

Centrifugal Fans for Petroleum, Chemical, and Gas Industry Services

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Introduction

Users of this standard should be aware that further or different requirements may be needed for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This may be particularly appropriate where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this standard and provide details.

This standard requires the purchaser to specify certain details and features. A bullet (•) at the beginning of a paragraph indicates that either a decision by, or further information from, the purchaser is required. Further information should be shown on the datasheets (see Annex A) or stated in the quotation request and purchase order.

Centrifugal Fans for Petroleum, Chemical, and Gas Industry Services

1 Scope

1.1 This standard covers the minimum requirements for centrifugal fans for use in petroleum, chemical, and gas industry services. Fan static pressure rise is limited to differential usually not exceeding 130 in. (330 cm) of water equivalent air pressure from a single impeller or each impeller in a two stage fan. This standard does not apply to axial flow, aerial cooler, cooling tower, and ventilation fans and positive displacement blowers.

- **1.2** This standard covers equipment for both general purpose and special purpose applications. The purchaser shall determine which classification applies.

NOTE Refer to Section 3 for definition of the terms general purpose and special purpose.

1.3 Additional or overriding requirements applicable to special purpose applications are included at the end of each section (e.g. 6.7.5, etc.).

2 Normative References

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

API Specification 5L, *Specification for Line Pipe*, Forty-Fifth Edition

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*, Second Edition

API Standard 541, *Form-wound Squirrel-cage Induction Motors—500 Horsepower and Larger*, Fourth Edition

API Standard 546, *Brushless Synchronous Machines—500 kVA and Larger*, Third Edition

API Standard 547, *General-purpose Form-wound Squirrel Cage Induction Motors 250 Horsepower and Larger*, First Edition

API Recommended Practice 578, *Material Verification Program for New and Existing Alloy Piping Systems*, Second Edition

API Standard 611, *General-purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services*, Fifth Edition

API Standard 612, *Petroleum, Petrochemical and Natural Gas Industries—Steam Turbines—Special-Purpose Applications*, Sixth Edition

API Standard 613, *Special Purpose Gear Units for Petroleum, Chemical, and Gas Industry Services*, Fifth Edition

API Standard 614, *Lubrication, Shaft-sealing, and Control-oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services*, Fifth Edition

API Standard 670, *Machinery Protection Systems*, Fourth Edition

API Standard 671, *Special-purpose Couplings for Petroleum, Chemical, and Gas Industry Services*, Fourth Edition

API Standard 677, *General-purpose Gear Units for Petroleum, Chemical and Gas Industry Services*, Third Edition

API Recommended Practice 684, *Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals and Rotor Balancing*, Second Edition

API Recommended Practice 686, *Recommended Practices for Machinery Installation and Installation Design*, Second Edition

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

ABMA Standard 8.1:1986, *Ball and Roller Bearing Mounting Accessories, Metric Design*

ABMA Standard 8.2:1999 (R2008), *Ball and Roller Bearing Mounting Accessories, Inch Design*

ABMA Standard 9:1990 (R2008), *Load Ratings and Fatigue Life for Ball Bearings*

ABMA Standard 19.1:2011, *Tapered Roller Bearings—Radial Metric Design*

ABMA Standard 19.2:1994 (R2008), *Tapered Roller Bearings—Radial Inch Design*

ABMA Standard 20:2011, *Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types Metric Design*

AGMA 9000:2011 ², *Flexible Couplings—Potential Unbalance Classification*

AGMA 9002:2004 (R2011), *Bores and Keyways for Flexible Couplings (Inch Series)*

AMCA Standard 99-10 ³, *Standards Handbook*

AMCA Standard 99-2404-03, *Drive Arrangements for Centrifugal Fans*

AMCA Standard 201-02 (R2011), *Fans and Systems*

AMCA Publication 203-90 (R2011), *Field Performance Measurement of Fan Systems*

AMCA Standard 210-99 (R2007), *Laboratory Methods of Testing Fans for Rating*

AMCA Publication 801-01 (R2008), *Industrial Process/Power Generation Fans: Specification Guidelines*

AMCA Publication 802-02 (R2008), *Industrial Process/Power Generation Fans: Establishing Performance Using Laboratory Models*

AMCA Standard 803-02 (R2008), *Industrial Process/Power Performance Fans: Site Performance Test Standard*

ANSI ⁴/AWS D1.1/D1.1M:2010 ⁵, *Structural Welding Code—Steel*

ANSI/AWS D14.6/D14.6M:2011, *Specification for Welding of Rotating Elements of Equipment*

ASME B1.1:2003(R2008) ⁶, *Unified Inch Screw Threads (UN and UN and UNR Thread Form)*

ASME B1.15:1995, *Unified Inch Screw Threads (UNS Thread Form)*

¹ American Boiler Manufacturers Association, 8221 Old Courthouse Road, Suite 207, Vienna, Virginia 22182, www.abma.com.

² American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, www.agma.org.

³ Air Movement and Control Association, 30 West University Drive, Arlington Heights, Illinois 60004, www.amca.org.

⁴ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

⁵ American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126, www.aws.org.

⁶ ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

ASME B1.20.1:1983 (R2006), *Pipe Threads, General Purpose (Inch)*

ASME B1.21M:1997, *Metric Screw Threads*

ASME B15.1:2000, *Safety Standard for Mechanical Power Transmission Apparatus*

ASME B16.1:2010, *Gray Iron Pipe Flanges and Flanged Fittings (Classes 25, 125, and 250)*

ASME B16.5:2013, *Pipe Flanges and Flanged Fittings NPS 1/2 Through NPS 24*

ASME B16.11:2011, *Forged Fittings, Socket-Welding and Threaded*

ASME B16.42:2011, *Ductile Iron Pipe Flanges and Flanged Fittings Classes 150 and 300*

ASME B16.47:2011, *Large Diameter Steel Flanges NPS 26 Through NPS 60*

ASME B17.1:1967 (R2013), *Keys and Keyseats*

ASME B31.3:2012, *Process Piping*

ASME PTC 36, *Measurement of Industrial Sound*

ASME Boiler and Pressure Vessel Code (BPVC), Section VIII: *Pressure Vessels*

ASME Boiler and Pressure Vessel Code (BPVC), Section IX: *Welding and Brazing Qualifications*

ASTM A53/A53M-2012 ⁷, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc Coated, Welded and Seamless*

ASTM A105/A105M-2012, *Standard Specification for aron Steel Forgings for Piping Application*

ASTM A106/A106-2011, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*

ASTM A153/A153M-2009, *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*

ASTM A181/A181M-2012, *Standard Specification for Carbon Steel Forgings for General Service Piping*

ASTM A193/A193M-2012, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194/A194M-2012, *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature or Both*

ASTM A197/A197M-2000 (R2011), *Standard Specification for Cupola Malleable Iron*

ASTM A269-2010, *Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service*

ASTM A312/A312M Rev A-2013, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*

ASTM A338-1984 (R2009), *Standard Specification for Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine, and Other Heavy Duty Service at Temperatures Up To 650 Degrees F (345 Degrees C)*

⁷ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM A388/A388M, *Standard Practice for Ultrasonic Examination of Heavy Steel Forgings*

ASTM A515/A515M:2010, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate and Higher Temperature Service*

ASTM A524-1996, *Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures*

ASTM A578/A578M:2007 (R2012), *Standard Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications*

ASTM A609/A609M:2012, *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

ASTM E94:2004 (R2010), *Standard Guide for Radiographic Examination*

ASTM E165:2012, *Standard Test Method for Liquid Penetrant Examination*

ASTM E709:2008, *Standard Guide for Magnetic Particle Examination*

ASTM E1003:2013, *Standard Practice for Hydrostatic Leak Testing*

EN 287:2011 ⁸, *Qualification Test of Welders*

EN 288:2011, *Specification and Approval of Welding Procedures for Metallic Materials*

EN 953:2009, *Safety of Machinery—Guards—General Requirements for the Design and Construction of Fixed and Movable Guards*

IEC 60034-5 ⁹, *Rotating electrical machines—Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP Code)—Classification*

