. Where shaft noncontacting probes or provisions for probes are not specified, only bearing-housing vibration measurements are required (see 4.4.5.1.7 for requirements at probe sensing areas). Shaft and bearing housing vibration data shall be recorded for unfiltered amplitudes and for filtered amplitudes at one half running speed, one times running speed (including phase angle), two times running speed, and one and two times line frequency.

**6.3.3.5** Unfiltered and filtered radial and axial vibration, electrical input, and temperature data shall be recorded at 30 minute intervals during all mechanical running tests. If the vibration pulsates, the high and low values shall be recorded.

**6.3.3.6** (This paragraph intentionally left blank.)

- **6.3.3.7** When specified, the purchaser may use his/her monitoring or recording equipment in conjunction with the vibration transducers mounted on the machine to record the dynamic behavior of the machine during testing.

**6.3.3.8** All purchased vibration probes, transducers, oscillator-demodulators, and accelerometers shall be in use during the test. If vibration probes are not furnished by the equipment vendor or if the purchased probes are not compatible with shop readout facilities, then shop probes and readouts that meet the accuracy requirements of API 670 shall be used.

**6.3.3.9** Shop test facilities shall include a computer based data acquisition and reduction system with the capability of continuously monitoring, displaying, and plotting required unfiltered and filtered vibration data to include revolutions per minute, peak-to-peak displacement, phase angle, and zero-to-peak velocity. The data shall be submitted to the purchaser together with the final test report. In addition, an oscilloscope and spectrum analyzer shall be available.

**6.3.3.10** The vibration characteristics determined by the use of the instrumentation specified in 6.3.3.4, 6.3.3.7 and 6.3.3.8 shall serve as a basis for acceptance or rejection of the machine.

**6.3.3.11** (This paragraph intentionally left blank.)

**6.3.3.12** During the shop test of machines with two or more bearings and while operating at rated voltage and rated speed or at any other voltage and speed within the specified operating speed range, the shaft displacement and bearing housing velocity of vibration shall not exceed the limits specified in 6.3.3.12.1 through 6.3.3.12.5. Values for single bearing machines shall be the same unless otherwise determined by agreement between the purchaser and vendor. When a complete test (6.3.5.1) or a rated rotor temperature test (6.3.5.2) is specified, vibration shall be within the filtered and unfiltered limits specified in 6.3.3.12.1 through 6.3.3.12.5 throughout the temperature range from the test ambient temperature to the total design temperature as tested per 6.3.5.1.1 item d. The hot vibration reading for thermal vector test shall be taken at the completion of the test in 6.3.5.1.1 item d.

**6.3.3.12.1** The unfiltered vibration limits for machines up to 3000 rpm rated speed shall not exceed 50  $\mu\text{m}$  (2 mil) peak-to-peak (p-p) displacement. For machines with rated speeds in excess of 3000 rpm, the unfiltered vibration limit shall not exceed:

In SI units:

$$25.4 \times \sqrt{[12,000 / N]} \mu\text{m p-p} \quad (10)$$

In USC units:

$$\sqrt{[12,000 / N]} \text{ mils p-p} \quad (11)$$

where

$N$  is the maximum rated speed (rpm).

These shaft readings include a maximum allowance for electrical and mechanical runout in accordance with 6.3.3.1. The vibration limits are shown graphically in Figure 2 and Figure 3.

**6.3.3.12.2** Shaft vibration displacement at any filtered frequency below running-speed frequency shall not exceed 2.5  $\mu\text{m}$  (0.1 mil) or 20 % of the measured unfiltered vibration displacement, whichever is greater.

**6.3.3.12.3** Shaft vibration displacement at any filtered frequency above running-speed frequency shall not exceed 12.5  $\mu\text{m}$  (0.5 mil) p-p.

**6.3.3.12.4** Shaft vibration displacement filtered at running speed frequency (runout compensated) shall not exceed 80 % of the unfiltered limit.

**6.3.3.12.5** Bearing housing radial and axial vibration velocity shall not exceed, in total (unfiltered) or at an individual frequency, 2.5 mm/s (0.1 in./s) zero-to-peak (0-p) or the velocity calculated by Equation (12) and Equation (13), whichever is less.

In SI units:

$$2.5 \times N / 1000 \text{ mm/s 0-p} \quad (12)$$

In USC units:

$$0.1 \times N / 1000 \text{ in./s 0-p}$$

(13)

The vibration limits are shown graphically in Figure 4 and Figure 5. NOTE 1 For total bearing housing radial or axial velocity limit, rpm = maximum rated speed. Individual vibration frequencies can be converted to the corresponding rpm, i.e. 120 Hz = 7200 rpm, 60 Hz = 3600 rpm.

NOTE 2 The intent of equations (12) and (13) is to limit the bearing housing displacement below 1000 rpm to 50  $\mu\text{m}$  and 2 mils respectively. Often for machines rated below 1000 rpm, 1X is not the largest source of vibration.

**6.3.3.13** The magnitude of the resultant vector (filtered 1X vibration) change from the cold point to rated temperature shall not exceed 20  $\mu\text{m}$  (0.80 mil) p-p for shaft vibration and 1.25 mm/s (0.05 in./s) 0-p for the bearing housing vibration. Annex G outlines a procedure for determining the resultant vector change.

**6.3.3.14** For machines that do not comply with the vibration vector change limits in 6.3.3.13 or Annex G (Figure G.4) while remaining within the limits of 6.3.3.12, subsections 6.3.3.14.1 through 6.3.3.14.3 represent an alternate vibration acceptance criterion, which can be applied when specifically approved by the purchaser.

**6.3.3.14.1** The vendor shall repeat the temperature test of 6.3.3.12.

**6.3.3.14.2** Prior to starting the repeat temperature test and again after completing the repeat temperature test, the machine shall be cooled down to no load stabilized temperatures.

**6.3.3.14.3** The magnitude of the resultant 1X running speed vibration vector change between subsequent tests for the cold machine under no load and for the hot machine at rated temperature shall be within 10 % of the allowable limits in 6.3.3.12. This is illustrated graphically by example in Annex G, Figure G.4.

**6.3.3.15** The magnitude of the unfiltered horizontal vibration of any loaded structural member of the frame along the axis of the shaft centerline shall not exceed two times the limit given in 6.3.3.12.5 when operating at no-load, full voltage, and rated frequency. Measurements shall be taken on the outside of the machine at the loaded structural member of the frame. A loaded structural member of the frame is defined as one of the steel plates or structural sections that support the stator core in the case of box frames. For other designs, measurement points shall be agreed between the vendor and purchaser prior to the purchase order.

**6.3.3.15.1** In small or medium size machines, all measurement points may not be accessible due to the location of conduit or accessory boxes that can block the required position of the sensor. In that case, if the location for the sensor on the opposite side of the machine is accessible, the frame vibration at the sensor location that is not accessible does not need to be measured. If neither sensor location is accessible, then the test shall be conducted with conduit or accessory boxes removed as required to provide access for the measurement.

- ◆ **6.3.3.15.2** For ASD driven units, it may not be possible to guarantee the above value across the entire speed range due to local panel resonances that can be present and affect the overall value at the measurement points. For such cases, an acceptance value shall be agreed between the vendor and the purchaser prior to the purchase order, and the vendor shall demonstrate that the frame has infinite fatigue life for the frequency where the peak vibration occurs.

**6.3.3.16** While the equipment is operating at maximum continuous speed and a stable temperature, sweeps shall be made for vibration amplitudes at frequencies other than running speed. These sweeps shall cover a frequency range from 25 % of the running-speed frequency to four times the line frequency. Limits on individual frequency components are set in 6.3.3.12.1 through 6.3.3.12.5.

- **6.3.3.17** When specified, an electronic copy of the vibration data shall be provided in a format mutually agreed upon between the purchaser and vendor.

**6.3.3.18** In-frame balancing shall require owner approval prior to order entry (or manufacturing). Any trim balance shall require approval by the owner. If addition or modification of balance weights is approved, details of the change including at a minimum the balance weight location and procedure of the balance addition shall be documented and provided to the owner. A residual unbalance test (4.4.6.3.4 and Annex F) shall be performed after any trim balancing has occurred, even if the residual unbalance test was not selected on the datasheet. Trim balancing shall not be used to compensate for thermal bow, or other mechanical instability. Any balancing done after the start of testing shall void any prior vibration (6.3.3 and 6.3.5.3) or heat run (6.3.5.1.1 and 6.3.5.2.2) testing and these tests shall be repeated.

- ◆ **6.3.3.19** The vibration limits for motors driven by ASDs are the same as for fixed speed units. The limits shall be met at all supply frequencies in the specified operating speed range. Complete shaft, bearing housing, and frame vibration data as specified in 6.3.3.4 and 6.3.3.15 shall be documented at the maximum operating speed plus other mutually agreed upon speeds that represent the normal operating or worst case vibration conditions.

#### **6.3.4 Stator Tests**

- **6.3.4.1 Stator Core Test**

When specified, prior to insertion of the stator coils into the core, the stator core interlaminar insulation integrity shall be verified.

The test shall be performed by inducing flux in the stator to magnetize the core at rated flux density by placing coils through it in a manner similar to a transformer winding as described in IEEE 56 and IEEE 62.2. Rated flux shall be maintained for a minimum of 30 minutes while continuously monitoring stator temperatures with an infrared camera. There shall be no location (hot spots) on the stator core having a temperature greater than 5 °C (9 °F) above the adjacent core temperature. Adjacent core is defined as packs of laminations and teeth next to each other and separated by radial vents as shown in Figure 6. When radial vents do not exist, an adjacent core hot spot is defined as being within 6 cm (2.2 in.).

The rated flux and the watts loss per kilogram (watts loss per lb) of back iron at that flux shall also be recorded for reference purposes only and for comparison with other similar machines using the same test equipment.

NOTE The watts loss at any flux density varies with the frequency, harmonics and test equipment and will not necessarily be the same under different test conditions. However, comparison with data from other machines from the same manufacturer may help diagnose future problems.



**Key**

- 1. adjacent core
- 2. radial vent

Figure 6—Adjacent Core

#### 6.3.4.2 Surge Test

For multi-turn windings, surge comparison tests shall be made of the turn insulation for each coil in the fully wound stator just before the coil-to-coil connections are made, at test levels and methods for uncured coils in accordance with Figure 1 of IEEE 522-2004 or IEC 60034-15.

NOTE In designs where bar windings are used for the stator winding, a turn to turn surge test is not useful. Strand to strand tests (before the ends are connected) have been known to detect strand faults.

- **6.3.4.2.1** When specified, two additional stator coils for special surge tests of the main and turn insulation shall be manufactured at the same time as the complete stator winding. These coils shall be completely cured and tested as follows.
  - a) Coils that use semi-conductive coating in the slot section shall be subjected to a partial discharge test at rated line-to-neutral AC voltage. When the slot sections are wrapped with grounded conductive foil or enclosed in a grounded metallic simulated slot, the partial discharge shall be measured at rated line-to-neutral voltage in accordance with IEC TS 60034-27. Test calibration shall be in accordance with

ASTM D1868 or IEC 60270. This test is performed when specifically requested and for information only. This test shall be performed before any other tests listed below.

b) The main insulation shall be subjected to three successive applications of a 1.2/50  $\mu$ s impulse voltage and withstand a crest value of 5 PU on each of the three impulse tests. The impulse voltage shall be applied to both terminals of the coil conductor while the conducting surfaces of the simulated slot portions of the coil are grounded.

c) The test of the turn insulation shall consist of at least five successive applications at 3.5 pu within 1 minute intervals of voltage impulses having a rise time of 0.1 to 0.2  $\mu$ s applied between the coil terminations. After successfully passing the test, the crest value of the voltage impulse shall be gradually increased until either the point of insulation failure or the limitation of the test equipment is reached.

Note: Increasing the voltage to the point of failure is for informational purposes only. When a failure occurs, the cut would typically be made at the location of the failure

d) At the completion of the tests, the sacrificial coils shall be cut into at least three segments at mutually agreed locations and shall be available at the test location to the purchaser or their representative on the same day the surge test is completed.

- **6.3.4.3 Power Factor Tip-Up Test**

When specified, a power factor tip-up (tan-delta) test shall be performed on the completely wound stator in accordance with IEEE 286 or IEC 60034-27.

- **6.3.4.4 Sealed Winding Conformance Test**

When specified, machine stators shall be tested in accordance with NEMA MG 1, Part 20 by means of a water-immersion or spray test. These tests shall be in addition to all other tests.

At the completion of the test, the stators shall be rinsed and dried, at which point any other required tests may be performed.

Any internal ionization or carbonization initiated during a failure of the test will weaken the insulation and shall be repaired. If the winding fails the AC overpotential test upon the second attempt, the winding shall be replaced at the purchaser's option.

NOTE This test exposes certain parts of the insulation to stress levels that are in excess of what it sees during normal operation.

- **6.3.4.5 Stator Inspection Prior to VPI**

When specified, the fully wound and connected stator shall be inspected prior to VPI.

- **6.3.4.6 Partial Discharge Test**

When specified for machines rated 6 kV and greater, an off-line partial discharge test shall be performed on the stator windings, in accordance with Clause 10.2 of IEEE 1434 or IEC TS 60034-27. Where possible, the tests shall be performed on each phase individually with the other phases grounded. Test voltage shall be 120 % of the rated phase-to-neutral voltage, and the test voltage shall be maintained for at least 5 minutes conditioning time. As a minimum, partial discharge inception voltage and partial discharge extinction voltage shall be recorded for each phase as well as the power supply frequency, temperature and humidity at the time of test. The vendor shall provide the purchaser with partial discharge test data of similar machines with the

same insulation system for comparison. The acceptance criteria shall be mutually agreed upon between the vendor and purchaser prior to performing the tests.

NOTE 1 Partial discharge performance of insulation systems varies between vendors and specifying absolute levels is not presently considered appropriate. Of greater importance is that the performance of a particular machine's insulation system is consistent with the performance of similar systems from the same source. Significant variation in performance may be an indication of voids or other problems with the insulation.

NOTE 2 The performance of a particular machine's insulation system often improves after some time in service. Therefore, comparison of factory test results with site performance of existing machines may not be valid.

- **6.3.4.7 External Discharge Test**

When specified, an external discharge (corona) test shall be performed on the completed stator according to the line-to-line test per IEEE 1799 on each phase in turn with the other phases grounded. The test shall be performed using either a UV camera or a "blackout" test. Acceptance criteria shall be mutually decided between Purchaser and Vendor.