IEC 60079, *Electrical apparatus for explosive gas mixtures*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEEE 841 ¹⁰, *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 7-1:1994 ¹¹, *Pipe threads where pressure-tight joints are made on the threads—Part 1: Dimensions, tolerances and designation*

ISO 15:1998, *Rolling bearings—Radial bearings—Boundary dimensions, general plan*

ISO 261:1998, *ISO general purpose metric screw threads*

ISO 281:2007, *Rolling bearings—Dynamic load ratings and rating life*

ISO 286-2:2010, *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*

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

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

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

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

- ISO 355:1977, *Metric tapered roller bearings—Flanged cups—Boundary dimensions*
- ISO 492:2002, *Rolling bearings—Radial bearings—Tolerances*
- ISO 582:1995, *Rolling bearings—Chamfer dimensions—Maximum values*
- ISO 1940-1:2003, *Mechanical vibration—Balance quality requirements for rotors in a constant (rigid) state—Part 1: Specification and verification of balance tolerance*
- ISO 3290:2001, *Rolling bearings—Balls—Dimensions and tolerances*
- ISO 3448:1993, *Industrial liquid lubricants—ISO viscosity classification*
- ISO 3740:2000, *Acoustics—Determination of sound power levels of noise sources—Guidelines for the use of basic standards*
- ISO 3744:1994, *Acoustics—Determination of sound power levels of noise sources using sound pressure—Engineering method in an essentially free field over a reflecting plane*
- ISO 3746:1995, *Acoustics—Determination of sound power levels of noise sources using sound pressure—Survey method using an enveloping measurement surface over a reflecting plane*
- ISO 5753:1991, *Rolling bearings—Radial internal clearance*
- ISO 5855:1999, *Aerospace—MJ threads*
- ISO 6708:1995, *Pipework components—Definition and selection of DN (nominal size)*
- ISO 7005-1:1992, *Metallic flanges—Part 1: Steel flanges*
- ISO 7005-2:1988, *Metallic flanges—Part 2: Cast iron flanges*
- ISO 8068:2006, *Lubricants, industrial oils and related products (class L) family T (turbines) specification for lubricating oils for turbines*
- ISO 8501-1:1988, *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness—Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*
- ISO 8821:1989, *Mechanical vibration—Balancing—Shaft and fitment key convention*
- ISO 10438:2003, *Petroleum, petrochemical and natural gas industries—Lubrication, shaft-sealing and control-oil systems and auxiliaries*
- ISO 10441:1999, *Petroleum and natural gas industries—Flexible couplings for mechanical power transmission—Special purpose applications*
- ISO 14120:2002, *Safety of machinery—Guards—General requirements for the design and construction of fixed and movable guards*
- ISO 14691:1999, *Petroleum and natural gas industries—Flexible couplings for mechanical power transmission—General purpose applications*
- ISO 15156-1:2009, *Petroleum and natural gas industries—Materials for use in H₂S containing environments in oil and gas production—Part 1: General principles for selection of cracking-resistant materials*

ISO 15607:2004, *Specification and qualification of welding procedures for metallic materials*

ISO 15614:2005, *Specification and qualification of welding materials*

NACE MR0103 ¹², *Materials resistant to sulfide stress cracking in corrosive petroleum refining environments*

NACE MR0175/ISO 15156, *Petroleum and natural gas industries—Materials for use in H₂S-containing environments in oil and gas production—Part 1: General principles for selection of cracking-resistant materials—Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons—Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys—Item No 21306; ISO 15156-1, ISO 15156-2, ISO 15156-3; Technical Corrigendum 1:09/01/2005*

NEMA SM 23 ¹³, *Steam Turbines for Mechanical Drive Service*

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

NFPA Publication 70 ¹⁴, *National Electric Code, Articles 500, 501, 502, 504, and 505*

SSPC SP-6 ¹⁵/NACE No. 3, *Commercial Blast Cleaning*, 2000

2.2 The purchaser and vendor shall mutually determine the measures required to comply with any governmental codes, regulations, ordinances, or rules that are applicable to the equipment.

2.3 It is the vendor's responsibility to invoke all applicable specifications to each subvendor.

3 Terms and Definitions

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

3.1

alarm point

Preset value of a measured parameter at which an alarm is activated to warn of a condition that requires corrective action.

3.2

anchor bolts

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

3.3

axially split joint

Joint split with the principal face parallel to the shaft centerline.

3.4

certified point

Point to which the performance tolerances are applied.

NOTE This is usually the normal operating point and the vendor will normally require that this point is within the preferred selection range.

¹² NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.

¹³ National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.

¹⁴ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

¹⁵ The Society for Protective Coatings, 40 24th Street, Sixth Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.

3.5**critical speed**

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

3.6**evase**

Transition piece with increasing cross-sectional area in the direction of flow at the fan discharge.

3.7**fan impeller**

Assembly comprised of the blades, center plate (or back plate), shroud(s), hub, and wear plates, if used.

3.8**fan rated point**

Defined as 1) the highest speed necessary to meet any specified operating condition and 2) the rated capacity required by fan designs to meet all specified operating points. (The vendor shall select this capacity point to best encompass specified operating conditions within the scope of the expected performance curve.) (See Figure 1.)

NOTE This term is NOT to be confused with the AMCA 802-02 definition of RATING point, which more nearly matches “normal point” per paragraph 3.2.5. It is suggested the user add head and/or volume margins for process uncertainties, reduced performance resulting from time related “wear and tear” and other operating conditions known to exist. The API “rated” point will be the same as the AMCA defined “MCR Test Block” (paragraph 3.1.13, AMCA 801-01) condition unless otherwise defined by the user in specifications or datasheets. For most applications this will coincide with “test block” (paragraph 3.1.14, AMCA 801-01).

3.9**fan rotor**

Assembly of the fan impeller and the shaft.

3.10**forced draft fans**

Usually have ambient inlet conditions and usually are in air service. This type of fan is providing ambient supply air to a unit such as fired heater for combustion air.

3.11**general purpose application**

Application that is usually spared or is in noncritical service.

NOTE Ambient air fans such as forced draft fans may be unspared and may be deemed as general purpose.

3.12**hold-down bolts**

mounting bolts

Bolts holding the equipment to the mounting plate.

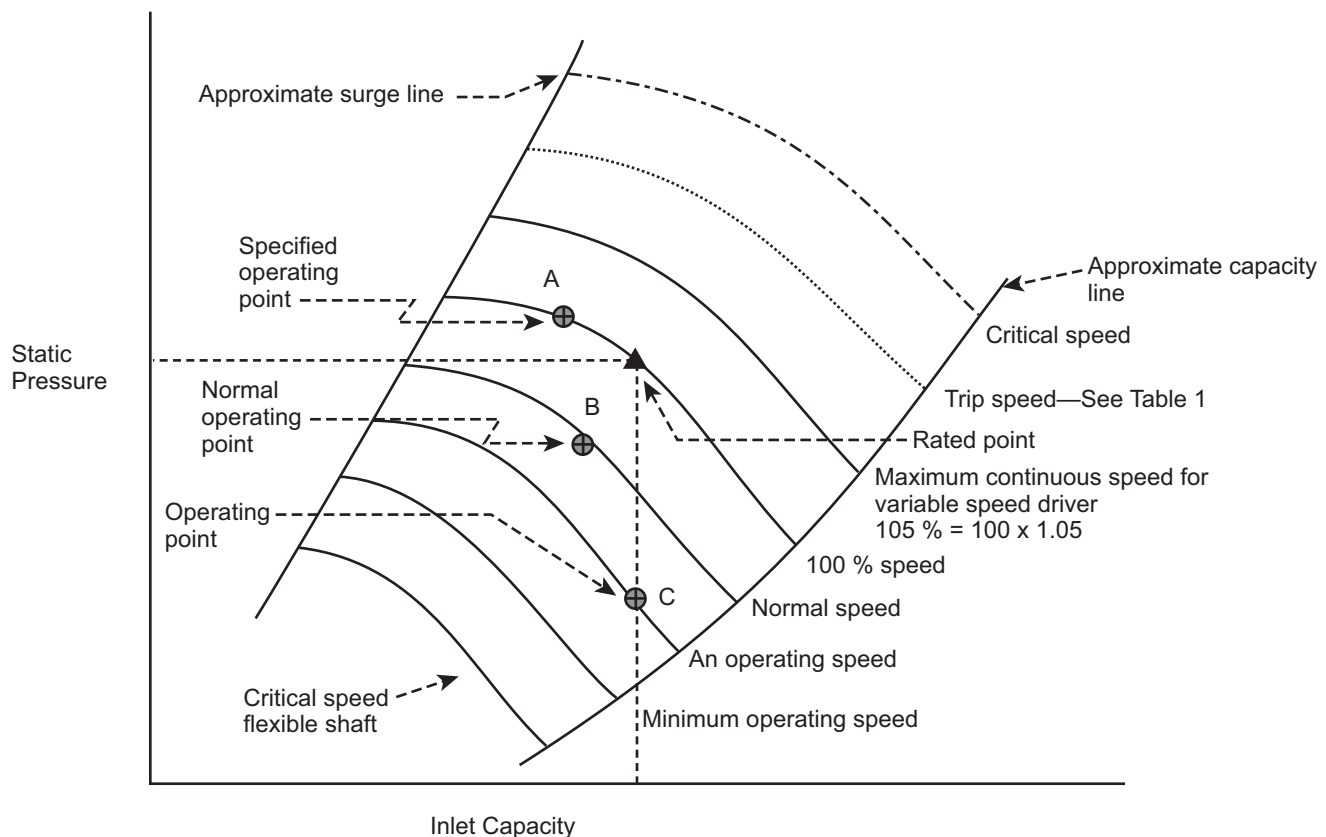
3.13**hydrodynamic bearings**

Bearings that use the principles of hydrodynamic lubrication.

NOTE The bearing surfaces are oriented so that relative motion forms an oil wedge, or wedges, to support the load without shaft-to-bearing contact.

3.14**induced draft fans**

Usually have inlet conditions that are below atmospheric pressure and can be found in a wide variety of gas services. This type of fan is normally downstream of combustion air such as outlet of fired heater or furnace so fan air temperature is elevated.



NOTE 1 Except where specific numerical relationships are stated, the relative values implied in this figure are assumed values for illustration only.

NOTE 2 The 100 % speed curve is determined from the operating point requiring the highest static pressure; point A in the illustration.

NOTE 3 The fan rated point is the intersection on the 100 % speed curve corresponding to the highest flow of any operating point; point C in the illustration.

NOTE 4 Refer to 6.7 for discussion of critical speeds.

Figure 1—Fan Performance Terms

3.15

inlet volume flow

Flow rate expressed in volume flow units at the conditions of pressure, temperature, compressibility, and gas composition, including moisture content, at the fan inlet flange.

NOTE Inlet volume flow is a specific example of actual volume flow. Actual volume flow is the volume flow at any particular location such as interstage, impeller inlet, discharge, or fan discharge. Actual volume flow should not be used interchangeably therefore with inlet volume flow.

3.16

maximum allowable speed

Highest speed at which the manufacturer's design will permit continuous operation.

NOTE The maximum allowable speed is usually set by rotor stress values.

3.17**maximum allowable temperature**

Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating pressure.

3.18**maximum allowable working pressure****MAWP**

Maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating temperature.

3.19**maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the machine, as built and tested, is capable of continuous operation with the specified fluid at any of the specified operating conditions.

3.20**maximum discharge pressure**

Maximum suction pressure plus the maximum differential pressure the fan is able to develop when operating within the specified operating conditions.

3.21**maximum sealing pressure**

Highest pressure the seals are required to seal during any specified static or operating condition and during start-up and shutdown.

3.22**minimum allowable speed**

Lowest speed (revolutions per minute) at which the manufacturer's design will permit continuous operation.

3.23**minimum allowable temperature**

Lowest temperature for which the manufacturer has designed the equipment (or any part to which the term is referred).

3.24**normal operating point**

Point at which usual operation is expected and optimum efficiency is desired. This point is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

3.25**observed**

Inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed as scheduled even if the purchaser or his/her representative is not present.

3.26**oil mist lubrication**

Lubrication systems that employ oil mist produced by atomization in a central unit and transported to the bearing housing, or housings, by compressed air.

3.27**owner**

Final recipient of the equipment who may delegate another agent as the purchaser of the equipment.

3.28**purchaser**

Agency that issues the order and specification to the vendor.

3.29**pure oil mist lubrication**

Lubrication systems in which the mist both lubricates the bearing and purges the housing.

NOTE There is no oil level in the bearing housing when using pure oil mist lubrication (i.e. dry sump).

3.30**purge oil mist lubrication**

Lubrication systems in which the mist purges the bearing housing.

NOTE 1 There is an oil level in the bearing housing when using purge oil mist lubrication and the bearing is lubricated by a conventional oil bath, flinger, or oil ring lubrication system (i.e. wet sump).

NOTE 2 The purchaser may be the owner of the plant in which the equipment is to be installed or the owner's appointed agent.

3.31**rated speed**

100 % speed

Highest rotational speed (revolutions per minute) required to meet any of the specified operating conditions.

3.32**shaft cooler**

heat slinger

A fan (impeller), mounted on the shaft between the seal(s) and bearings, which reduces transfer of heat from the fan interior to the bearings.

3.33**shutdown point**

Preset value of a measured parameter at which automatic or manual shutdown of the system or equipment is required.

3.34**soleplate**

Plate attached to the foundation, with a mounting surface for equipment or for a baseplate.

3.35**special purpose application**

Application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no installed spare equipment.

3.36**standard volume flow**

Flow rate expressed in volume flow units at standard conditions as follows.

U.S. Standard Conditions

Flow: Standard cubic feet per minute (scfm)
Million standard cubic feet per day (mmscfd)
Pressure: 14.7 psi
Temperature: 60 °F

ISO Standard Conditions

Flow: Cubic meters per hour (m³/h)
 Cubic meters per minute (m³/min.)
Pressure: 1.013 bar
Temperature: 0 °C

3.37**standby**

Service state in which a piece of equipment is normally idle or idling and is capable of immediate automatic or manual start-up for continuous operation.

3.38**total indicator reading**

total indicated runout

TIR

Difference between the maximum and minimum readings of a dial indicator or similar device, monitoring a face or cylindrical surface during one complete revolution of the monitored surface.

NOTE For a cylindrical surface, the indicated runout implies an eccentricity equal to half the reading. For a flat face the indicated runout implies an out-of-squareness equal to the reading. If the diameter in question is not cylindrical or flat, the interpretation of the meaning of TIR is more complex and may represent ovality or surface irregularities.

3.38.1**trip speed** (revolutions per minute)

Speed at which an independent emergency overspeed device operates to shut down a prime mover (see Table 1).

3.39**unit responsibility**

Obligation for coordinating the documentation, delivery, and technical aspects of the equipment and all auxiliary systems included in the scope of the order.

NOTE The technical aspects to be considered include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications, and testing of components.

3.40**witnessed**

Inspection or test where the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or the purchaser's representative is in attendance.

4 General**4.1 Unit Responsibility**

The vendor who has unit responsibility shall assure that all subvendors comply with the requirements of this standard and all referenced documents.

4.2 Unit Conversion

The factors in API *MPMS* Ch. 15 were used to convert from U.S. customary (USC) to SI units. The resulting exact SI units were then rounded off.

4.3 Nomenclature

A guide to API 673 nomenclature can be found in Annex B.

5 Requirements

5.1 Dimensions

The purchaser will specify whether data, drawings, hardware (including fasteners), and equipment supplied to this standard shall use the USC or SI system of measurements.

5.2 Statutory Requirements

The purchaser and the vendor shall mutually determine the measures that must be taken to comply with any governmental codes, regulations, ordinances, or rules that are applicable to the equipment, its packaging, and any preservatives used.

5.3 Alternative Designs

The vendor may offer alternative designs for consideration by the purchaser.

5.4 Conflicting Requirements

In case of conflict between this standard and the inquiry, the inquiry shall govern. At the time of the order, the order shall govern.

6 Design

6.1 General

- **6.1.1** The purchaser shall specify the period of uninterrupted continuous operation, during which time the equipment should not require shutdown to perform maintenance or inspection.