Note: This test is typically useful on machines rated 6 kV and greater.

### **6.3.5 Special Test**

#### **6.3.5.1 Complete Test**

- **6.3.5.1.1** When specified, each machine shall be given the complete test described below [items a) through g)] in addition to the tests specified in 6.3.2. This test shall be documented and in accordance with the applicable portions of IEEE 115 and NEMA MG 1 or IEC 60034-2 and IEC 60034-4 and shall include the following items.

a) Determination of efficiency at 100 %, 75 %, and 50 % of full load and any other specified load point(s) at specified power factor. The vendor shall indicate which method will be used in determining the performance data. Efficiency determination method and supply frequencies of motors on ASDs shall be determined by mutual agreement between the purchaser and the vendor. Motors that are designed to be operated only on an ASD shall not require tests in Items b) and f) below.

b) For motors, Ddetermination of the locked-rotor current, power factor during starting, mean torque, and a determination by calculation of pull-out torque as applicable.

c) Tests for the construction of the open-circuit saturation and core loss curve and for the short-circuit saturation and loss curve.

d) A heat run (temperature) test of the main armature and field at the maximum continuous rated service factor ~~and power factor~~ (using the zero power factor method or the synchronous feedback technique) for a minimum of four hours or until the bearing and winding temperatures stabilize (whichever is greater). Temperature rise shall be in accordance with 4.3.1.1 b) including worst case allowances for any uncertainties associated with the test and temperature.

NOTE For larger machine sizes, a heat run test may be limited to only open-circuit and short-circuit tests.

e) An exciter heat run (temperature test in conjunction with the main machine test or certified data from a duplicate design).

f) Tests for the construction of the no-load V curve (stator current versus exciter field current curve at the machine's rated voltage).

g) Noise test in accordance with ANSI S12.54 or ISO 1680 with the machine operating at no load, full voltage, rated frequency, and sinusoidal power.

h) When supplied, functional and performance test of excitation control system, including verification of protection and alarm setpoints.

- **6.3.5.1.2** When specified, the machine's insulation shall be tested by means of a DC high-potential test to the maximum voltage listed in Table 8. The test procedure shall be to apply voltage in not less than four approximately equal steps, pausing one minute at each step and five minutes at the final voltage, taking 15 seconds to increase the voltage slowly at the beginning of each step. During the test, a micro ammeter shall be watched closely for the inception of any leakage-current advance and the results recorded at each step.

**Table 8—DC High-potential Test Voltage Levels**

<b>Machine Rated Voltage (KV) E</b>	<b>DC High-Potential Test Voltage (kV) (2E + 1)(0.75)(1.75)</b>
2.3	7.4
2.4	7.6
4.0	11.8
4.16	12.2
6.6	18.6
6.9	19.4
13.2	36.0
13.8	37.5

- **6.3.5.1.3** When started asynchronously, all four and six pole motors shall have tests performed to determine pulsating torques in accordance with IEEE 1255. When a transient torsional analysis is specified, this test shall be applied to 8 pole and slower speed motors.

#### **6.3.5.2 Rated Rotor Temperature Vibration Test**

- **6.3.5.2.1** When specified for machines that do not receive the complete tests of 6.3.5.1.1, a heat run test in accordance with 6.3.5.1.1 d) shall be performed.

**6.3.5.2.2** If the heat run test specified in 6.3.5.1.1 d) cannot be performed due to test stand limitations, the vendor shall submit complete details of an alternative test that permits measurements of vibration for at least four hours with the rotor reaching full load temperature.

- **6.3.5.3 Unbalanced Response Test**

When specified, satisfactory dynamic performance (see 4.4.6.1.1) shall be verified by attaching the machine to a massive foundation support and subjecting the machine to the following unbalanced response test. Special considerations may be required for super-synchronous machines. For critical speed considerations of machines operating above 400 rpm, the test shall be made with a mass moment that simulates the mass and center of gravity of all components supported by the machine shaft extension (e.g. machine coupling hub and half of the coupling spacer). The purchaser shall supply either a complete half-coupling mass

moment simulator, or the contract machine coupling hub plus any additional mass moment simulator necessary to facilitate the preceding, or shall provide applicable half-coupling mass moment and center of gravity data to facilitate provision of a coupling mass moment simulator by the machine manufacturer. The test specified in 6.3.1.5 to check vibration with the half-coupling assembly installed shall be performed prior to the unbalance response test.

NOTE 1 If the vendor provides the purchaser with a lateral critical speed study showing adequate separation margin and no significant effect on the separation margin by including the simulated mass moment, then the mounting of these devices may not be required. Adequate separation margin and no significant effect of the mass moment inclusion is defined as at least a 25 % separation margin and less than or equal to 2 % change when including the simulated mass moment. If the above is satisfied, then the physical inclusion of these devices for the unbalance response test may not be required if mutually agreed upon by the purchaser and vendor.

NOTE 2 Unbalance response testing on single bearing machines 514 RPM and slower is typically not specified as being neither practical nor necessary.

- a) A balanced coastdown shall be performed with the machine in balanced state. The machine shall be run to 120 % of its rated speed and then allowed to coast to rest. The shaft vibration and phase angle relative to the bearing housing and the bearing housing vibration shall be plotted versus speed at increments of no more than 50 RPM and recorded for reference purposes.
- b) A deliberate unbalance of  $4U_B$  per plane [see 4.4.6.3.3, Equation (5) or Equation (6)] shall be applied to the rotor. The weights shall be placed at the balance planes in-phase to excite the first lateral critical speed. In cases where the 2nd or higher order lateral critical speeds may encroach on the running speed range separation margin, the test shall also be performed with the weights placed at the balance planes 180° out-of-phase. In cases where an overhung mass is present (e.g. a fan or coupling) resulting in a bending mode with maximum deflections at the shaft end, the tests shall also be performed with unbalance weights placed on the coupling. The amount of unbalance to be added to the overhung mass shall be based on four times the allowable residual unbalance in the overhung mass (e.g. from API 671, the assembled coupling may be balanced to  $40W_c/N$ , where  $W_c$  is the weight of the coupling and  $N$  is the maximum continuous speed; in this case, the amount of unbalance to be added to the coupling should be  $160W_c/N$  where  $W_o$  is the weight of the overhung mass).
- c) The unbalance weights may be placed placed at any location on the balance planes or coupling. Each test also shall be repeated with the weights moved to new positions 90° from the original positions to determine the sensitivity of the rotor response to unbalance weight placement. The maximum response obtained shall be used as the acceptance criteria.
- d) The machine shall be run to 120 % of its rated speed with the unbalance weights attached and then allowed to coast to rest. The shaft vibration relative to the bearing housing shall be plotted versus speed at increments of no more than 50 RPM and recorded. Machines shall meet the following criteria.
  - i. The 1X runout compensated shaft displacement relative to the bearing housing at any speed within the operating speed range or 15 % separation-margin limit shall not exceed the smaller of 1.5 times the vibration limit at the operating speed nearest the resonant speed of concern from 6.3.3.12.1 or 55 % of the minimum design shaft-to-bearing diametric running clearances.
  - ii. If the 1X runout compensated shaft displacement relative to the bearing housing exceeds this limit, vector subtraction may be used to demonstrate compliance with the limit. For each speed increment within the separation margin speed range, subtract the recorded balanced coastdown vibration vector from the recorded unbalanced coastdown vibration vector to create an unbalance response vibration vector. The magnitude of each unbalance response vibration vector

shall not exceed the smaller of 1.5 times the vibration limit at the respective speed or 55 % of the minimum design shaft-to-bearing diametric running clearances.

In some instances, with the permission of the owner, it may be necessary to relax the requirement for the shaft displacement limit of 1.5 times the vibration limit at the operating speed nearest the resonant speed of concern from 6.3.3.12.1.

Alternatively, with permission of the owner, the 1.5 times limit may be used for the operating speed range and the 55% limit used for the separation margin.

NOTE: API 684 also uses vector subtraction to as part of the unbalance response test procedure for turbines.

ii. The shaft displacement relative to the bearing housing at any speed outside the operating speed range or separation-margin limits shall not exceed 80 % of the minimum design shaft-to-bearing diametric running clearance.

ii. If the 1X runout compensated shaft displacement relative to the bearing housing exceeds this limit, vector subtraction may be used to demonstrate compliance with the limit. For each speed increment within the separation margin speed range, subtract the recorded balanced coastdown vibration vector from the recorded unbalanced coastdown vibration vector to create an unbalance response vibration vector. The magnitude of each unbalance response vibration vector shall not exceed the smaller of 1.5 times the vibration limit at the respective speed or 55 % of the minimum design shaft-to-bearing diametric running clearances.

NOTE 1: The purpose for the limits is to protect the machine while validating that the critical speed is outside the separation margins.

NOTE 2: Bearing clearances are the only limits applied outside of the separation margin.

e) For machines that do not comply with the separation margin of 4.4.6.1.1 and when specifically approved by the purchaser, a well-damped resonance (response) shall be demonstrated. The machine shall be run to 120 % of its rated speed with the unbalance weights attached as described in 6.3.5.3 a), 6.3.5.3 b), and 6.3.5.3 c) and then allowed to coast to rest. The 1X runout compensated shaft displacement over the entire speed range, from 0 % to 120 %, shall not exceed 1.5 times the vibration limit at the maximum rated speed from 6.3.3.12.1. (When specifically approved by the purchaser, Annex H may be used as alternate criteria for defining a well-damped resonance.)

#### **6.3.5.4 Bearing Housing Natural Frequency Test**

- **6.3.5.4.1** When specified, bearing housings or end bracket supports shall be checked for resonance on one fully assembled machine (see 6.3.1.3) of each group of identical machines. The resulting response shall be plotted for a frequency sweep of 0 % to 400 % of line frequency. In order to eliminate the interaction between the bearing housings, the rotor shall be turned at a slow roll (200 rpm to 300 rpm). The response plots shall be made on each bearing housing in the horizontal, vertical and axial directions. The application of the excitation force shall be made in these same directions.

**6.3.5.4.2** No significant resonance shall occur within  $\pm 15$  % of one and two times running speed,  $\pm 15$  % of one and two times line frequency, or between 40 % and 60 % of running speed as required by 4.4.2.1. A significant resonance is defined as a peak that lies within 6 dB in amplitude (acceleration) of the fundamental bearing housing resonance in the particular direction being tested. The frequency range may be expanded in order to determine the fundamental bearing housing resonance in the direction of the excitation. Percentages are based upon one times running speed and electric line frequency.

- ◆ **6.3.5.4.3** On adjustable speed machines where the criteria in 6.3.5.4.2 cannot be satisfied, the vendor shall propose an alternate method in the proposal to verify that the natural frequency of the bearing housing will not be excited within the operating speed range. The purchaser shall approve this method.

- **6.3.5.5 Heat Exchanger Performance Verification Test**

When specified for machines with TEWAC heat exchangers, the performance of the heat exchanger shall be demonstrated. The test shall be conducted during a heat run of at least four hours with the cooling water flow and temperature maintained as close as practical to rated conditions while the machine is operating as close as practical to rated voltage, current, and frequency. During this test, all pertinent mechanical, electrical, temperature, and flow rate data shall be recorded. The heat exchanger air outlet temperature shall not exceed the specified value, usually 40° C. If the heat exchanger test at rated conditions is not possible due to either the machine size or the test facility capabilities, the vendor and purchaser shall jointly develop a test method to satisfactorily demonstrate the heat exchanger performance.

NOTE If a complete test is specified, this heat exchanger test may be performed in conjunction with the heat run required as part of the complete test.

- ◆◆ **6.3.5.6 Overspeed Test**

When specified, the machine shall be run for two minutes at the overspeed listed in NEMA MG 1, Part 21; IEC 60034-1; or to the specified trip speed (including overshoot) of the connected equipment (whichever is greater). The magnitude of the vectorial change in the 1X vibration on the shaft and bearing housings, when operated at running speed after the overspeed test shall not exceed 10 % of the vibration limits given in Figure 2, Figure 3, Figure 4, and Figure 5. If the vibration change or amplitude exceeds the allowable limits, the vendor and purchaser shall mutually agree on the appropriate corrective action. For machines driven by ASDs, the purchaser and vendor shall mutually decide the overspeed capability.

- **6.3.5.7 Bearing Insulation Test**

Bearing insulation resistance shall be a minimum of 1 M-ohm as measured using a megohmmeter at a minimum 100 VDC test voltage for one continuous minute.

## **6.4 Preparation for Shipment**

- **6.4.1** Each unit shall be suitably prepared for the type and mode of shipment specified. Preparation for shipment shall be performed after all testing and inspection have been completed and the purchaser has released the equipment for shipment. The vendor shall provide the purchaser with the instructions necessary to preserve the integrity of the storage preparation after the equipment arrives at the job site and before start-up. One copy of the vendor's standard installation instructions shall be packed and shipped with the equipment.
  - a) Exterior surfaces, except for machined surfaces or corrosion resistant material, shall be coated with vendor's standard paint. Exposed shafts and shaft couplings shall be wrapped with an easily removed waterproof coating or wrapping. Bearing assemblies shall be fully protected from the entry of moisture and dirt. Machined surfaces and exposed threads of soleplates and baseplates shall be suitably protected for shipping and storage.
  - b) After thorough cleaning, internal areas of bearings and auxiliary equipment for carbon steel oil systems shall be coated with a suitable oil-soluble rust preventive.
  - c) For shipping purposes, flanged openings shall be provided with metal closures at least 5.0 mm (<sup>3</sup>/<sub>16</sub> in.) thick, with synthetic rubber gaskets and at least four full-diameter bolts.