NOTE 1 It is realized that there are some services where this objective is easily attainable and others where it is difficult.

NOTE 2 Auxiliary system design and design of the process in which the equipment is installed are very important in meeting this objective.

NOTE 3 Section 9.2.3 requires the vendor to identify any component or maintenance requirement that would result in the need to shut down the equipment within the uninterrupted operational period.

6.1.2 The vendor shall advise in the proposal any component designed for finite life.

6.1.3 The vendor shall assume unit responsibility for all equipment and all auxiliary systems included in the scope of the order.

6.1.4 The purchaser shall specify the equipment's normal operating point.

6.1.5 The equipment shall be capable of operating within the entire performance map at all specified operating conditions, as well as accommodating other conditions such as momentary surge, trip, and start-up.

6.1.6 Equipment driven by induction motors shall be rated at the actual motor speed for the load conditions.

- **6.1.7** Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor having unit responsibility. The equipment furnished by the vendor shall conform to the maximum allowable

SPL specified. In order to determine compliance, the vendor shall provide both maximum sound pressure and sound power level data per octave band for the equipment.

NOTE ISO 3740, ISO 3744, and ISO 3746 or ASME PTC 36 may be consulted for guidance.

6.1.8 Unless otherwise specified, cooling water system or systems shall be designed for the following conditions.

Water velocity over heat exchange surfaces	5 ft/s to 8 ft/s	≥1.5 m/s to 2.5 m/s
Maximum allowable working pressure, MAWP (gauge)	≥100 psig	≥7 bar
Test pressure (≥1.5 MAWP)	≥150 psig	≥1050 kPa (10.5 bar)
Maximum pressure drop	15 psi	100 kPa (1 bar)
Maximum inlet temperature	90 °F	30 °C
Maximum outlet temperature	120 °F	50 °C
Maximum temperature rise	30 °F	20 K
Minimum temperature rise	20 °F	10 K
Water side fouling factor	0.002 h-ft ² -°F/Btu	0.35 m ² K/kW
Corrosion allowance for carbon steel shells	1/8 in.	3 mm

The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity over heat exchange surfaces result in a conflict. 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. If such a conflict exists the purchaser shall approve the final selection.

NOTE For water cooled bearing housings, maintaining the inlet water temperature above ambient air temp will prevent condensation of water in the bearing housing.

Provision shall be made for complete venting and draining of the system or systems.

6.1.9 The equipment's maximum continuous speed shall be not less than 105 % of the rated speed for variable speed machines [including variable-frequency drive (VFD) controlled electric motors] and shall be equal to the synchronous speed for constant speed motor drives.

6.1.10 The equipment's trip speed shall not be less than the values in Table 1.

Table 1—Driver Trip Speeds

Driver Type	Trip Speed (% of Maximum Continuous Speed)
Steam Turbine	
NEMA Class A ^a	115 %
NEMA Class B, C, D ^a	110 %
Variable-speed Motor	110 %
Constant-speed Motor	100 %
^a Indicates governor class as specified in NEMA SM 23.	

6.1.11 The arrangement of the equipment, including ducting and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance. See Annex C for typical arrangements.

• 6.1.12 Electrical Classification

6.1.12.1 Locations for installed equipment can be classified as hazardous electrical areas or they can be unclassified. An unclassified area is considered nonhazardous; therefore, motors, electrical instrumentation, equipment, components, and electrical installations for unclassified areas are not governed by hazardous area electrical codes.

- **6.1.12.2** If an installation location is classified as hazardous, motors, electrical instrumentation, equipment, components, and electrical installations shall be suitable for the hazardous electrical area classification designation as specified.

- **6.1.12.3** All applicable electrical codes shall be specified. Local electrical codes that apply shall be provided by the purchaser upon request.

NOTE 1 Electrical codes vary by installation location. Refer to Table 2 for a tabulation of common hazardous area electrical codes in use.

Table 2—Common Hazardous Area Electrical Codes

Standards Organization ^a	Codes	Where Used	Hazardous Electrical Area Classification Designation
IEC CENELEC	IEC 60079 EN 60079	EU countries and worldwide, except U.S.	Zone, Gas Group, Temperature Class
EU	ATEX Directive 94/9/EC	Required, in addition to IEC, in EU countries only. May be requested in other countries.	Equipment Group, Category
NEC [®]	NFPA 70, Sections 500–502, 504	United States	Class, Division, Group, Temperature Class
NEC [®]	NFPA 70, Section 505	United States	Class I, Zone, Gas Group, Temperature Class
CEC [®]	CSA C22.1-06, Section 18	Canada	<i>Primary:</i> Adoption of IEC—Zone, Gas Group, Temperature Class <i>In Appendix:</i> Class, Division, Group, Temperature Class

^a IEC: International Electrotechnical Commission; CENELEC: European Committee for Electrotechnical Standardization; ATEX: Atmospheres Explosibles, *Equipment intended for use in potentially explosive atmospheres*; EU: European Union; NEC[®]: *National Electrical Code*[®], published by National Fire Protection Association (NFPA); CEC[®]: *Canadian Electrical Code*[®], published by Canadian Standards Association (CSA).

NOTE 2 The ATEX directive, 94/9/EC, became effective on June 30, 2003 and applies to all equipment (mechanical and electrical) that is intended for use in a potentially explosive atmosphere, in the European Economic Area. While not a specific electrical code, it is listed in the table because most electrical products cannot be put into use in a hazardous area in the European Economic Area without ATEX certification. Also, mechanical products, which are used in the EU in a hazardous area, are required to conform to the ATEX directive. The ATEX directive defines categories, which determine the approach used to obtain ATEX certification. Electrical and mechanical equipment are required to meet the essential health and safety requirements set forth in the ATEX directive.

6.1.13 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 minimize contamination by moisture, dust, and other foreign matter during periods of operation and idleness.

6.1.14 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as casing components and bearing housings shall be designed and manufactured to ensure accurate alignment on reassembly.

NOTE This can be accomplished by the use of shouldering, cylindrical dowels, or keys.

6.1.15 The equipment (machine, driver, and ancillary equipment) shall perform on the test stand(s) and on their permanent foundation within the specified acceptance criteria. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

- **6.1.16** Many factors can adversely affect site performance. These factors include such items as duct loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site. To minimize the influence of these factors, the vendor shall review and comment on the purchaser's duct and foundation drawings. If specified, the vendor's representative shall witness:
 - a) a check of the duct alignment performed by unfastening the major flanged connections of the equipment,
 - b) the initial shaft alignment check at ambient conditions,
 - c) shaft alignment at operating temperature (i.e. hot alignment check).
- **6.1.17** The equipment, including all auxiliaries, shall be suitable for operation under the environmental conditions specified. These conditions shall include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions.
- **6.1.18** The equipment, including all auxiliaries, shall be suitable for operation, using the utility stream conditions specified.
- **6.1.19** Spare and replacement parts for the machine and all furnished auxiliaries shall meet all the criteria of this standard.

6.1.20 Bolting and Threads

- **6.1.20.1** The threading shall conform to ASME B1.1 or ISO 261, as specified.

NOTE 1 ASME B1.1 covers general inch series screw threads, and ISO 261 covers general metric screw threads.

NOTE 2 For the purposes of this provision, ASME B1.13M is equivalent to ISO 261.

NOTE 3 Glossary of terms for screw threads can be found in ASME B18.12:2001.

NOTE 4 J profile threads are covered in 6.1.20.2.

6.1.20.1.1 When ASME B1.1 threads have been specified, the thread series shall be variable pitch series UNC or UNRC, or constant pitch series 4, 6, or 8 UN or UNR. Diameters shall be selected from Table 2, Column 1 of ASME B1.1. The threads shall be Class 2 for bolting, studs, and nuts. For other threads and nuts they shall be Class 2 or Class 3.

In order to prevent galling, when ASME B1.1, Class 3 external threads are used, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ASME B1.1, Class 3 tolerance for the OD of the external thread and the ID of the internal thread results in zero clearances. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads do not have any allowance, and therefore even if a Class 2 nut is used with a Class 3 external thread, metal-to-metal at maximum material conditions can develop.

6.1.20.1.2 When ISO 261 has been specified, the thread series shall be coarse or 3, 4, 6, or 8 pitch. Diameters shall be selected from Table 2, Column 1 of ISO 261. The threads shall be Class 6g for bolting and studs and Class 6H for nuts. For other threads they shall be Class 6g or 4h for external threads and Class 6H or 5H for internal threads.

In order to prevent galling, when ISO Class h/H position is specified for mating components, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ISO position h/H clearance for the OD of the external thread and the ID of the internal thread can result in 0 clearance between the mating components. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads position G in the ISO system have an allowance, and therefore a nut using position G can be used with a position h external thread and not develop metal-to-metal contact.

- **6.1.20.2** When J profile threads are used, they shall comply with ASME B1.15 or ISO 5855-1 as specified.

NOTE 1 ASME B1.15 covers J profile screw threads, and ISO 5855-1 covers general metric J profile screw threads,

NOTE 2 For the purposes of this provision, ASME B1.21M:1978 is equivalent to ISO 5855-1 and ISO 5855-2.

6.1.20.2.1 When ISO 5855-1 has been specified, the thread series shall be coarse or 3 pitch as required by Table 2 of ASME B1.21M. Diameters shall be selected from Table 2, Column 1 of ASME B1.21M. The threads shall be Class 4h6h for bolting studs and 4H5H for nuts. Threads other than those for fasteners shall be Class 6g or 4h for external threads and Class 6H or 5H for internal threads. In order to prevent galling, when ISO Class h/H position is specified for mating components, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ISO position h/H clearance for the OD of the external thread and the ID of the internal thread can result in 0 clearances. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads position G in the ISO system have an allowance, and therefore a nut using position G can be used with a position h external thread and not develop metal-to-metal contact.

6.1.20.2.2 When ASME B1.15 (inch series) threads have been specified, the thread series shall be variable pitch series UNJC or constant pitch series 8-UNJ. The threads shall be Class 2 or Class 3. Diameters shall be selected from Table 2, Column 1 of ASME B1.15.

In order to prevent galling, when ASME B1.15, Class 3 external threads are used, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ASME B1.15, Class 3 tolerance for the OD of the external thread and the ID of the internal thread results in zero clearances. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads do not have any allowance, and therefore even if a Class 2 nut is used with a Class 3 external thread, metal-to-metal at maximum material conditions can develop.

6.1.20.2.3 When J profile threads are used, external threads shall be formed by rolling.

6.1.20.3 Gaging

6.1.20.3.1 Inspection or gaging requirements of threads shall be identified in accordance with ASME B1.1, Section 6—Screw Thread Designation.

6.1.20.3.2 All threaded products shall be visually inspected for gross defects. This visual inspection shall be made without magnification and is intended to detect such gross defects as missing or incomplete threads, defective thread profile, torn or ruptured surfaces and cracks, etc.

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

6.1.20.5 Internal socket-type, slotted-nut, or spanner-type bolting shall not be used unless approved by the purchaser.

NOTE For limited space locations, integrally flanged fasteners may be required.

6.1.20.6 Manufacturers marking shall be located on all fasteners $\frac{1}{4}$ in. (6 mm) and larger (excluding washers and headless set screws). For studs, the marking shall be on the nut end of the exposed stud end.

NOTE A set screw is a headless screw with an internal hex opening on one end.

- **6.1.21** Fluids that are flammable, hazardous, or toxic shall be identified by the purchaser.

6.1.22 Fan speed shall not exceed 1800 rpm for any operating condition.

6.1.23 Fan arrangement and bearing support shall be in accordance with AMCA 99-86 and AMCA 99-2404-78, arrangement 3 or 7, with fan impeller located between bearings, the bearings mounted independently of fan housing on rigid pedestals and soleplates, and the bearings protected from the air or gas stream when any of the following conditions exist:

- a) the driver rated power is 150 BHP (120 kW) or greater,
- b) the maximum specified operating temperature is greater than 450 °F (233 °C),
- c) when operating in a corrosive or erosive service,
- d) the operating service is subject to fouling deposits that could cause rotor unbalance.

6.1.24 When drivers are rated less than 40 BHP (30 kW), AMCA arrangements 1, 8, and 9 may be specified on the datasheet.

6.1.25 Fan performance shall be based on the static pressure rise across the fan inlet and outlet flanges. In specifying required operating conditions on the datasheet, the purchaser is responsible for accounting for inlet velocity pressure. The fan vendor is responsible for including the pressure losses attributed to all items within his/her scope to obtain the required static pressure rise. Refer to Figure 2 and AMCA 801-01, Section 3.

The performance curves in Figure 3 reflect general characteristics of various types of fans commonly used. They are not intended to provide complete selection criteria for application purposes since other pertinent parameters are not defined.

6.1.26 The fan shall be capable of stable operation at all operating conditions specified by the purchaser.

NOTE This may require the use of dampers or variable speed control.

6.1.27 Unless otherwise specified, fan curves shall have continuously rising pressure characteristic (pressure versus flow plot) from the rated capacity to 70 % or less of rated flow.

Performance curves, corrected for the specified gas at the specified conditions, shall be based on performance tests in accordance with AMCA 210, including, where applicable, evase and inlet box(es).

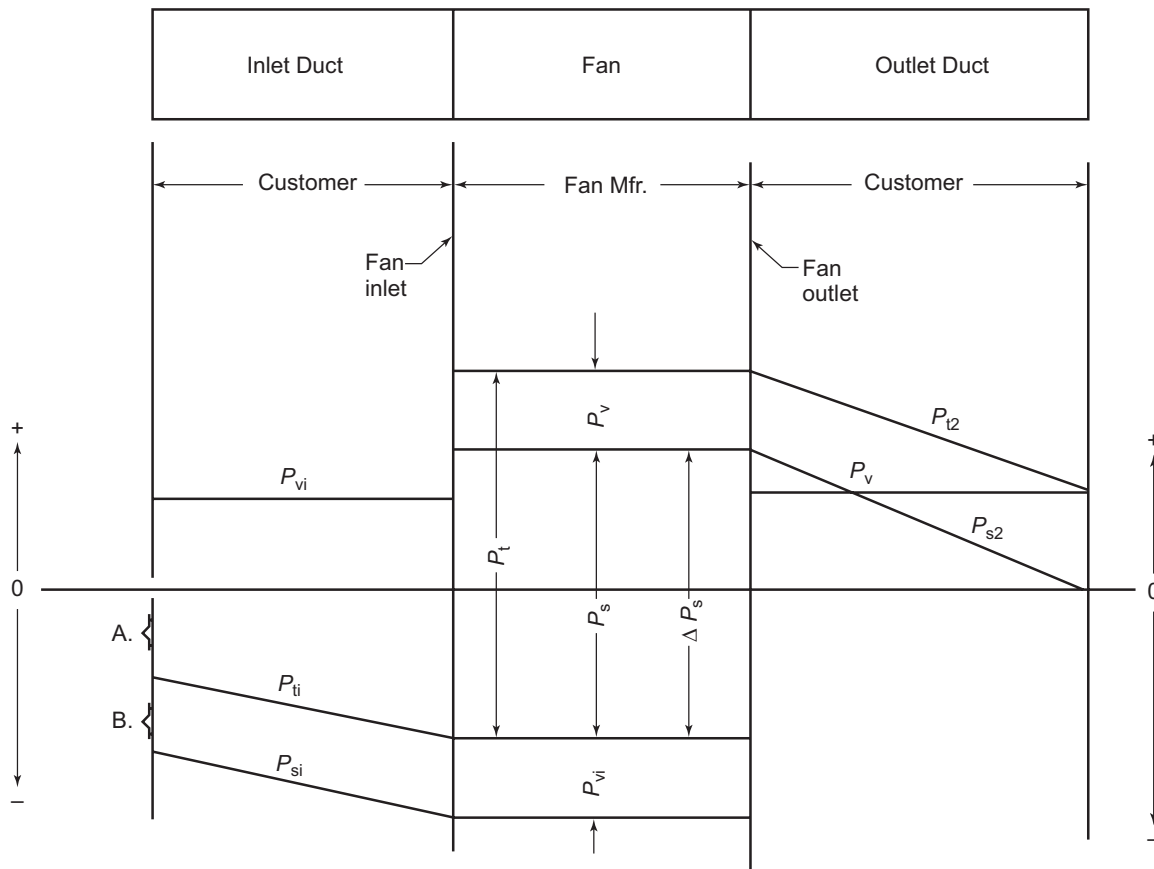
6.1.28 Fans shall be designed such that the first bending critical speed is a minimum of 20 % above the maximum continuous speed.