- d) For shipping purposes, threaded openings shall be provided with steel caps or solid-shank steel plugs. Nonmetallic threaded plugs may only be used for terminal box openings.
- e) The equipment shall be mounted on a rigid skid or base suitable for handling by forklift, truck, or crane. This skid shall extend beyond all surfaces of the machine.
- f) Lifting points and lifting lugs shall be clearly marked. Each machine shall be properly identified with item and serial numbers. Material shipped in separate crates shall be suitably identified with securely affixed, corrosion-resistant metal tags indicating the item and serial number of the equipment for which it is intended. The recommended lifting arrangement shall be identified on boxed equipment.
- g) If vapor-phase-inhibitor crystals in bags are installed in large cavities to absorb moisture, the bags shall be attached in an accessible area for ease of removal. Where applicable, bags shall be installed in wire cages attached to flanged covers, and corrosion-resistant tags attached with stainless steel wire shall indicate bag locations.
- h) The fit-up and assembly of machine-mounted piping, coolers, terminal boxes and other equipment shall be completed in the vendor's shop before shipping, unless specifically approved otherwise by the purchaser. Auxiliary piping connections furnished on the purchased equipment shall be impression stamped or permanently tagged to agree with the vendor's connection table or general arrangement drawing. Service and connection designations shall be indicated. Components (both individual pieces and packaged sets) shipped with mounted preassembled piping, tubing, or wiring shall comply with the requirements of the Occupational Safety and Health Administration.
- i) Machines that are disassembled for shipment or storage shall be provided with marine type plywood over all openings and sloped for proper watershed when protected with exterior covering.
- j) The rotor shall be blocked to prevent axial and radial movement, and clearly marked or tagged.
- k) When specified or when required by machine size, configuration, or method of transportation, the normal running bearings shall be removed and shipped in protective crates, and the machine shall be equipped with special bearings for shipment.
- l) Space heater leads shall be accessible without disturbing the shipping package and shall be suitably tagged for easy identification.
- m) Each bearing that is shipped with a temporary shipping liner shall be clearly identified with a tag.
- **6.4.2** When specified, the preparation shall make the equipment suitable for at least six months of outdoor storage from the time of shipment and shall include 6.4.1 a) through 6.4.1 l) as required.

## **7 Guarantee and Warranty**

The details of the guarantee and warranty shall be developed jointly by the purchaser and vendor subsequent to submission of the proposal, and supporting documentation included in the contract documents.

## 8 Vendor's Data

### 8.1 GENERAL

8.1.1 The purchaser may specify the content of proposals, meeting frequency and vendor data content/format identified in Annex L. Annex L provides a general outline of information that potentially may be requested by the purchaser.

- 8.1.2 If specified, the information specified in Annex L shall be provided.
- 8.1.3 If specified, the vendor shall complete the Vendor Drawing and Data Requirements form (see Annex C) detailing the schedule for transmission of drawings, curves, and data as agreed to at the time of the order, as well as the number and type of copies required by the purchaser.

#### Proposals

~~Vendor's proposals shall provide the information specified in this section and include completed "Machine Proposal Data" of the datasheets in Annex A or Annex B.~~

~~8.1.1 The vendor shall be responsible for providing the purchaser with all details necessary for proposal evaluation, contract performance, installation, operation, and maintenance of the machine as an integral part of the complete unit assembly.~~

- ~~8.1.2 When the evaluation factor (e.g. dollars per kilowatt) is shown on the datasheets, machines shall be evaluated on the basis of life-cycle cost (purchase price plus present worth of losses).~~

~~8.1.3 The vendor shall provide complete performance curves and data to fully define the envelope of operations and the point at which the vendor has rated the equipment, including the following items [Items a), b), d), and e) are not required for motors that are designed to operate only on ASDs].~~

#### ~~8.1.3.1 For motors.~~

- ~~a) Average torque and twice slip frequency pulsating torque versus speed during starting at rated voltage and minimum starting conditions (voltage and short circuit MVA) and any other specified conditions.~~

- ~~b) Current versus speed during starting at rated voltage and minimum starting conditions (voltage and short circuit MVA) and any other specified conditions.~~

~~c) The inertia of the rotor.~~

- ~~d) Estimated times for acceleration at rated voltage and minimum starting conditions (voltage and short circuit MVA) and any other specified conditions.~~

- ~~e) The locked-rotor (stalled) withstand time, with the motor at ambient temperature and at its maximum rated operating temperature for rated voltage and minimum starting conditions (voltage and short circuit MVA) and any other specified conditions plus the limit curves and wait times specified in 4.2.4.2.~~

- ~~f) Expected efficiencies as determined in accordance with IEEE 115 or IEC 60034-2, or by certified data from previously tested designs. The purchaser shall specify on the datasheet the efficiency test method to be used. For motors driving reciprocating machines, the expected pulsating currents shall be considered in calculating the efficiencies. For motors to be driven by ASDs, the vendor shall state the methods of efficiency determination to be used along with the base frequencies and the harmonics present in the supply waveform(s).~~

• g) —When specified, the guaranteed efficiencies (with no negative tolerance) at  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$ , and full load calculated in accordance with the agreed upon test method from 8.1.3.1 f).—

• h) —For motors that drive reciprocating machines the maximum current variation under actual operating conditions. Compressor crank effort diagrams, power supply system information, and other relevant data shall be supplied by the purchaser for the determination of current pulsations.—

i) NOTE —To verify performance, it may be necessary to check motor current pulsations under load in the field using an appropriate digital waveform recording instrument. A description of the field application and synchronization circuit and devices.—

j) Synchronizing power per electrical radian ( $P_r$ ) at no load and full load.—

### **~~8.1.3.2 For generators.~~**

a) Short circuit currents vs. time for three phase, line to line, and line to ground fault conditions.—

• b) Transient (momentary) voltage regulation during sudden application and removal of 100 % full load or any other specified load value.—

c) Total and single harmonic voltages expressed in % of fundamental voltage for line to line and line to neutral with unit operating at rated voltage, frequency and no load.—

d) The inertia of the rotor.—

e) Zero sequence reactance to enable the purchaser to complete ground fault calculations.—

f) Expected efficiency as determined in accordance with IEEE 115 or IEC 60034-1-1, or by certified data from previously tested designs. The purchaser in consultation with the vendor shall specify the method to be used.—

• g) —When specified, the guaranteed efficiencies (with no negative tolerance) at  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$ , and full load calculated in accordance with the agreed upon test method from 8.1.3.2 f).—

h) Synchronizing power per electrical radian ( $P_r$ ) at no load and full load.—

• **~~8.1.3.3~~** —When specified, information shall be supplied with the proposal to facilitate a preliminary power system short-circuit analysis. The required machine parameters include “ $X_{dv}$ ” [rated voltage (saturated) subtransient reactance],  $X_{2v}$  [rated voltage (saturated) negative-sequence reactance],  $T_{a3}$  [rated voltage (saturated) armature time constant (seconds)], rated MVA, and rated terminal voltage.—

NOTE —IEEE Std C37.010, Table 8, footnote “a,” describes the use of the above information to determine the effective resistance to be used for the  $X/R$  of the machine during short circuit calculations.—

**~~8.1.4~~** —The vendor shall provide utility requirements (e.g. water, air, and lube oil) including the quantity of lube oil required at the supply pressure and the heat load to be removed by the oil. (Approximate data shall be defined and clearly identified as such.) This information shall be entered on the datasheets.—

**~~8.1.5~~** —The vendor shall provide net weights and maximum erection weights with identification of the item. This data shall be stated individually where separate shipments, packages, or assemblies are involved. This data shall be entered on the datasheets.—

**~~8.1.6~~** —The vendor shall provide a preliminary dimensional outline drawing showing the location of inlet and discharge connections and the direction of rotation when viewed from the non-drive end.—

~~8.1.7 If applicable, the vendor shall provide schematic diagrams of auxiliary subsystems (e.g. lube oil or cooling water systems).~~

~~• 8.1.8 When specified, the vendor shall provide typical drawings and literature to fully describe the details of the offering or offerings. The vendor shall show shaft sealing and bearing details, internal construction, rotor construction, and the method of attaching the amortisseur bar to the shorting ring if applicable.~~

**8.1.49** The vendor shall provide a specific statement that the complete machine and all auxiliary equipment are in strict accordance with this standard. If the machine and auxiliary equipment are not in strict accordance, the vendor shall include a specific list that details and explains each exception. Exceptions may include alternative designs or systems equivalent to and rated for the specified duties.

~~8.1.10 The vendor shall provide an explicit statement of the proposed guarantee and warranty (see Section 7).~~

~~8.1.11 The vendor shall provide a statement of the fixed number of weeks required to effect shipment after receipt of the order and all engineering data. Separate times shall be stated for multiple shipments as in the case of separate packages or assemblies or multiple units.~~

~~8.1.12 The vendor shall provide a schedule of the promised time or times after placement of the order for transmittal of the contract data and drawings (see 8.3.1 and Annex A or B). This information shall be presented in the form of an explicit schedule.~~

~~8.1.13 The vendor shall provide an itemized list of the special tools included in the offering. The vendor shall list any metric items included in the offering.~~

~~• 8.1.14 When specified, the vendor shall provide a separate price for each test that is specified and a packaged price for all the tests specified on the datasheets.~~

~~• 8.1.15 When specified, the vendor shall provide a description of all necessary weather and winterizing protection required for the machine and its auxiliaries for storage, start-up, operation, and idleness. The vendor shall quote separately the protective items he/she proposes to furnish.~~

~~8.1.16 The vendor shall provide technical data, specifications, catalog cut sheets, or similar information that describe all the auxiliary equipment.~~

~~• 8.1.17 When specified, the vendor shall provide a statement of the rate for furnishing a supervisor for installation and erection of the machine as well as an estimate of the length of time the supervisor's services will be required under normal conditions. The vendor shall also include the rate and estimated time required for the services of a startup commissioning supervisor or engineer.~~

~~• 8.1.18 When specified, materials defined by the purchaser shall be identified in the proposal with their applicable AISI, ANSI, ASTM, and ANSI/ASME or ISO numbers, including the material grade. When no such designation is available, the vendor's material specification, giving physical properties, chemical composition, and test requirements shall be included in the proposal.~~

~~• 8.2 When specified, the vendor shall support a coordination meeting to be held as soon as possible after the purchase order placement. The meeting should include the end user, the electric machine supplier, driven equipment or prime mover supplier, ASD supplier (as applicable), engineering firm, consultant and other sub-suppliers as required. The following items should be reviewed:~~

~~a) the purchase order, scope of supply, unit responsibility, sub-vendor items, document procedures and lines of communications;~~

- ~~b) contract data and API 546 datasheets (see 8.3);~~
- ~~c) API 546 comments and exceptions, applicable specifications, and previously agreed exceptions;~~
- ~~d) speed-torque curves (for motors) and rotating equipment inertias;~~
- ~~e) schedules for the transmittal of data, production, testing, and shipment (Annex C);~~
- ~~f) the quality assurance program and procedures;~~
- ~~g) equipment performance, alternate operating conditions, start-up, shutdown and any operating limitations;~~
- ~~h) instrumentation, controls, and any other interfaces;~~
- ~~i) scope, performance, operating parameters, and P&IDs for auxiliary subsystems (e.g. lube oil or cooling water consoles);~~
- ~~j) identification of items requiring design review;~~
- ~~k) inspection, test procedures and related acceptance criteria; and~~
- ~~l) other technical items.~~

### **8.3—Contract Data**

Subsequent to the issuance of a contract, the vendor shall submit the “Order Data” pages of the datasheets in Annex A or Annex B. These pages shall be marked “As Designed” using the associated symbols.—

**8.3.1**—The vendor shall complete the Vendor Drawing and Data Requirements form (see Annex C), detailing the schedule for transmission of drawings, curves, and data as agreed to at the time of the order, as well as the number and type of copies required by the purchaser.—

- **8.3.2**—The following information shall be furnished on the datasheets by the purchaser and vendor (where applicable). This information shall be added to title blocks on the drawings, data, curves and transmittal letters which are forwarded to the purchaser:

- ~~a) the purchaser and user’s corporate name;~~
- ~~b) the job and project number;~~
- ~~c) the equipment name and item number;~~
- ~~d) the purchase order number;~~
- ~~e) any other identification specified in the purchase order; and~~
- ~~f) the vendor’s identifying shop order number, serial number, or other reference required to identify returned correspondence completely.~~

**8.3.2.1**—If not previously supplied with the proposal, the vendor shall supply a recommended list of spare parts complete with catalog numbers and ordering information.—

- **8.4**—When specified, a design review meeting shall be held at the electric machine vendor’s manufacturing facility at the time certified drawings and data are available for approval by the purchaser. The meeting should include the end user, electric machine supplier, driven equipment or prime mover supplier, ASD—supplier (as applicable), engineering firm, consultant and other sub-suppliers as required. Suggested items for review are as follows:

- a) contract data and API 546 datasheets (see 8.3);

- b) performance curves, e.g. thermal damage limit curves, acceleration times, allowable stall times, temperatures of rotor parts, capability curves, etc.;
- c) method of efficiency determination and guarantee of efficiency;
- d) current pulsations for reciprocating loads;
- e) number of starts allowed (for motors);
- f) inertia of the machine and coupled equipment;
- g) stator winding and winding insulation system;
- h) rotor winding, mechanical design, fits, construction, balance;
- i) shaft design stress, short-circuit torques;
- j) torsional and lateral critical speed analysis, and rotor sensitivity analysis (response to an intentional unbalance);
- k) foundation and base stiffness;
- l) coupling type and coordination;
- m) bearing and seal details;
- n) bearing and coupling insulation;
- o) lubricating oil type and oil inlet temperature range;
- p) test agenda;
- q) "witness" and "observe" points for inspections and tests;
- r) data for performance of electrical power system studies by the purchaser;
- s) excitation system design and interconnection with other equipment;
- t) review of machine drawings, and where applicable: P&IDs, auxiliary subsystem console drawings;
- u) installation and commissioning procedures; and
- v) packaging, shipping and long term storage.

NOTE—It is important that the design review meeting be held early enough in the project cycle so any needed design modification will not adversely affect machine cost and manufacturing schedule.

## 8.5—Drawings

- **8.5.1** Documents and drawings shall be supplied in a mutually agreed electronic format. In addition, the purchaser shall state in the inquiry and in the order the number of prints and reproducibles required and the times within which they are to be submitted by the vendor (see 8.3.1 and Annex C). When specified by the purchaser, the vendor's performance curves and response curves shall be supplied in a mutually agreed electronic tabular format so that the purchaser can insert the information into computer program models.

- ~~8.5.2~~ The purchaser shall promptly review and comment the vendor's drawings when received. This review shall not constitute permission to deviate from any requirements in the order unless specifically agreed upon in writing. After the drawings have been reviewed and mutually agreed, the vendor shall furnish certified copies in the quantity specified. Drawings shall be clearly legible.

~~8.5.3~~ The drawings furnished shall contain sufficient information so that when they are combined with the manuals specified in 8.7, the purchaser may properly install, operate, and maintain the ordered equipment. As a minimum, the following details shall be provided.

- a) Overall dimensions and weights for each separately installed piece. Maintenance clearances and weight-handling capability required for erection and maintenance shall be included.
- b) The direction of rotation.
- c) As applicable, the size, type, location, and identification of all the purchaser's connections. This shall include power, control, and instrument wiring; supply and drain details for lubrication oil and cooling water, and inlet and discharge details for cooling or purge air, as well as frame vents and drains. For all terminal block connections, this shall include the range of wire sizes accepted. Any piping, frame or bearing connections plugged by the vendor shall be identified.
- d) The make, size, and type of couplings (where applicable).
- e) Detail drawings of the bearings and bearing seals. The drawings shall include the vendor's type and catalog number of the bearings and seals.
- f) A list of any special weather protection and climatization features supplied by the vendor and required by the purchaser.
- g) A list of auxiliary or other equipment furnished by the vendor for mounting by the purchaser.
- h) The location of each lifting point, including a description of components the lifting point is designed to support.
- i) ~~i)~~ Rigging provisions for removal of parts that weigh more than 135 kg (300 lb).
- j) Complete information to permit adequate foundation design by the purchaser. This shall include the following items:
  - i. the size and location of hold-down bolts;
  - 2) the weight distribution for each bolt and sub-soleplate location;
  - 3) any unbalanced forces or moments generated by the unit or units in the specified operating range;
  - 4) the location of the center of gravity; and
  - 5) foundation forces as a result of worst-case transient conditions.

~~8.5.4~~ The vendor shall supply schematic diagrams, dimensional outline drawings, and bill of materials for each auxiliary system in the vendor's scope of supply, including control systems, accessories, and instruments. The bill of materials shall include and identify all components by make, type, size, capacity rating, materials, and other data as applicable.

~~— 8.5.5 — Each drawing and diagram shall have a title block in the lower right corner, showing certification, reference to all identification data specified in 8.3.2, the revision number and date, and the drawing title. The title block shall be visible when the drawing is folded to A4 metric size or 8 1/2 in. × 11 in. Bills of materials shall be similarly identified.~~

~~— 8.5.6 — A complete list of vendor drawings shall be included with the first issue major drawings. This list shall contain the titles and a schedule for transmission of all the drawings to be furnished by the vendor.~~

~~— Note: Standard drawings of sub-equipment is typically supplied with a cover sheet in the instruction manual.~~

## **8.6 Final Data**

~~8.6.1 — Subsequent to completion of manufacture and testing, the vendor shall revise and resubmit the previously supplied purchase data (see 8.3) and completed “Vendors Sections” of datasheets in Annex A or Annex B. These datasheets shall be marked “As Built”. Drawings shall be marked and re-submitted as “Final.”~~

~~8.6.2 — The vendor shall provide the following additional information to the purchaser.~~

- ~~● a) A record of shop test data which the vendor shall maintain for at least five years after the date of shipment. Included are the shop test reports for auxiliary subsystems (e.g. lube oil or cooling water consoles). When specified, the vendor shall submit certified copies of the test data to the purchaser before shipment. This requirement is also applicable to sub-vendors and sub-contractors.~~
- ~~● b) When specified, the calculated rotor response curves (4.4.6.2.1).~~
- ~~e) The rotor balance report.~~
- ~~d) Complete winding data presented on a form shown in Annex J. The data shall be sufficient to permit the owner to have a set of stator coils built if required and shall include:
  - ~~ii. — number of coils, winding connection and throw;~~
  - ~~2) — total copper weight, copper strand sizes and details of both turn and ground wall insulation;~~
  - ~~3) — turns per coil and number of parallel circuits;~~
  - ~~4) — length of iron including vents;~~
  - ~~5) — stator bore diameter, slot depth and width, plus depth below wedge; and~~
  - ~~6) — finished coil dimensions in slot, plus details of semi-conducting finish and stress or gradient paint treatment at the coil end turns, if any.~~~~

## **8.7 Instruction Manuals**

- ~~● 8.7.1 — The number of manuals, the specific information, and the data required for each purchase shall be defined in the datasheet or purchasing document included with the inquiry.~~
- ~~8.7.2 — The vendor shall provide written instructions and a cross-referenced list of all drawings to enable the purchaser to install, operate, and maintain the complete equipment ordered. This information shall be compiled in manuals with title pages containing section titles and complete lists of the included reference drawings by title and drawing number. If the instruction manuals apply to more than one model or series of equipment, the instructions shall clearly indicate the specific sections that apply to the equipment involved.~~

~~8.7.3 The installation manual shall include any special information required for proper installation design and actual installation that is not on the drawings. This manual shall be forwarded at a time mutually agreed upon in the order but not later than the final issue prints. It shall contain information such as special alignment procedures, bearing and bearing seal installation considerations, utility specifications (including quantity), and all installation design data.~~

~~8.7.4 Operation and maintenance manuals shall be forwarded no more than two weeks after successful completion of all specified tests or with the machine latest. If required, these manuals shall include a section of special instruction for operation at specified extreme environmental (e.g. temperature) conditions. The following items shall be included in the manual.~~

~~a) Instructions covering start-up, normal shutdown, emergency shutdown, operating limits, and routine operational procedures.~~

~~b) Outline and sectional drawing, schematics, and illustrative sketches in sufficient detail to identify all parts and to clearly show the operation of all equipment and components and the method of inspection and repair. Standardized sectional drawings are acceptable only if they represent the actual construction.~~

~~• c) When specified, detailed instructions, including pictures and sketches, outlining the appropriate methods for disassembly, inspection, re-assembly and maintenance of the machine's bearings and bearing seals.~~

~~• 8.7.5 When specified, one complete set of photographs showing the assembly of the machine shall be provided. Each step of the bearing assembly shall be individually photographed.~~

~~• 8.7.6 When specified, copies of documentation for Nationally Recognized Testing Laboratory (NRTL) certification, positive material identification (PMI), material certification, or other unique records relating to the provision of the order shall be provided.~~

## **9 Bibliography (Informative References)**

API Recommended Practice 686, *Machinery Installation and Installation Design*

ABMA 8.2, *Ball and Roller Bearing Mounting Accessories—Inch Design*

IEEE C37.010 <sup>11</sup>, *Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

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

IEEE 1349, *Guide for the Application of Electric Motors in Class 1, Division 2 Hazardous (Classified) Locations*

ISO 76, *Rolling Bearings—Static Load Ratings*

ISO 281, *Rolling Bearings—Dynamic Load Ratings and Rating Life, Part 1—Calculation Methods*

ISO 3448, *Industrial Liquid Lubricants-ISO Viscosity Classification*

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*

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<sup>11</sup> Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, New Jersey 08854, [www.ieee.org](http://www.ieee.org).

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## **~~ANNEX A—MOTOR DATA SHEETS~~**

~~(Not yet updated)~~

## **~~ANNEX B—GENERATOR DATA SHEETS~~**

~~(Not yet updated)~~

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ANNEX C ~~VENDOR DRAWING AND DATA REQUIREMENTS~~

~~SYNCHRONOUS MACHINE~~  
~~VENDOR DRAWING AND~~  
~~DATA REQUIREMENTS~~

JOB NO. \_\_\_\_\_ ITEM-N  
PURCHASE ORDER NO. \_\_\_\_\_ DATE  
REQUISITION NO. \_\_\_\_\_ DATE  
INQUIRY NO. \_\_\_\_\_  
DATE \_\_\_\_\_  
PAGE 1 OF 3 BY \_\_\_\_\_  
REVISION \_\_\_\_\_  
UNIT \_\_\_\_\_  
NO. REQUIRED \_\_\_\_\_

FOR \_\_\_\_\_  
SITE \_\_\_\_\_  
SERVICE \_\_\_\_\_

\_\_\_\_\_ Proposal<sup>a</sup> Bidder shall furnish \_\_\_\_\_ copies  
of data for all items indicated by an X.

\_\_\_\_\_ Review<sup>b</sup> Vendor shall furnish  
\_\_\_\_\_ copies and \_\_\_\_\_ transparencies of drawings and data indicated.

\_\_\_\_\_ Final<sup>b</sup> Vendor shall furnish  
\_\_\_\_\_ copies and \_\_\_\_\_ transparencies of drawings and data indicated.

\_\_\_\_\_ Vendor  
shall furnish \_\_\_\_\_ operating and maintenance manuals.

Final - Received from vendor

Due from vendor<sup>c</sup>

Review - Returned to vendor

Review - Received from vendor

DISTRIBUTION

RECORD

Review - Due from vendor:

DESCRIPTION

			A.1 Dimensioned outline drawings with major and minor connections:				
			a. Primary equipment:				
			b. Auxiliary equipment:				
			c. Maintenance weights:				
			d. Size of shipping sections:				
			e. Sole plates:				
			f. Heat exchangers:				
			g:				
			h:				
			i:				
			j:				
			A.2 Foundation loading diagrams:				
			a:				
			b:				
			c:				
			A.3 Schematic wiring and/or flow diagrams:				
			a. Speed sensor:				
			b. Space heaters:				

			_____c._____Locked rotor protection package.				
			_____d._____Cooling and exchanger.				
			_____e._____Lubrication (if applicable).				
			_____f._____Vibration monitoring.				
			_____g._____Temperature sensors.				
			_____h._____Differential current transformers.				
			_____i._____Phase current transformers.				
			_____j._____Excitation/voltage regulation panel.				
			_____k._____				
			_____l._____				
			_____m._____				
			_____n._____.				

\_\_\_\_\_

\*Proposal drawings and data do not have to be certified or as-built.

\_\_\_\_\_

\*Purchaser will indicate in this column the time frame for submission of materials using the nomenclature given at the end of the form.

\_\_\_\_\_

\*Bidder shall complete these two columns to reflect his actual distribution schedule and include this form with his proposal. \_\_\_\_\_

~~SYNCHRONOUS MACHINE~~  
~~VENDOR DRAWING AND~~  
~~DATA REQUIREMENTS~~

JOB NO. \_\_\_\_\_ ITEM NO. \_\_\_\_\_  
PAGE 2 OF 3 BY \_\_\_\_\_  
DATE \_\_\_\_\_ REV. \_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_\_ Proposal\* Bidder shall furnish \_\_\_\_\_ copies  
of data for all items indicated by an X.

\_\_\_\_\_ Review\* Vendor shall furnish  
\_\_\_\_\_ copies and \_\_\_\_\_ transparencies of drawings and data indicated.

\_\_\_\_\_ Final\* Vendor shall furnish  
\_\_\_\_\_ copies and \_\_\_\_\_ transparencies of drawings and data indicated.

\_\_\_\_\_ Vendor  
shall furnish \_\_\_\_\_ operating and maintenance manuals.

Final - Received from vendor

Due from vendor\*

Review - Returned to vendor

RECORD \_\_\_\_\_  
Review - Received from vendor

Review - Due from vendor\* \_\_\_\_\_

DESCRIPTION \_\_\_\_\_

			B.1	Detail drawings and cross-sectional drawings.					
--	--	--	-----	---	--	--	--	--	--

			_____ a. _____ Shaft end details.				
			_____ b. _____				
			_____ c. _____				
			B.2 _____ Erection/assembly drawings:				
			_____ a. _____				
			_____ b. _____				
			_____ c. _____				
			B.3 _____ Calculations torsional/lateral response:				
			_____ a. _____				
			_____ b. _____				
			_____ c. _____				
			B.4 _____ Predicted performance curves. _____				
			_____ a. _____ Power factor versus speed:				
			_____ b. _____ Motor and rotor heating ( $I^2T$ ):				
			_____ c. _____ Torque versus speed at rated voltage:				
			_____ d. _____ Torque versus speed at _____ percent voltage:				
			_____ e. _____ Current versus speed at rated voltage:				
			_____ f. _____ Current versus speed at _____ percent voltage:				
			_____ g. _____ Expected efficiency:				
			_____ h. _____ Acceleration time curves:				
			_____ i. _____				
			_____ j. _____				
			_____ k. _____				
			B.5 _____ For generators; predicted performance curves, including the following:				
			_____ a. _____ Reactive capability curve				



[illegible]

\_\_\_\_\_ \*Proposal drawings and data do not have to be certified or as-built.

\_\_\_\_\_ \*Purchaser will indicate in this column the time frame for submission of materials using the nomenclature given at the end of the form.

\_\_\_\_\_ \*Bidder shall complete these two columns to reflect his actual distribution schedule and include this form with his proposal.

## **~~ANNEX D – MOTOR DATA SHEET GUIDE~~**

~~(Not yet updated)~~

## **~~ANNEX E – GENERATOR DATA SHEETS~~**

~~(Not yet updated)~~

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## **ANNEX F**

### **PROCEDURE FOR DETERMINATION OF RESIDUAL UNBALANCE**

#### **F.1—GENERAL**

~~—This appendix describes the procedure to be used to determine residual unbalance in machine rotors. Although some balancing machines may be set up to read out the exact amount of unbalance, the calibration can be in error. The only sure method of determining is to test the rotor with a known amount of unbalance.~~

#### **F.2—RESIDUAL UNBALANCE**

~~Residual unbalance is the amount of unbalance remaining in a rotor after balancing. Unless otherwise specified, residual unbalance shall be expressed in g-mm (g-in).~~

#### **F.3—MAXIMUM ALLOWABLE RESIDUAL UNBALANCE**

~~F.3.1—The maximum allowable residual unbalance, per plane, shall be calculated according to the paragraph from the standard to which this appendix is attached.—~~

~~F.3.2—The static weight on each journal shall be determined by physical measurement. (Calculation methods may introduce errors). It should NOT simply be assumed that that rotor weight is equally divided between the two journals. There can be great discrepancies in the journal weight to the point of being very low (even *negative* on over hung rotors). In the example problem, the left plane has a journal weight of 530.7 kg (1170 lbs.). The right plane has a journal weight of 571.5 kg (1260 lbs.).~~

#### **F.4—RESIDUAL UNBALANCE CHECK**

##### **F.4.1—GENERAL**

~~F.4.1.1—When the balancing machine readings indicate that the rotor has been balanced within the specified tolerance, a residual unbalance check shall be performed before the rotor is removed from the balancing machine.—~~

**F.4.1.2** — To check the residual unbalance, a known trial weight is attached to the rotor sequentially in six equally spaced radial positions (60 degrees apart), each at the same radius (i.e., same moment {g-in}). The check is run at each balance machine readout plane, and the readings in each plane are tabulated and plotted on the polar graph using the procedure specified in F.4.2.