6.1.29 Induced draft fans shall be mechanically designed for operation at 100 °F (55 °C) above maximum specified inlet gas temperature.

6.1.30 Fan, components, and accessories shall be designed to withstand all loads and stresses during rapid load changes, such as across-the-line starting of motor drivers, failure of damper operator, and sudden opening of dampers.

6.1.31 On forced draft fans, the provision of inlet equipment and arrangements, including silencer(s) and transition piece(s), shall be coordinated between the purchaser and the fan vendor. Unless otherwise specified, air intake(s) shall be at least 15 ft (4.5 m) above the grade.

NOTE The purchaser should evaluate air intake elevation requirements, considering the possibility of dust entering the system and causing surface fouling, the area noise limitation requirement and corresponding need for a silencer, possibility of a combustible vapor entering the fan, and possible horsepower penalties of inlet stack and silencer configurations.



A. Entrance Loss B. Acceleration Energy

1. Static Pressure is that portion of the air pressure which exists by virtue of the degree of compression only. It may be positive or negative relative to the ambient atmospheric pressure.

2. Velocity Pressure is that portion of the air pressure which exists by virtue of the rate of motion only. It is always positive.

3. Total Pressure is the air pressure that exists by virtue of the degree of compression and the rate of motion. It is the algebraic sum of the velocity pressure and the static pressure at a point.

4. Fan Total Pressure (P_t) is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

$$P_t = P_{t2} - P_{t1}$$

5. Fan Velocity Pressure (P_v) is the pressure corresponding to the average velocity at the specified fan outlet area.

$$P_v = P_{v2}$$

6. Fan Static Pressure (P_s) is the difference between the fan total pressure and the fan velocity pressure. Therefore, the fan static pressure is the difference between the static pressure at the fan outlet and the total pressure at the fan inlet.

$$\begin{aligned} P_s &= P_t - P_v \\ &= P_{t2} - P_{t1} - P_{v2} \\ &= (P_{s2} + P_{v2}) - P_{t1} - P_{v2} \\ &= P_{s2} - P_{t1} \end{aligned}$$

7. Fan Static Pressure Rise (ΔP_s) is the static pressure at the fan outlet minus the static pressure at the fan inlet.

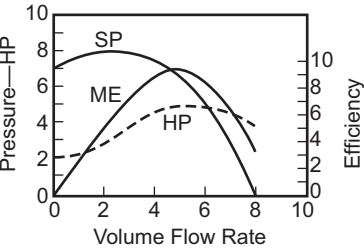
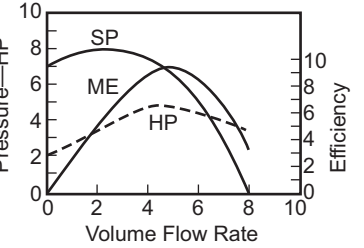
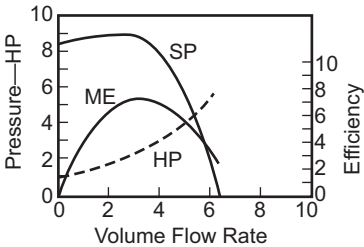
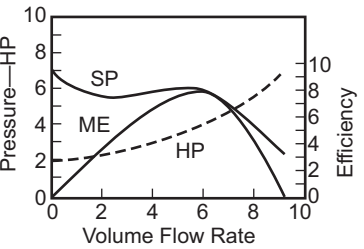
$$\Delta P_s = P_{s2} - P_{s1}$$

The difference between fan static pressure and static pressure rise is the inlet velocity pressure.

$$\begin{aligned} \Delta P_s - P_s &= (P_{s2} - P_{s1}) - (P_{s2} - P_{t1}) \\ &= P_{s2} - P_{s1} - P_{s2} + P_{t1} + P_{v1} \\ &= P_{v1} \end{aligned}$$

Adapted from AMCA Publication 801-01 (R2008), *Industrial Process/Power Generation Fans: Specification Guidelines*.

Figure 2—Fan Pressure Rise Terms

	Highest efficiencies occur 50 % to 65 % of wide open volume. This is also the area of good pressure characteristics; the horsepower curve reaches a maximum near the peak efficiency area and becomes lower toward free delivery, a self-limiting power characteristic as shown.	General heating, ventilating, and air-conditioning systems. Used in large sizes for clean air industrial applications where power savings are significant.
	Operating characteristics of this fan are similar to the airfoil fan mentioned above. Peak efficiency for this fan is slightly lower than the airfoil fan. Normally unstable left of peak pressure.	Same heating, ventilating, and air-conditioning applications as the airfoil fan. Also used in some industrial applications where the airfoil blade is not acceptable because of corrosive and/or erosion environment.
	Higher pressure characteristics than the above mentioned fans. Power rises continually to free delivery.	Used primarily for material-handling applications in industrial plants. Wheel can be of rugged construction and is simple to repair in the field. Wheel is sometimes coated with special material. This design is also used for high-pressure industrial requirements. Not commonly found in HVAC applications.
	Pressure curve is less steep than that of backward-curved bladed fans. There is a dip in the pressure curve left of the peak pressure point and highest efficiency occurs to the right of peak pressure, 40 % to 50 % of wide open volume. Fan should be rated to the right of peak pressure. Power curve rises continually toward free delivery, and this must be taken into account when motor is selected.	Used primarily in low-pressure heating, ventilating, and air-conditioning applications such as domestic furnaces, central station units, and packaged air-conditioning equipment from room air-conditioning units to rooftop units.

Adapted from AMCA 201-02 (R2011), *Fans and Systems*

Figure 3—Fan Characteristic Curves

6.1.32 Fan inlet equipment for atmospheric air intake applications shall include intake cap or hood, trash screen, ducting and support, inlet damper or guide vanes, inlet boxes, and silencer, as required. All components shipped separately shall be flanged for assembly. The inlet equipment assembly shall be designed for the wind load shown on the fan datasheet. The minimum thickness for the above components shall be $\frac{3}{16}$ in. (4.75 mm).

- **6.1.33** If specified, fans shall be designed to allow installation of fan blade cleaning systems. The fan vendor shall provide drawings showing the suggested mounting of this system. As a minimum these drawings shall include:

- 1) connection size, location, and material;
- 2) recommended element make, model, size, and material;

- 3) recommended cleaning medium, with required pressure and temperature;
- 4) recommended frequency and duration of cleaning;
- 5) any other operating limitations.

Elements of the blade cleaning system inside the fan housing shall be supplied by the fan vendor and made of corrosion resistant material. The internal system shall be supported to prevent vibration damage. The purchaser will specify available cleaning media pressure and temperature.

6.2 Fan Housing

6.2.1 The fan scroll and housing shall be continuously welded plate construction. For corrosive, erosive, or hazardous gas service, the pressure containing joints of the fan housing shall be continuously welded inside and out. For arrangement 3 fans (see Annex C), the housing and inlet box(es) shall be split with a bolted, flanged, and gasketed connection to allow for removal of the assembled rotor without disturbing the duct connections. Other arrangements shall be similarly constructed when rotor diameters exceed 43 in. (1100 mm). Minimum housing plate thickness shall be $\frac{3}{16}$ in. (5 mm) for forced draft fans and $\frac{1}{4}$ in. (6 mm) for induced draft fans. The housing shall be free of fan induced structural resonance(s) and limit vibration and noise. Stiffeners shall be provided when required. Stiffeners shall be noncontinuously welded and caulked. The inlet cone shall be split, separately removable, or removable as an assembly with the rotor.

6.2.2 Bolted and gasketed access doors, minimum 24 in. × 24 in. (600 mm × 600 mm) shall be provided in the scroll and inlet box(es) to access the fan internals for inspection, cleaning, rotor balancing, and any internal bolting necessary for rotor removal. If fan size and construction will not permit this size access doors, the largest practical access openings shall be provided in the scroll and inlet box(es).