#### **F.4.2 — PROCEDURE**

**F.4.2.1** — Select a trial weight and radius that will be equivalent to between one and two times the maximum allowable residual unbalance [e.g., if  $U_{max}$  is 488.4 g-mm (19.2 g-in), the trial weight should cause 488.4 to 976.8 g-mm (19.2 to 38.4 g-in) of unbalance]. This trial weight and radius shall be sufficient so that the resulting plot in F.4.2.5 encompasses the origin of the polar plot.

**F.4.2.2** — Starting at a convenient reference plane (i.e., — last heavy spot), mark off the specified six radial positions (60° increments) around the rotor. Add the trial weight near the last known heavy spot for that plane. Verify that the balance machine is responding and is within the range and graph selected for taking the residual unbalance check.

**F.4.2.3** — Verify that the balancing machine is responding reasonably (i.e., no faulty sensors or displays) — For example if the trial weight is added to the last known heavy spot, the first meter reading should be at least twice as much as the last reading taken before the trial weight was added. Little or no meter reading generally indicates that the rotor was not balanced to the correct tolerance, the balancing machine was not sensitive enough, or that a balancing machine fault exists (ie, a faulty pickup). Proceed, if this check is OK.

**F.4.2.4** — Remove the trial weight and rotate the trial weight to the next trial position (that is, 60, 120, 180, 240, 300 and 360 degrees from the initial trial weight position). Repeat the initial position as a check for repeatability on the Residual Unbalance Worksheet. All verification shall be performed using only one sensitivity range on the balance machine.

**F.4.2.5** — Plot the balancing machine amplitude readout versus angular location of trial weight (NOT balancing machine phase angle) on the Residual Unbalance Worksheet and calculate the amount of residual unbalance — [refer to work sheets, Figures F-3 & F-5].

Note: The maximum reading occurs when the trial weight is placed at the rotor's remaining heavy spot; the minimum reading occurs when the trial weight is placed opposite the rotor's heavy spot (light spot). The plotted readings should form an approximate circle around the origin of the polar chart. The balance machine angular location readout should approximate the location of the trial weight. The maximum deviation (highest reading) is the heavy spot (represents the plane of the residual unbalance). Blank work sheets are Figures F-1 & F-2.

**F.4.2.6** — Repeat the steps described in F.4.2.1 through F.4.2.5 for each balance machine readout plane. If the specified maximum allowable residual unbalance has been exceeded in any balance machine readout plane, the rotor shall be balanced more precisely and checked again. If a balance correction is made in any balance machine readout plane, then the residual unbalance check shall be repeated in all balance machine readout planes.

~~F.4.2.7—For stacked component balanced rotors, a residual unbalance check shall be performed after the addition and balancing of the rotor after the addition of the first rotor component, and at the completion of balancing of the entire rotor, as a minimum.—~~

**NOTES:—**

~~1) This ensures that time is not wasted and rotor components are not subjected to unnecessary material removal in attempting to balance a multiple component rotor with a faulty balancing machine.~~

~~2) For large multi stage rotors, the journal reactions may be considerably different from the case of a partially stacked to a completely stacked rotor.~~

~~Fig. F 1: (Blank) Residual Unbalance Work Sheet—~~

~~Fig. F 2: (Blank) Residual Unbalance Polar Plot Work Sheet~~

~~Fig. F 3: Sample Residual Unbalance Work Sheet for Left Plane~~

~~Fig. F 4: Sample Residual Unbalance Polar Plot Work Sheet—~~

~~for Left Plane~~

~~Fig. F 5: Sample Residual Unbalance Work Sheet for Right Plane~~

~~Fig. F 6: Sample Residual Unbalance Polar Plot Work Sheet—~~

~~for Right Plane~~

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Fig. F-1: (Blank) Residual Unbalance Work Sheet

Customer:							
Job / Project Number:							
OEM Equipment S / N:							
Rotor Identification Number:							
Repair Purchase Order Number:							
Vendor Job Number:							
Correction Plane (Left or Right) - use sketch				(plane)			

**RESIDUAL UNBALANCE POLAR PLOT**

Rotor Rotation:		<input type="checkbox"/> CCW	Phase is layed out:		<input type="checkbox"/> CCW
		<input type="checkbox"/> CW			<input type="checkbox"/> CW

Calculate Y and Z values:

Calculate Y and Z values:

Maximum amplitude value is:		Minimum amplitude value is:	
Y = (Maximum - Minimum) / 2 (	-	) / 2	=
Z = (Maximum + Minimum) / 2 (	+	) / 2	=

Residual Unbalance						
Left in Rotor =	(TU)	X	(Y)	/	(Z)	
SI Units:		X		/		= g-mm
Customary Units:		X		/		= oz-in

Allowable Unbalance Tolerance = Umax =		g-mm		oz-in
--	--	------	--	-------

RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance?

<input type="checkbox"/> As Received	<input type="checkbox"/> Final	<input type="checkbox"/> PASS	<input type="checkbox"/> FAIL
		<input type="checkbox"/> Other:	

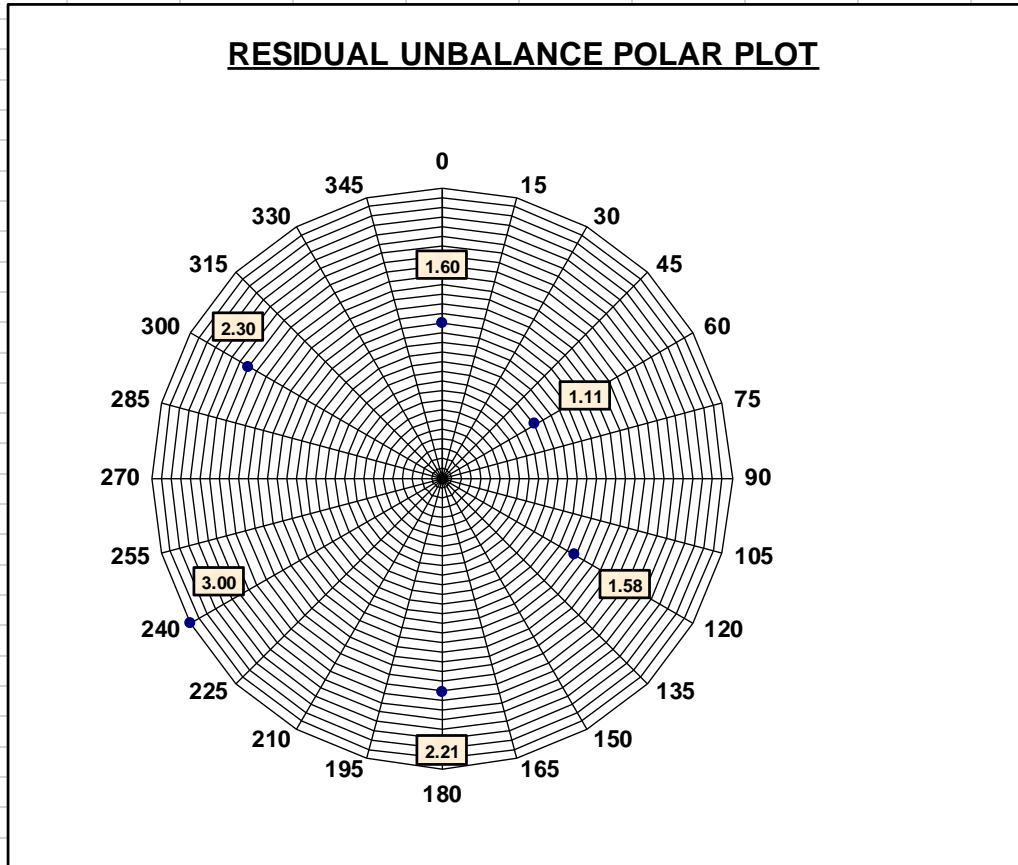
Balanced By:		Date:	
Approved By:		Date:	

Fig. F-2: (Blank) Residual Unbalance Polar Plot Work Sheet

Customer:	ABC Refining Co.																
Job / Project Number:	00 - 1234																
OEM Equipment S / N:	C - 1234																
Rotor Identification Number:	1234 - C - 4320																
Repair Purchase Order Number:	PO 12345678																
Vendor Job Number:	Shop - 00 - 1234																
Correction Plane (Left or Right) - use sketch	Left (plane)																
Balancing Speed	800	(rpm)															
Maximum Rotor Operating Speed (N)	6900	(rpm)															
Static Journal Weight Closest to This Correction Plane (W)	530.7	(kg)	1170 (lbs)														
Trial Weight Radius (R) - the radius at which the trial weight will be placed	381	(mm)	15 (in)														
Calculate Maximum Allowable Residual Unbalance (Umax):																	
SI Units:																	
$U_{max} = \frac{(6350) \times (W)}{(N)} = \frac{(6350) \times 530.7}{6900} = 488.4 \text{ (g-mm)}$																	
Customary Units:																	
$U_{max} = \frac{(4) \times (W)}{(N)} = \frac{(4) \times 1170}{6900} = 0.7 \text{ (oz-in)}$																	
Calculate the trial unbalance (TU):																	
Trial Unbalance (TU) is between (1 X Umax) and (2 X Umax)																	
SI Units:		488.4	to 976.8														
Customary units:		0.7	to 1.4														
		(1 X)	(2 X)														
		to	is														
		(Selected Multiplier is)	1.6														
		781.4	(g-mm)														
		1.1	(oz-in)														
Calculate the trial weight (TW):																	
Trial Weight (TW) = $\frac{U_{max}}{R}$ =																	
		781	g-mm														
		381	mm														
		2.1	(g)														
		1.1	oz-in														
		15	in														
		0.07	(oz)														
Conversion Information:																	
1kg = 2.2046 lbs      1 ounce = 28.345 grams      1 inch = 25.4 mm																	
Obtain the test data and complete the table:		Sketch the rotor configuration:															
Test Data		Rotor Sketch															
Position	Trial Weight	Balancing Mach Readout															
	Angular Location on Rotor (degrees)	Amplitude	Phase Angle (degrees)														
1	0	1.60	358														
2	60	1.11	59														
3	120	1.58	123														
4	180	2.21	182														
5	240	3.00	241														
6	300	2.30	301														
Repeat 1	0	1.58	359														
PROCEDURE:		HALF KEYS USED FOR ROTOR BALANCING															
Step 1: Plot the balancing machine amplitude versus trial weight angular location on the polar chart (Figure F-2) such that the largest and smallest values will fit.		(add sketch for clarification if necessary)															
Step 2: The points located on the Polar Chart should closely approximate a circle. If it does not, then it is probably that the recorded data it is in error and the test should be repeated.		<table border="1"> <thead> <tr> <th>Location</th> <th>Weight</th> </tr> </thead> <tbody> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </tbody> </table>		Location	Weight												
Location	Weight																
Step 3: Determine the maximum and minimum balancing machine amplitude readings.																	
Step 4: Using the worksheet, (Figure F-2), determine the Y and Z values required for the residual unbalance calculation.																	
Step 5: Using the worksheet, (Figure F-2), calculate the residual unbalance remaining in the rotor.																	
Step 6: Verify that the determined residual unbalance is equal to or less than the maximum allowable residual unbalance (Umax).																	
NOTES:																	
1) The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor. The preferred location is the location of the once-per-revolution mark (for the phase reference transducer).																	
2) The balancing machine amplitude readout for the Repeat of 1 should be the same as Position 1, indicating repeatability.																	
3) A primary source for error is not maintaining the same radius for each trial weight location.																	
Balanced By:	CJ, TR, & RC	Date:	5/24/2000														
Approved By:	CC	Date:	5/24/2000														

Fig. F-3: Sample Residual Unbalance Work Sheet for Left Plane

Customer:	ABC Refining Co.
Job / Project Number:	00 - 1234
OEM Equipment S / N:	C - 1234
Rotor Identification Number:	1234 - C - 4320
Repair Purchase Order Number:	PO 12345678
Vendor Job Number:	Shop - 00 - 1234
Correction Plane (Left or Right) - use sketch	Left (plane)



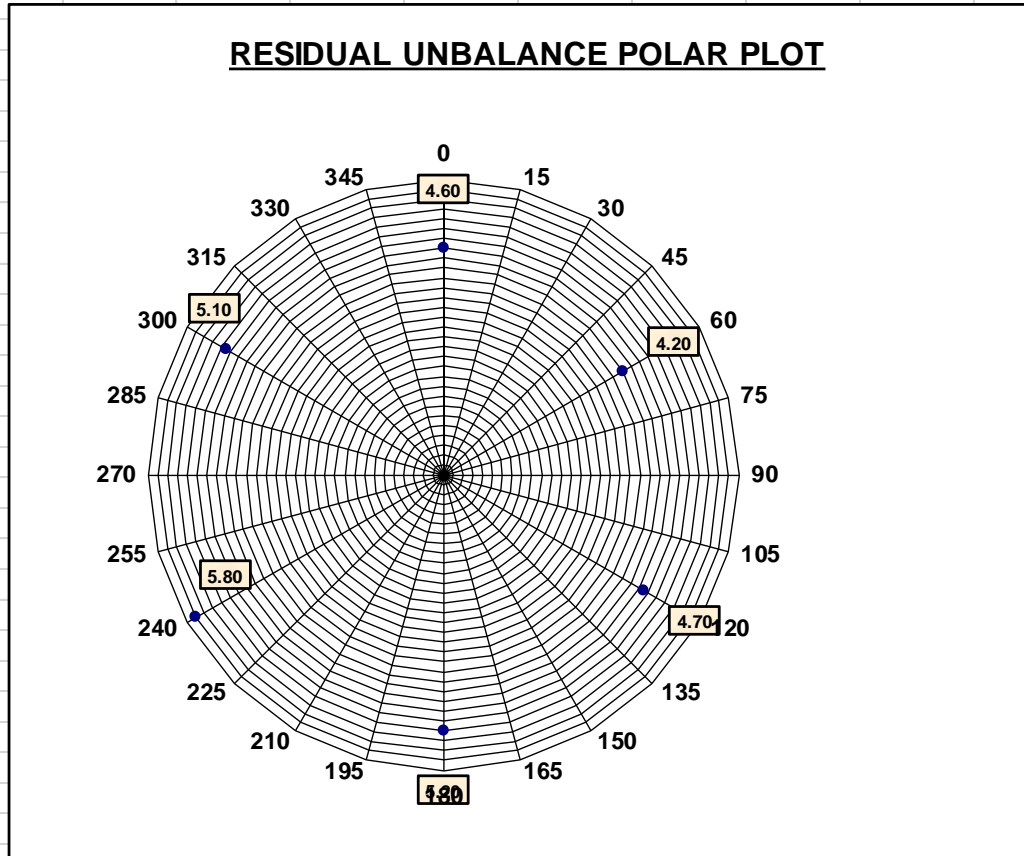
Rotor Rotation:	<input checked="" type="checkbox"/> CCW	Phase is layed out:	<input type="checkbox"/> CCW
	<input type="checkbox"/> CW		<input checked="" type="checkbox"/> CW
Calculate Y and Z values:			
Maximum amplitude value is:	3.00	Minimum amplitude value is:	1.11
Y = (Maximum - Minimum) / 2 (	3.00	-	1.11) / 2 = 0.95
Z = (Maximum + Minimum) / 2 (	3.00	+	1.11) / 2 = 2.06
Residual Unbalance			
Left in Rotor =	(TU)	X	(Y) / (Z)
SI Units:	781	X	0.95 / 2.06 = 359.3 g-mm
Customary Units:	1.09	X	0.95 / 2.06 = 0.50 oz-in
Allowable Unbalance Tolerance = Umax =		488.4 g-mm	0.68 oz-in
RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance?			
			<b>PASS</b>
<input type="checkbox"/> As Received	<input type="checkbox"/> Final	<input checked="" type="checkbox"/> Other: <u>w/o trim hardware</u>	
Balanced By:	CJ, TR & RC	Date:	5/24/2000
Approved By:	CC	Date:	5/24/2000

Fig. F-4: Sample Residual Unbalance Polar Plot Work Sheet for Left Plane

Customer:	ABC Refining Co.																																															
Job / Project Number:	00 - 1234																																															
OEM Equipment S / N:	C - 1234																																															
Rotor Identification Number:	1234 - C - 4320																																															
Repair Purchase Order Number:	PO 12345678																																															
Vendor Job Number:	Shop - 00 - 1234																																															
Correction Plane (Left or Right) - use sketch	Right (plane)																																															
Balancing Speed	800	(rpm)																																														
Maximum Rotor Operating Speed (N)	6900	(rpm)																																														
Static Journal Weight Closest to This Correction Plane (W)	571.5	(kg)	1260	(lbs)																																												
Trial Weight Radius (R) - the radius at which the trial weight will be placed	203	(mm)	8	(in)																																												
Calculate Maximum Allowable Residual Unbalance (U <sub>max</sub> ):																																																
SI Units:																																																
U <sub>max</sub> = $\frac{(6350) \times (W)}{(N)}$ = $\frac{(6350) \times 571.5}{6900}$	= 525.9 (g-mm)																																															
Customary Units:																																																
U <sub>max</sub> = $\frac{(4) \times (W)}{(N)}$ = $\frac{(4) \times 1260}{6900}$	= 0.7 (oz-in)																																															
Calculate the trial unbalance (TU):																																																
Trial Unbalance (TU) is between (1 X U <sub>max</sub> ) and (2 X U <sub>max</sub> )	(1 X)	to	(2 X)	(Selected Multiplier is) 1.6																																												
SI Units:	525.9	to	1051.9	is 841.5 (g-mm)																																												
Customary units:	0.7	to	1.5	is 1.2 (oz-in)																																												
Calculate the trial weight (TW):																																																
Trial Weight (TW) = $\frac{U_{max}}{R}$	842	g-mm	or	1.17 oz-in																																												
	203	mm		8 in																																												
	4.1	(g)		0.15 (oz)																																												
Conversion Information:																																																
1kg = 2.2046 lbs	1 ounce = 28.345 grams	1 inch = 25.4 mm																																														
Obtain the test data and complete the table:		Sketch the rotor configuration:																																														
<table border="1"> <thead> <tr> <th colspan="4">Test Data</th> </tr> <tr> <th>Position</th> <th>Trial Weight Angular Location on Rotor (degrees)</th> <th colspan="2">Balancing Mach Readout</th> </tr> <tr> <th></th> <th></th> <th>Amplitude</th> <th>Phase Angle (degrees)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0</td> <td>4.60</td> <td>3</td> </tr> <tr> <td>2</td> <td>60</td> <td>4.20</td> <td>58</td> </tr> <tr> <td>3</td> <td>120</td> <td>4.70</td> <td>121</td> </tr> <tr> <td>4</td> <td>180</td> <td>5.20</td> <td>180</td> </tr> <tr> <td>5</td> <td>240</td> <td>5.80</td> <td>235</td> </tr> <tr> <td>6</td> <td>300</td> <td>5.10</td> <td>301</td> </tr> <tr> <td>Repeat 1</td> <td>0</td> <td>4.60</td> <td>2</td> </tr> </tbody> </table>				Test Data				Position	Trial Weight Angular Location on Rotor (degrees)	Balancing Mach Readout				Amplitude	Phase Angle (degrees)	1	0	4.60	3	2	60	4.20	58	3	120	4.70	121	4	180	5.20	180	5	240	5.80	235	6	300	5.10	301	Repeat 1	0	4.60	2	<table border="1"> <thead> <tr> <th colspan="2">Rotor Sketch</th> </tr> </thead> <tbody> <tr> <td colspan="2"> </td> </tr> </tbody> </table>	Rotor Sketch			
Test Data																																																
Position	Trial Weight Angular Location on Rotor (degrees)	Balancing Mach Readout																																														
		Amplitude	Phase Angle (degrees)																																													
1	0	4.60	3																																													
2	60	4.20	58																																													
3	120	4.70	121																																													
4	180	5.20	180																																													
5	240	5.80	235																																													
6	300	5.10	301																																													
Repeat 1	0	4.60	2																																													
Rotor Sketch																																																
PROCEDURE:		HALF KEYS USED FOR ROTOR BALANCING																																														
Step 1: Plot the balancing machine amplitude versus trial weight angular location on the polar chart (Figure F-2) such that the largest and smallest values will fit.		(add sketch for clarification if necessary)																																														
Step 2: The points located on the Polar Chart should closely approximate a circle. If it does not, then it is probable that the recorded data is in error and the test should be repeated.		<table border="1"> <thead> <tr> <th>Location</th> <th>Weight</th> </tr> </thead> <tbody> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </tbody> </table>			Location	Weight																																										
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Balanced By:	CJ, TR, & RC	Date:	5/24/2000																																													
Approved By:	CC	Date:	5/24/2000																																													

Fig. F-5: Sample Residual Unbalance Work Sheet for Right Plane

Customer:	ABC Refining Co.
Job / Project Number:	00 - 1234
OEM Equipment S / N:	C - 1234
Rotor Identification Number:	1234 - C - 4320
Repair Purchase Order Number:	PO 12345678
Vendor Job Number:	Shop - 00 - 1234
Correction Plane (Left or Right) - use sketch	Right (plane)



Rotor Rotation:	<input checked="" type="checkbox"/> CCW <input type="checkbox"/> CW	Phase is layed out:	<input type="checkbox"/> CCW <input checked="" type="checkbox"/> CW
Calculate Y and Z values:			
Maximum amplitude value is:	5.80	Minimum amplitude value is:	4.20
Y = (Maximum - Minimum) / 2 (	5.80	-	4.20) / 2 = 0.80
Z = (Maximum + Minimum) / 2 (	5.80	+	4.20) / 2 = 5.00
Residual Unbalance			
Left in Rotor =	(TU)	X	(Y) / (Z)
SI Units:	842	X	0.80 / 5.00 = 134.6 g-mm
Customary Units:	1.17	X	0.80 / 5.00 = 0.19 oz-in
Allowable Unbalance Tolerance = Umax =		525.9 g-mm	0.73 oz-in
RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance?			
<input type="checkbox"/> As Received <input type="checkbox"/> Final <input checked="" type="checkbox"/> Other: <u>w/o trim hardware</u>			<b>PASS</b>
Balanced By:	CJ, TR & RC	Date:	5/24/2000
Approved By:	CC	Date:	5/24/2000

Fig. F-6: Sample Residual Unbalance Polar Plot Work Sheet

## **Annex G**

### **(normative)**

#### **~~—Procedure and Guidance for Determining the Allowable Resultant Vector Change During a Heat Run Test of a Synchronous Machine~~**

~~The purpose of this procedure is to verify that the rotor has minimal movement of the winding, laminations, rotor end rings, etc. Some small amount of change in vibration will always occur because of the movement of the rotor components when the rotor is heated from cold to the running condition.~~

~~This procedure is used to verify that the amount of movement of the rotor components is acceptable and repeatable. It also describes further tests that can be performed, at the purchasers' option, to establish repeatability, when the motor does not meet the requirements. Other methods are available to demonstrate thermal stability and must be agreed to by the purchaser prior to accepting the motor.~~

~~Vectors are used to represent the amount of vibration that this procedure describes. A vector is a measure of a quantity that has both magnitude and direction or phase angle. In vibration analysis, vectors are used to represent vibration quantities and their relative location, expressed in degrees, with respect to a reference point on the shaft that supports the rotor. The point of reference for the vector orientation is usually the keyway or another fixed point on the shaft such as reflective tape.~~

~~In each of the polar plots shown below the arrow of the cold vibration vector represents the starting point and magnitude of the vibration vector at the beginning of the heat run test. The cold point is achieved when the bearing temperature has stabilized at the no-load condition. Transient conditions associated with field application should be ignored. The arrow of the hot vibration vector represents the end of the heat run test. The resultant vector represents the change from the cold vibration to hot vibration.~~

~~The vibration vectors in the following figures are filtered at one times running speed and represent the fundamental frequency of vibration.~~

~~The vibration vectors are represented using a polar plot format. In such a format the angle of displacement from the reference point on the shaft starts at zero degrees in the first quadrant and encompasses 360 degrees in the counter clockwise direction. The magnitude of the vector starts at zero at the origin of the plot and increases as the vector length increase from the origin.~~

~~This procedure can only be used when the motor is tested with non-contact radial vibration probes.~~

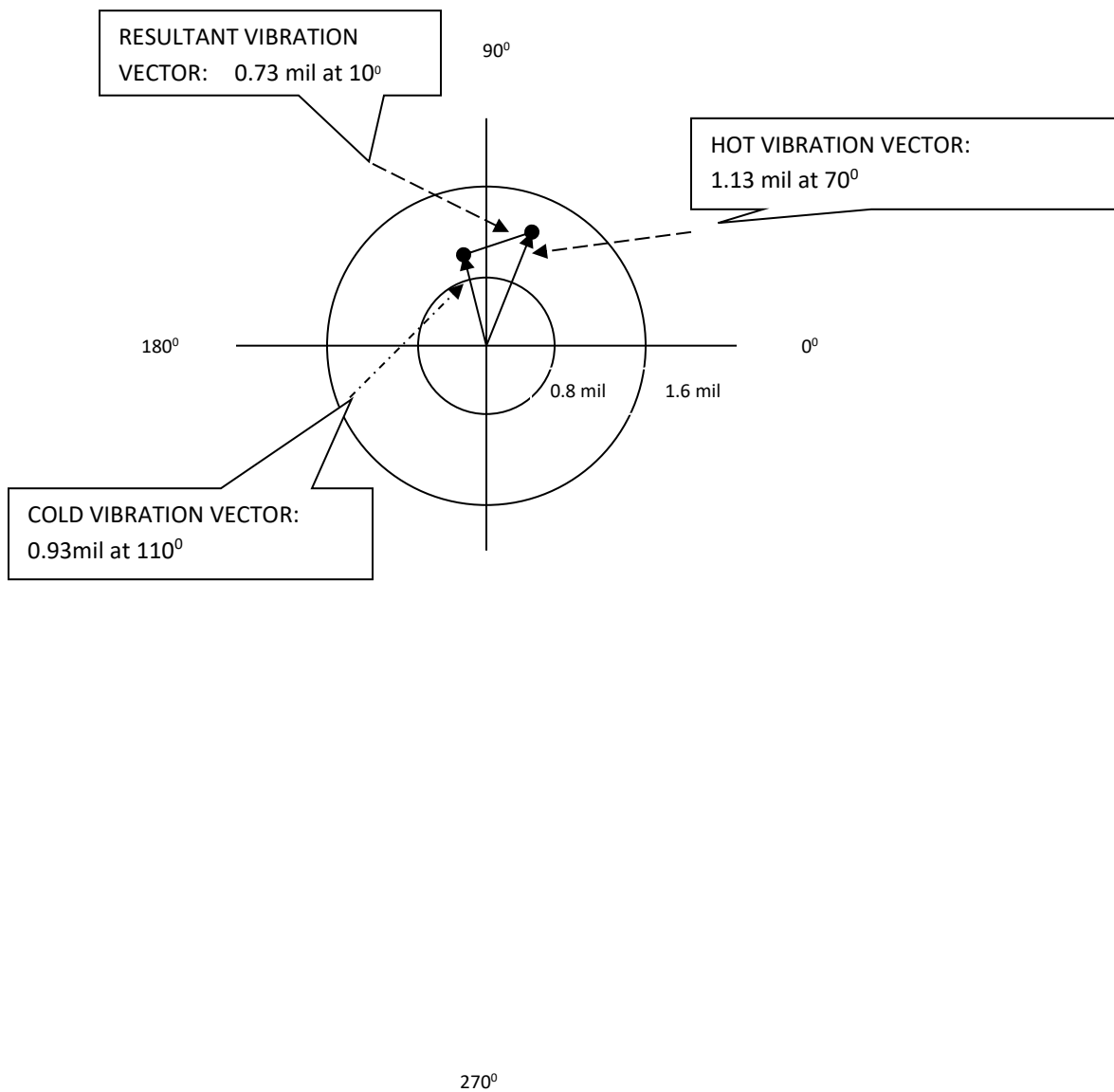
—

~~A plot for each probe shall be performed to verify that compliance with this Specification has been achieved.~~

~~The maximum amount of vibration that is allowed is 1.6 mils because this is the maximum allowable vibration displacement filtered at running speed frequency. See Figure 2, Figure 3, and 6.3.3.12.4 of this Standard for more information.~~

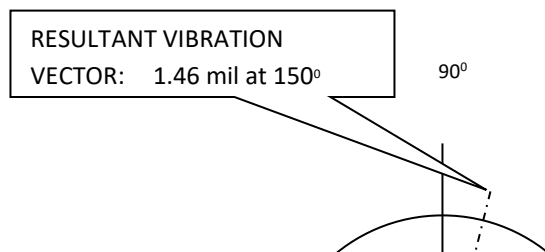
~~All of the following examples are presented with the vibration vectors in the first and second quadrant of the polar plot for purpose of explanation only. In practical applications, the vibration vectors may be in any quadrant, and providing the values are acceptable, compliance with the requirement has been achieved.~~