6.2.3 Adequate flanged sections shall be provided in the fan housing and inlet box(es) so that the rotor can be removed and installed without requiring personnel to enter the inlet box(es) or fan housing.

NOTE Access to enclosed spaces should be limited because of the safety considerations of personnel entering a confined area. An exception to this requirement may be acceptable for specific application(s) provided confined space safety considerations are properly addressed. Appropriate procedures that meet the requirements of OSHA 29 CFR 1910.146, *Permit Required Confined Spaces* and OSHA 29 CFR 1910.147, *The Control of Hazardous Energy (Lockout/Tag Out)* should be observed, and measures should be taken to positively mechanically disconnect all prime movers from the fan. This can include removal of coupling elements and the application of temporary shaft clamping devices to prevent autorotation of the fan rotor.

6.2.4 If specified, induced-draft fan housings shall have side and full width scroll liner(s) of abrasion-resistant material. The material shall be retained in place as agreed by the vendor and purchaser. As an option double thick scroll and side-wall of "standard" materials may be specified.

- **6.2.5** If specified, or when deemed necessary by the fan vendor, the fan housing shall be supported close to the horizontal centerline to minimize changes in housing/rotor relative position and maintain shaft to housing seal clearances and alignment within manufacturer's limits. It is the fan vendor's responsibility to ensure that all clearances are adequately controlled over the range of temperatures for which the fan is specified to operate.

NOTE A fan housing is normally supported from feet mounted at the lowest point. Because the fan rotor is usually separately supported, changes in relative position between rotor and housing will result from thermal expansion.

6.2.6 All mounting surfaces shall be in the same horizontal plane within 0.0625 in. (1 mm). Hold-down bolt holes shall be drilled perpendicular to the mounting surface(s), machined or spot faced to a diameter 3 times that of the bolt. To allow for equipment alignment the hole shall be $\frac{1}{2}$ in. (12 mm) larger in diameter than the hold-down bolt.

6.3 Fan Housing Connections

6.3.1 Inlet and discharge connections shall be flanged and bolted. Facings, gaskets, and bolting of all connections shall be adequate to prevent leakage when using gaskets of at least $\frac{1}{8}$ in. (3 mm) thickness. Unless otherwise specified, gaskets and bolting for the purchaser's inlet and discharge connection shall be specified by the vendor and will be provided by the purchaser.

- **6.3.1.1** When inlet and discharge connections of different size or shape than those covered by ASME are supplied (such as for ducting), the vendor shall supply equipment flange details to the purchaser for the purpose of manufacturing mating parts. If specified, the mating parts shall be furnished by the vendor.

6.3.1.2 Flanged inlets are not mandatory for open inlet fans, but may be provided at the manufacturer's discretion. Alternate acceptable inlet types are bell mouth inlets, coned inlets, or straight inlets. Safety guards to prevent ingress of foreign objects and/or prevent bodily contact with moving parts shall be provided on an open inlet as defined in 7.7.

6.3.2 Auxiliary Connections

6.3.2.1 Fan housing openings for pipe connections shall be NPS $\frac{3}{4}$ (DN 20) or larger and shall be in accordance with ISO-6708:1995. Sizes NPS 1 $\frac{1}{4}$, 2 $\frac{1}{2}$, 3 $\frac{1}{2}$, 5, 7, and 9 (DN 32, DN 65, DN 90, DN 125, DN 175, and DN 225) shall not be used.

6.3.2.2 All connections shall be flanged or machined and studded, except where threaded connections are permitted by 6.3.2.5. All connections shall be suitable for the MAWP of the fan casing. Flanged connections may be integral with the casing or, for casings of weldable material, may be formed by a socket-welded or butt-welded pipe nipple or transition piece and shall terminate with a welding-neck or socket-weld flange.

6.3.2.3 Connections welded to the casing shall meet the material requirements of the casing, including impact values rather than the requirements of the connected piping (see 6.10.3).

6.3.2.4 Butt-welded connections, size NPS 1 $\frac{1}{2}$ (DN 40) and smaller, shall be reinforced by using forged welding inserts or gussets.

6.3.2.5 For connections other than main process connections, if flanged or machined and studded openings are impractical, threaded connections for pipe sizes not exceeding NPS 1 (DN 25) may be used with purchaser approval as follows:

- a) on nonweldable materials, such as cast iron;
- b) where essential for maintenance (disassembly and assembly).

6.3.2.6 Pipe nipples screwed or welded to the casing should not be more than 6 in. (150 mm) long and shall be a minimum of Schedule 160 seamless for sizes NPS 1 (DN 25) and smaller and a minimum of Schedule 80 for NPS 1 $\frac{1}{2}$ (DN 40).

6.3.2.7 The nipple and flange materials shall meet the requirements of 6.3.2.3.

6.3.2.8 Threaded openings for tapered pipe threads shall conform to ASME B1.20.1 or ISO 7-1 as specified. If ISO 7-1 has been specified, tapered or straight internal threads shall also be specified. Bosses for pipe threads shall conform to ASME B16.5.

6.3.2.9 Threaded connections shall not be seal welded.

6.3.2.10 Threaded openings not required to be connected to piping shall be plugged with solid, round-head steel plugs furnished in accordance with ASME B16.11. As a minimum, these plugs shall meet the material requirements of the casing. Plugs that may later require removal shall be of corrosion-resistant material. Plastic plugs are not permitted.

6.3.2.11 A process compatible thread lubricant of proper temperature specification shall be used on all threaded connections. Thread tape shall not be used.

6.3.2.12 Pipe Flanges

- **6.3.2.12.1** Pipe flanges shall conform to ISO 7005-1, Series 1, including Annex D and Annex E; ISO 7005-2, Series 1; ASME B16.1; ASME B16.5; ASME B16.42; or ASME B16.47 (Series B) as specified, except as specified in 6.3.2.12.2 through 6.3.2.12.6.

NOTE 1 ISO 7005-1 (steel flanges) PN 20, 50, 110, 150, 260, and 420 are designed to be interchangeable with ASME B16.5 and MSS SP-44 flanges—ISO 7005-1 flanges are not identical to ASME B16.5 and MSS SP-44 flanges but are deemed to comply with the dimensions specified in ASME B16.5 and MSS SP-44.

NOTE 2 ISO PN 2.5 and 6 do not have a corresponding ASME class, and ASME Classes 75, 400, and 800 do not have corresponding ISO PN designation. The use of these PN and class flange ratings is therefore not recommended.

6.3.2.12.2 When ISO 7005-1 has been specified, materials shall be in accordance with ISO 7005-1 Annex D-1 (DIN) or Annex D-2 (ASTM) as specified. The pressure temperature ratings in Annex E shall correspond to the materials specified.

NOTE ISO 7005-1, Annex E, Table 1-4 covers D-1 materials and Table 5-21 covers D-2 materials.

- **6.3.2.12.3** If specified, ASME B16.47, Series A flanges shall be provided.

6.3.2.12.4 Flat face flanges with full raised face thickness are acceptable on casings of all materials. Flanges in all materials that are thicker or have a larger outside diameter than required by ISO or ASME are acceptable. Nonstandard (oversized) flanges shall be completely dimensioned on the arrangement drawing. If oversized flanges require studs or bolts of nonstandard length, this requirement shall be identified on the arrangement drawing.

6.3.2.12.5 Flanges shall be full faced or spot faced on the back and shall be designed for through bolting.

6.3.2.12.6 For all steel flanges, imperfections in the flange facing finish shall not exceed that permitted in ASME B16.5 or ASME B16.47 as applicable.

- **6.3.2.12.7** Machined and studded connections shall conform to the facing and drilling requirements of ISO 7005-1, ISO 7005-2, ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 as specified. Studs and nuts shall be provided and installed. The first 1.5 threads at both ends of each stud shall be removed.

6.3.2.12.8 Machined and studded connections and flanges not in accordance with ISO 7005-1, ISO 7005-2, or ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 require purchaser's approval. Unless otherwise specified, the vendor shall supply mating flanges, studs, and nuts for these nonstandard connections.