---



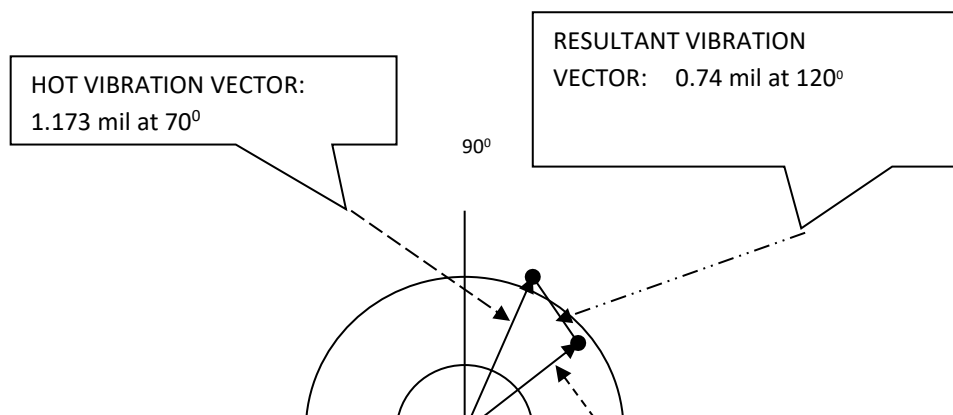
**Figure G1**

*Example of a polar plot of the relationship of cold to hot vibration complying with the requirements of section 4.3.3.11. This example is acceptable because the vibration is always less than 1.6 mil and the resultant vector change is less than 0.8 mil*



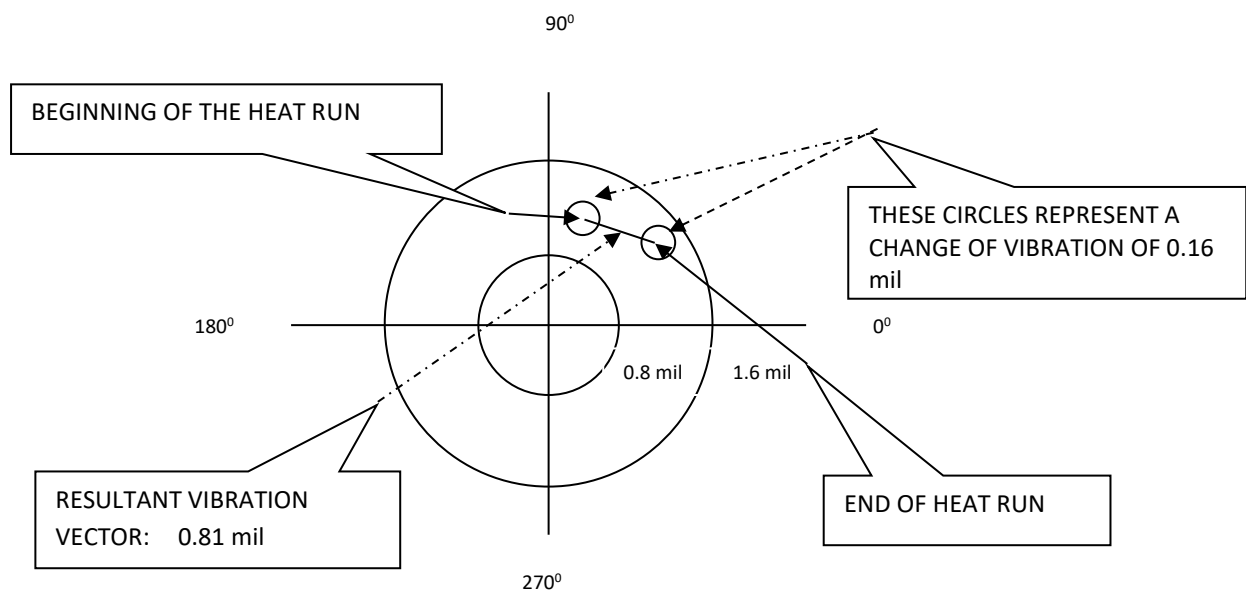
**Figure G2**

*Example of a polar plot of the relationship of cold to hot vibration not complying with the requirements of section 4.3.3.11. This example demonstrates lack of compliance because the resultant vector change of 1.46 mils exceeds the 0.8 mil limit.*



**Figure G3**

*Example of a polar plot of the relationship of cold to hot vibration not complying with the requirements of section 4.3.3.11. This example does not comply because the 1.73 mil hot vector exceeds the 1.6 mil limit.*



#### **Figure G4:**

*This figure represents a possible option that may be used if a motor fails the basic specification criteria of a change larger than 0.8 mil but has a repeatable thermally stable rotor. The circles represent the maximum limits of allowable deviation between heat runs. The maximum recommended vibration change is 1.12 mil, which is twice the maximum allowable deviation plus the allowable thermal excursion. This example represents a vibration change exceeding the 0.6 mil limit. A higher level of vibration change may be considered with the purchaser's approval. In this example, circles of 0.16 mil radius are shown around the cold and hot vibration points from the first vibration tests. A second heat run test can be performed and if the cold and hot vibration vector endpoints from the second test fall within the 0.16 mil circles the rotor can be considered to be stable. In this example, the maximum vibration vector change from cold to hot in the repeated heat run can be as much as 1.13 mil, which is the 0.16 mil maximum allowable deviation each for the cold run and the hot run plus the 0.81 mil thermal excursion.*

---

## **ANNEX ~~ALTERNATE PROCEDURE FOR THE DETERMINATION OF A WELL DAMPED RESONANCE~~**

The material in this Appendix provides an alternate procedure for the determination of a well damped resonance to that outlined in paragraph 4.3.5.3. The material presented in this Appendix follows the Standard Paragraphs (SP) of the API CRE Subcommittee on Mechanical Equipment, Rev22. Additional clarifications to the SP can be found in API Publication 684 (Tutorial on the API Standard Paragraphs Covering Rotor Dynamics and Balancing: An Introduction to Lateral Critical and Train Torsional Analysis and Rotor Balancing).

### **H.1—Definition of Terms:**

**H.1.1.**—*Amplification Factor (AF)* is a measure of a rotor bearing system's vibration sensitivity to unbalance when operating in the vicinity of one of its lateral critical speeds. A high amplification factor ( $AF \gg 10$ )

indicates that rotor vibration during operation near a critical speed could be considerable and that critical clearance components may rub stationary elements during periods of high vibration. A low amplification factor ( $AF < 5$ ) indicates that the system is not sensitive to unbalance when operating in the vicinity of the associated critical speed. Examples of the effect of the amplification factor on rotor response near the associated critical speed is presented in Figure F—1. The method of calculating the amplification factor from damped response calculation or vibration measurements is also presented in this figure. This calculation method is referred to as the half-power point method.

**H.1.2.**— *Bode Plot* is a graphical display of a rotor's synchronous vibration amplitude and phase angle as a function of shaft rotational speed. A Bode Plot is the typical result of a rotor damped unbalance response analysis and/or shop test data.

**H.1.3.**— *Critical Speed* is the shaft rotational speed that corresponds to a non-critically damped ( $AF > 2.5$ ) rotor system resonance frequency. The frequency location of the critical speed is defined as the frequency of the peak vibration response as defined by the Bode plot, resulting from a damped unbalanced response analysis and shop test data.

**H.1.4.**— *Undamped Unbalance Response analysis* is a calculation of the rotor's response to a set of applied unbalances. This applied unbalance excites the rotor synchronously, so the rotor's response to unbalance will occur at the frequency of the shafts rotational speed. This analysis is used to predict critical speed characteristics of a machine. The analysis results are typically presented in Bode plots.

**H.1.5.**— *Damping* is a property of a dynamic system by which mechanical energy is removed. Damping is important in controlling rotor vibration characteristics and is usually provided by viscous dissipation in fluid film bearings, floating ring oil seals, and so forth.

**H.1.6.**— *Phase Angle* is the angular distance between a shaft reference mark and the maximum shaft displacement measured by a fixed displacement transducer during one shaft rotation. The phase angle is useful in determining unbalance orientation, critical speed locations, and the amplification factors associated with critical speeds.

**H.1.7.**— *Resonance (Natural Frequency)* is the manner in which a rotor vibrates when the frequency of the harmonic (periodic) forcing function coincides with a natural frequency of the rotor system. When a rotor system operates in a state of resonance, the forced vibrations from a given exciting mechanism (such as unbalance) are amplified according to the level of damping present in the system. A resonance is typically identified by a substantial vibration amplitude increase and shift in the phase angle.

**H.1.8.**— *Sensitivity to Unbalance* is a measure of the vibration amplitude per unit of unbalance.

**H.1.9.** ~~*Separation Margin* defines how close the operating speed of a machine may be to its critical speed. If a machine has a  $AF < 2.5$ , then by definition, this is not a critical speed and requires no separation margin.~~

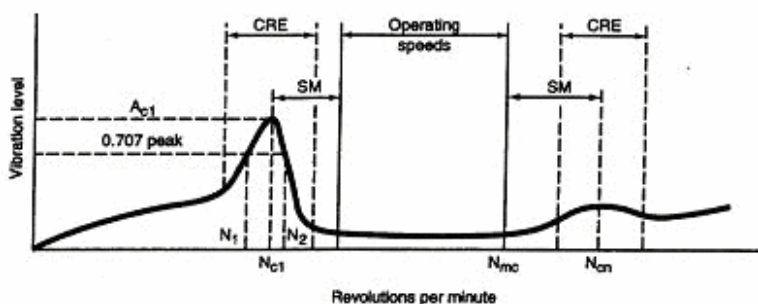
**H.1.10.** ~~*Unbalance* is a measure that quantifies how much the rotor mass centerline is displaced from the centerline of rotation (geometric centerline) resulting in an unequal radial mass distribution on a rotor system. Unbalance is usually given in gram-millimeters or ounce-inches.~~

---

## ~~H.2.—Comparison of Appendix H to API 541 Paragraph 4.3.5.3 c—~~

~~The main body of API 541 does not differentiate between a highly damped resonance and critical speed. As such, no method of calculating the amplification factor or separation margin is made.—~~

~~Definitions H.1.1 thru H.1.10. are based on the CRE API Standard paragraphs on Mechanical equipment. According to the API standard paragraphs, these definitions consider modes of vibration with amplification factors below 2.5 to be critically damped. These modes are not considered critical speeds because they do not result in high levels of rotor vibration.—~~



~~$N_{c1}$  = Rotor first resonant frequency, cycles per minute.~~

~~$N_{cn}$  = Critical Speed, nth.~~

~~$N_{mc}$  = Maximum continuous operating speed.~~

~~$N_1$  = Initial (lesser) speed at 0.707 x peak amplitude.~~

~~$N_2$  = Final (greater) speed at 0.707 x peak amplitude.~~

~~$N_2 - N_1$  = Peak width at the half power point.~~

~~$AF$  = Amplification factor =  $\frac{N_{c1}}{N_2 - N_1}$~~

~~$SM$  = Separation margin.~~

~~$CRE$  = Critical response envelope.~~

~~$A_{c1}$  = Amplitude at  $N_{c1}$ .~~

~~$A_{cn}$  = Amplitude at  $N_{cn}$ .~~

—

Figure H-1 — Evaluation of Amplification Factor (AF) from Speed Amplitude Plots

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## ANNEX I

(normative)

### Super Synchronous High Speed Motor Applications

This annex modifies the requirements of API 546 to address situations where a motor is driven by an ASD at speeds over 3600 rpm.

The requirements of API 546 4<sup>th</sup> Edition: Form-Wound Brushless Synchronous Machines—500 kVA and Larger apply, except where superseded by a clause in this document. The clauses requiring change, deletion, or addition are listed below:

**1.1.1 Scope: (Add)** The standard covers motors rated above 3600 rpm and driven by an ASD.

**4.2.1.1 Ratings (Delete Clause)**

**4.2.1.2 Voltages (Delete Clause)**

**4.2.2 Motor Load Requirements: (Replace with)** Load requirements shall be jointly developed by the ASD, motor, and driven equipment suppliers in conjunction with the Purchaser. The effect of the torque requirements and ASD output harmonics over the entire operating speed range shall be considered.

**4.2.3.1 Starting Conditions (Replace with)** The torque characteristics of the motor shall be selected to enable starting of the motor on the specified inverter.

**4.2.3.2 Purchaser Information (Delete Clause)**

**4.2.4 Motor Starting Capabilities: (Delete Clause)**

**4.2.5 Motor and ASD Coordination (Add new clause)** The purchaser, motor vendor, and ASD vendor shall coordinate the details necessary for the integration of the scopes of supply.

**4.4.1.1 f) Enclosures (Replace with) • f)** Unless otherwise specified, motors shall be Totally Enclosed (TE) with IP 54 protection or higher. Motors where the process gas is inside the motor shall be sealed so that there is no interchange between the outside air and the gas inside the motor.

**4.4.5.1.8 Rotating Element: (Replace with)** Shaft forgings shall be ultrasonically inspected in accordance with Clause 6.2.2.3.1.

**4.4.5.2.1 Assembly (Add)** Non-laminated rotors shall be integral with the shaft.

**4.4.5.2.15 (Add new clause)** When the motor has process gas inside the frame, the rotor materials shall not be affected by the process gasses specified on the datasheet.

**4.4.6.2.1 Dynamic Analysis (Modify)** Delete “when specified” in the first sentence.

**4.4.6.2.2 c) Dynamic Analysis (Add)** When active magnetic bearings (AMBs) are used, the controller and hardware (bearing, sensor, inverter, controller electronics) transfer function (comparable to bearing stiffnesses and damping factors over frequency) shall be used to ensure stable operation.

**4.4.6.2.6 d) Dynamic Analysis (Add)** ~~In cases where active magnetic bearings are used, the additional analysis shall be performed in accordance with API 684.~~

**4.4.6.2.7 Dynamic Analysis (Modify)** ~~Delete “when specified” in the first sentence.~~

**4.4.7.1.3 Bearings (Replace clause with)** ~~Hydrodynamic radial bearings or an active magnetic bearing system shall be provided on all horizontal motors. Anti friction bearings shall not be used except for emergency bearings where active magnetic bearings are provided. All active magnetic bearing systems shall comply with API RP 684.~~

**4.4.9.1 End Play and Couplings: (Add)** ~~End play limits for active magnetic bearing motors are the same as for hydrodynamic bearing motors.~~

**6.3.1.4 Testing (Add Note)** ~~Note 1: It is recommended that the motor and the associated ASD are tested as a package over the range of design speeds. Experience has shown that this testing significantly reduces site problems and time during commissioning.~~

**6.3.3.6 Testing (Add)** ~~For two pole motors after the bearing temperatures have stabilized, filtered and unfiltered vibration readings at each position shall be recorded continuously for a period of 15 minutes. This data shall be continuously plotted or tabulated at one minute increments over the 15 minute period. If the vibration modulates, the high and low values of vibration and the frequency of the modulation shall be recorded.~~

**6.3.3.10 Vibration limits (Add)** ~~Where active magnetic bearings are used, the maximum allowable shaft vibration shall be less than or equal to 0.3 times the minimum radial clearance in the auxiliary bearing in that axis. See API 617 7ed Annex F, paragraph F.7.6.~~

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## **ANNEX J**

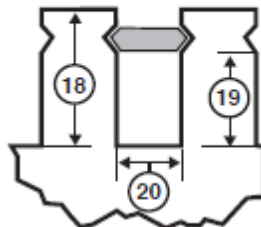
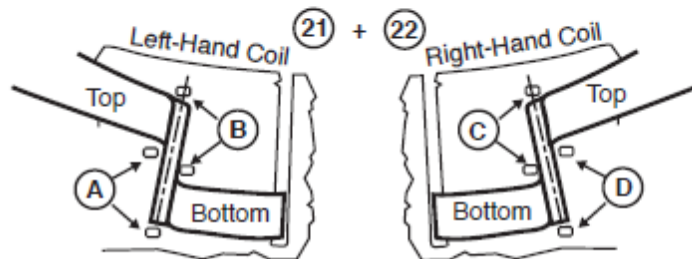
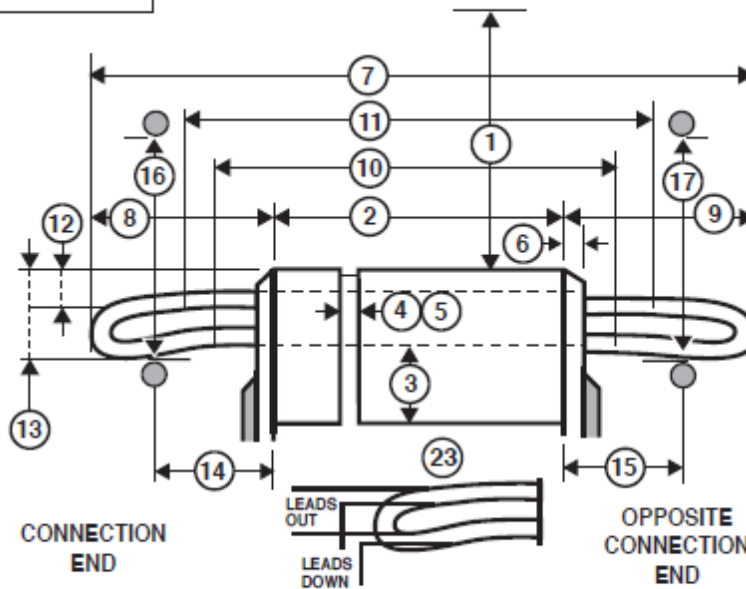
### **Coil Data**

---

## AC STATOR FORM COIL DATA

Y		CONTACT		DATE		JOB #	
S		CITY		STATE/PROVINCE		ZIP	
K		PHONE		FAX		E-MAIL	
		HP/KVA/KW		POLES		RPM	
		VOLTS		AMPS		HERTZ	
		TYPE				PHASES	

BORE DIAMETER	
AL CORE LENGTH	
K IRON	
OF VENTS	
H OF VENT(S)	
ER PLATE WIDTH	
HALL COIL LENGTH	
N. END EXTENSION	
CONN. END EXTENSION	
IGHT LENGTH, BOTTOM SIDE	
IGHT LENGTH, TOP SIDE	
L KNUCKLE DROP CE	OCE
E KNUCKLE DROP CE	OCE
N. SUPPORT RING FROM CORE	
CONN. SUPP. RING FROM CORE	
N SUPPORT RING I. D.	
CONN. SUPPORT RING I. D.	
AL SLOT DEPTH	
DEPTH UNDER WEDGE	
WIDTH	
LOCATION <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D	
TYPE <input type="checkbox"/> LEFT-HAND <input type="checkbox"/> RIGHT-HAND	
LEADS LONG # LG	
SHORT # LG	
<input type="checkbox"/> OUT <input type="checkbox"/> DOWN	
PER (1 - 4 OR 1 - 7)	1 -
NECTION (WYE OR DELTA)	
OF CIRCUITS	
OF SLOTS	
THROW	1 -
NS PER COIL	
AL WIRES IN PARALLEL	
E WIRE SIZES ( ) X	
( ) X	
ND INSULATION	
LM <input type="checkbox"/> GLASS <input type="checkbox"/> MICA <input type="checkbox"/> BARE <input type="checkbox"/> OTHER	
WEIGHT	LBS.
GROUPS OF COILS	
GROUPS OF COILS	
SKewed <input type="checkbox"/> RIGHT <input type="checkbox"/> LEFT IN.	



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SPECIAL FEATURES	YES	NO	COMMENTS
DATA CHANGE			
COIL SUPPORT RING STEEL			
TERRACE WOUND			
CORONA PROTECTION			
RTDs			
OHMS QTY			
HERMETIC			
SLOT PAPER USED			
INSULATION CLASS <input type="checkbox"/> B <input type="checkbox"/> F <input type="checkbox"/> H			
<input type="checkbox"/> VPI <input type="checkbox"/> DIP & BAKE <input type="checkbox"/> SEALED			
<input type="checkbox"/> LEADS TAPED <input type="checkbox"/> LEADS SLEEVED			

## INSTRUCTIONS

## GENERAL

● All dimensions should be taken to the nearest 1/16" (1 mm) except 18, 19, 20 and 31, which should be to the nearest .001" (0.03 mm) and 23, which should be to the nearest 1/4" (6 mm).

● All items must be completed unless otherwise explained.

● To make the data easier to read when the form is transmitted via facsimile machine, use only a blue or black felt or nylon tip pen. Please press heavily and record the data in the answer column provided.

1 **Core Bore Diameter**—Inside diameter of the stator iron. This is measured from tooth to tooth through the center line of the machine.

2 **Total Core Length**—Length of the stator iron including vents but excluding finger plates. Please make several measurements and give the average.

3 **Back Iron**—The distance from the outer edge of the stator iron near the frame to the bottom of the slot.

4 **No. of Vents**—The number of vents in the stator iron.

5 **Width of a Vent**

6 **Finger Plate Width**—When present, give the width of the plate that applies pressure to the stator laminations.

7 **Overall Coil Length**—The overall insulated coil length measured from the outer edge of one coil knuckle to the outer edge of the other knuckle.

8 **Connection End Extension**—The coil extension measured from the outer edge of the coil knuckle to the stator iron on the lead end.

9 **Opposite Connection End Extension**—The coil extension measured from the outer edge of the coil knuckle to the stator iron opposite the lead end.

10 **Straight Length, Bottom Side**—The length of the straight portion of the coil in the bottom of the slot. This is measured along the inside edge of the coil from point to point where the diamonds just begin to form.

11 **Straight Length, Top Side**—The length of the straight portion of the coil in the top of the slot. See Item 10 for details.

12 **Small Knuckle Drop**—When extending a straight edge across the stator iron and out over the coil extension, the distance from the bottom of the straight edge to the area of the coil where the knuckle starts to form. Measure on both ends.

13 **Large Knuckle Drop**—When extending a straight edge across the stator iron and out over the coil extension, the distance from the bottom of straight edge to the lowest point of the coil knuckle where it touches the support ring. Measure on both ends.

14 **Connection End Support Ring from Core**—The distance from the inside edge of the insulated front support ring to the stator iron on the lead end. If there is more than one ring on each end, note the number of rings and the distance between rings. Allow for ring insulation if it is not present when the measurements are made.

15 **Opposite Connection End Support Ring from Core**—The distance from the inside edge of the insulated support ring to the stator iron on the opposite lead end. See Item 14 for details.

16 **Connection End Support Ring Inside Diameter**—The inside diameter of the insulated support ring on the lead end. Scribe an arc from the inner edge of the ring to the opposite inner edge and take the largest measurement.

17 **Opposite Connection End Support Ring Inside Diameter**—The inside diameter of the insulated support ring on the opposite lead end. See Item 16 for details.

18 **Total Slot Depth**—The total slot depth of the stator slot measured from the top of the tooth to the bottom of the slot.

19 **Slot Depth Under Wedge**—The distance from the bottom of the slot to the bottom of the wedge groove.

20 **Slot Width**—The stator slot width measured at the bottom of the slot.

21 **Lead Location**—Choose one letter (A, B, C or D) to indicate which lead arrangement is applicable.

22 **Coil Type**—Indicate the type of coil desired, either left-hand or right-hand. Looking from the connection end of the coil, is the right-hand slot section of the coil in the top or bottom of the slot?

23 **Coil Lead Length and Number**—Both long and short leads. Indicate if leads are down (i.e., perpendicular to the length of the coil) or straight out.

24 **Jumper**—The internal connection of the coil group.

25 **Connection**—The connection of the stator windings: Wye or Delta.

26 **No. of Circuits**—Number of parallel circuits.

27 **No. of Slots**—The number of stator slots. This is also the number of coils unless otherwise advised.

28 **Coil Throw**—The span of the stator coil. The slot that holds the bottom coil side is Slot #1.

29 **Turns per Coil**—The number of turns that the coil conductor(s) is (are) looped. Count turns on the opposite connection end.

30 **Total Wires in Parallel**—The number of wires in parallel. This is easily indicated by the number of wires that make up one of the coil leads.

31 **Wire Sizes**—This measurement is taken on the bare copper. If more than one wire size is used, please indicate these sizes as well.

32 **Strand Insulation**—Wire insulation type. Examples are: glass, film, mica, glass over film, and bare.

33 **Coil Weight**—The weight of the one coil, preferably with the insulation removed.

34 **Groups of Coils**—Number of coil groups and the number of coils in each group.

35 **Iron Skewed?**—If the stator slots are skewed, measure the offset in inches.



## ANNEX K

### ~~Guidance and Alternate Procedures for Balance Check with Half Coupling~~

~~The material in this Annex provides guidance to help determine the probable causes for a vibration change when the half coupling is installed and alternate acceptance procedures for the half coupling balance check.~~

### ~~K.1 Troubleshooting cause of vibration change~~

#### ~~K.1.1 Runout~~

~~K.1.1.1 Check the runout at low speed (e.g. a few RPM) on the shaft while it is still assembled in 2 locations as follows:~~

- ~~i) ——— Identify a reference point (e.g. keyway, etc.) to be used for both measurements.~~
- ~~ii) ——— At the closest accessible point on the shaft next to the bearing, record the value and angular location with respect to the reference point for the highest and lowest reading. The calculated magnitude to be used is the highest minus lowest reading.~~
- ~~iii) ——— At the closest accessible point on the shaft next to the coupling, record the value and angular location with respect to the reference point for the highest and lowest reading. The calculated magnitude to be used is the highest minus lowest reading.~~
- ~~iv) ——— The resultant vector change between measurement (ii) and (iii) is the indication of the possible amount of bowing of the shaft.~~

~~K.1.1.2 Check the runout of the coupling hub (or flange) with the indicator placed parallel with the shaft (e.g. axial runout). The intent is to determine if the coupling face is perpendicular to the shaft.~~

~~Note: If the machine is too large to be rotated at a low speed by hand, then check with the electric machine manufacturer for methods to achieve safe shaft rotations for achieving runout checks listed above.~~

#### ~~K.1.2 Coupling key~~

~~If the shaft is keyed, then typically a special key is required to perform the balance check with the half coupling. If the key is not sized properly, then an unbalance will result. The key needs to be sized to fill the keyways, of both the shaft and half coupling. The top half of the key is not to extend beyond either end of the coupling.~~

#### ~~K.1.3 Stable vibration readings~~

~~Leveling (or stabilizing) on bearing temperatures may not be sufficiently level for the vibration readings. Investigate if vibration readings are sufficiently stable from the runs performed.~~

#### ~~K.1.4 Half coupling unbalance~~

~~The cause of the vibration change may be due to an unbalance in the half coupling.~~

~~K.1.4.1 If the coupling is not keyed (or if it has two opposite keys), the coupling could be rotated. If there is a change in angle of the 1X vibration vectors, it is an indication that the issue may be with the half coupling balance. When this occurs the purchaser and electric machine vendor need to mutually agree on a path forward regarding the half coupling unbalance.~~

~~K.1.4.2 Some couplings do not have an interference fit. These couplings typically have screws that push against the key. If the coupling clearance is large enough, the difference in concentricity between shaft centerline and coupling centerline can result in an unbalance. When this occurs the purchaser and electric machine vendor need to mutually agree on a path forward regarding the half coupling unbalance.~~

~~K.1.4.3 Confirm that the half coupling was balanced in accordance with API 671 or better.~~

~~Note: Couplings are often balanced at speeds of 400—600 rpm. If the electric machine operates at speeds significantly higher than this, it is possible that the balance machine used for the coupling doesn't have sufficient sensitivity to achieve a balance adequate to pass the criteria (unbalance force is proportional to the square of the speed).~~

## **K.2 Alternate procedures for balance check with half coupling**

*<Note to committee members (not to be included in API 546 draft): this is based on the requirements when a half coupling was installed on a rotor in the balance machine (API 3<sup>rd</sup> edition 4.3.1.6.1) while including the requirement to meet the overall vibration limits.>*

~~The following outlines two alternate acceptance procedures to paragraph 6.3.1.5 that could be used if the purchaser and electric machine vendor mutually agree to its use. The half coupling balance check is deemed acceptable if either of these criteria are met.~~

~~K.2.1 With the half coupling mounted, the machine shall be properly installed on a massive foundation and run at a voltage suitable to maintain magnetic center until the bearing temperatures stabilize and a complete set of vibration data recorded. All data shall be within the limits given in Figure 2, Figure 3, Figure 4 and Figure 5.~~

~~K.2.2 Perform testing to determine the residual unbalance (reference Annex F). The residual unbalance shall not exceed 1 unit of unbalance (U) as defined in paragraph 4.4.6.2.1.3.~~