6.3.2.12.9 To minimize nozzle loading, and facilitate installation of piping, machine flanges shall be parallel to the plane shown of the flange as shown on the general arrangement drawing to within 0.5°. Studs or bolt holes shall straddle centerlines parallel to the main axes of the equipment.

6.3.2.12.10 All of the purchaser's connections shall be accessible for disassembly without requiring the machine, or any major part of the machine, to be moved.

6.3.2.12.11 Accessible flanged drain connections, NPS 2 (DN 50) minimum size, shall be provided at the low points of the housing and inlet boxes.

6.3.2.12.12 The concentricity of the bolt circle and the bore of all circular standard flanges shall be such that the area of the machined gasket-seating surface is adequate to accommodate a complete standard gasket without protrusion of the gasket into the fluid flow.

6.3.2.12.13 For socket-welded construction, there shall be a $1/16$ in. (1.5 mm) gap between the pipe end and bottom of the socket before welding.

6.3.2.12.14 Slip-on flanges are permitted only with the purchaser's specific approval.

6.4 External Forces and Moments

6.4.1 It is the purchaser's responsibility to specify the external loads to be imposed on the fan housing from the ancillary equipment (ducting, sound trunks, silencers, filters, etc.) if this equipment is not supplied by the fan vendor. The vendor shall design the housing and supports to accept the specified loads such that:

- a) distortion resulting from imposed loads does not affect performance, and
- b) no internal rubs result.

6.5 Rotating Elements

6.5.1 Materials selection shall be by joint agreement between the purchaser and vendor. The vendor shall fully detail materials, thickness, and construction details for each rotor assembly.

6.5.2 Fan impellers shall be designed for the highest efficiency consistent with the application. Blade design shall be mutually agreed upon between the purchaser and vendor.

NOTE 1 Forced draft fan impellers may be provided with backward inclined or backward curved airfoil type. Induced-draft fans impellers may be radial, radial tipped, backward inclined, or backward curved airfoil type, with consideration of operation in possibly dirty gas environment.

NOTE 2 Design configurations listed below are available options.

- a) Hollow-shaped airfoil construction of 0.10 in. (2.5 mm) minimum thickness skin material, designed and constructed to prevent the internal accumulation of condensable foulants or corrosion products. The purchaser should exercise care in the application of this design in corrosive and/or erosive environments such as found in some induced draft services.
- b) Solid blades with airfoil shape.
- c) Single thickness, $1/4$ in. (6 mm) minimum, non-airfoil shape.

6.5.3 Welded construction of the fan impeller is required. Shrouds, back plates, and center plates shall normally be of one-piece construction but may be fabricated if the sections are joined by full strength/penetration butt welds. Corrosiveness, erosiveness, and temperature (including excursions) of gas specified by the purchaser shall be considered during material selection.

- **6.5.4** If specified, corrosion-resistant shaft sleeves shall be provided. Sleeves shall extend 6 in. (150 mm) into the fan housing or to the impeller hub. Shaft sleeves shall be installed with an interference fit, and the fit and assembly shall take into account differential thermal expansion at the highest operating temperature. After assembly of the shaft, mechanical run out on the shaft sleeve shall not exceed 0.002 in. (50 μ m) total indicated runout (TIR) in the seal area.

6.5.5 Impellers shall have solid hubs, be keyed to the shaft, and be secured with an interference fit. Unkeyed fits with appropriate interference are permissible with purchaser's approval. The fit shall have a minimum interference of 0.0005 in. per in. (0.0005 mm per mm) of bore diameter; however, the actual interference fit shall be shown on the datasheet and outline drawing. The impeller hub to shaft fit design shall preclude axial movement of the hub along the shaft caused by gross changes in temperature. The hub bore and shaft outside diameter shall be machined to a finish of 32 μ in. (0.8 μ m) arithmetic average roughness (Ra) or better in the interference fit contact area. Cast or ductile iron hubs or hollow hubs are not acceptable except in services below 300 °F (150 °C) or at a

fan tip speed of less than 20,000 ft/min. (100 m/s). When the impeller is to be bolted to the hub, the manufacturer will, by design, preclude relative movement between the impeller and hub.

- **6.5.6** The purchaser will specify on the datasheet the rate of temperature change—heating and cooling—for the process operating conditions. The vendor shall assure that an adequate interference fit (hub to shaft) is maintained considering purchaser's defined operating conditions, including transients.

6.5.7 Each rotor shall be clearly marked with a unique identification number. This number shall be on the nondrive end of the shaft or in another accessible area that is not prone to maintenance damage.

6.5.8 Shafting including shaft to coupling juncture shall be capable of transmitting torque at least equal to the maximum transient torque produced by the driver during acceleration including service factor, if any.

6.5.9 Shafts shall be machined from one-piece heat treated steel. Shafts with finished diameters 8 in. (200 mm) and larger shall be forged. Shafts with finished diameters less than 8 in. (200 mm) may be hot-rolled bar stock purchased to the same quality and heat treatment criteria as shaft forgings. Shafts made from forgings or from bar stock shall be stress relieved after rough machining and before final machining. Cold rolled steel, turned, ground, and polished, may be used for shafts not exceeding 4 in. (100 mm) finished diameter. Shaft diameter for arrangements 3 and 7 shall be stepped on both sides of impeller fit area to facilitate impeller removal. Fillets shall be provided at all changes in shaft diameters. Welding on the shaft is not permitted.

6.5.10 All shaft keyways shall have fillet radii conforming to ASME B17.1.

6.5.11 Shaft shoulders against which rolling element bearings seat shall have filets conforming to ISO 582. When inch series tapered roller bearings are used, the filets shall be in accordance with ABMA 19.2.

NOTE For the purpose of this provision ABMA 20 and ABMA 19.1 are equivalent to ISO 582.

6.6 Shaft Sealing of Fans

6.6.1 Shaft seals, including labyrinth, floating bushing (e.g. carbon ring), or close clearance annulus types shall be provided to minimize leakage from or into fans over the range of specified operating conditions and during periods of idleness. Seals shall be designed to operate for process conditions that may vary during start-up and shutdown or any special operation specified by the purchaser.

6.6.2 Fans with negative pressure at the shaft seals, except forced draft fans in air service and induced draft fans exhausting to the atmosphere, shall be provided with seals suitable for pressurization. System details shall be mutually agreed upon by the purchaser and the vendor.

6.6.3 When the seal is specified to be in toxic, high-pressure, or flammable service, provision for a centralized buffer gas injection and/or eductor system shall be supplied to minimize leakage. System details shall be mutually agreed upon by the purchaser and the vendor.

6.6.4 Shaft sealing elements shall be replaceable without disturbing the shaft and bearings or dismantling ductwork or the fan casing.

6.6.5 Shaft seal clearances and materials shall be based on the specified operating temperature. Temperature excursions shall also be considered in the design.

6.6.6 Requirements for Special Purpose Fans

- If specified, fan shall be equipped with mechanical seals or dry gas seals.

6.7 Dynamics

6.7.1 General

6.7.1.1 When the frequency of a periodic forcing phenomenon (excitation) applied to a rotor-bearing support system coincides with a natural frequency of that system, the system will be in a state of resonance. A rotor-bearing support system in resonance may have the magnitude of its normal vibration amplified. The magnitude of amplification and, in the case of critical speeds, the rate of change of the phase angle with respect to speed are related to the amount of damping in the system.

NOTE The mode shapes are commonly referred to as the first-rigid (translatory or bouncing) mode, the second (conical or rocking) mode, and the (first, second, third...*n*th) bending mode.

6.7.1.2 When the rotor amplification factor (see Figure 4), as measured at the shaft radial vibration probes, is greater than or equal to 2.5, the corresponding frequency is called a critical speed and the corresponding shaft rotational frequency is also called a critical speed. For the purpose of this standard, a critically damped system is one in which the amplification factor is less than 2.5.

NOTE This speed is defined in AMCA 801-01 under the heading "Design Criteria" as "design resonant speed."

6.7.1.3 In the design of rotor-bearing systems, consideration shall be given to all potential sources of periodic forcing phenomena (excitation), which shall include but are not limited to the following sources:

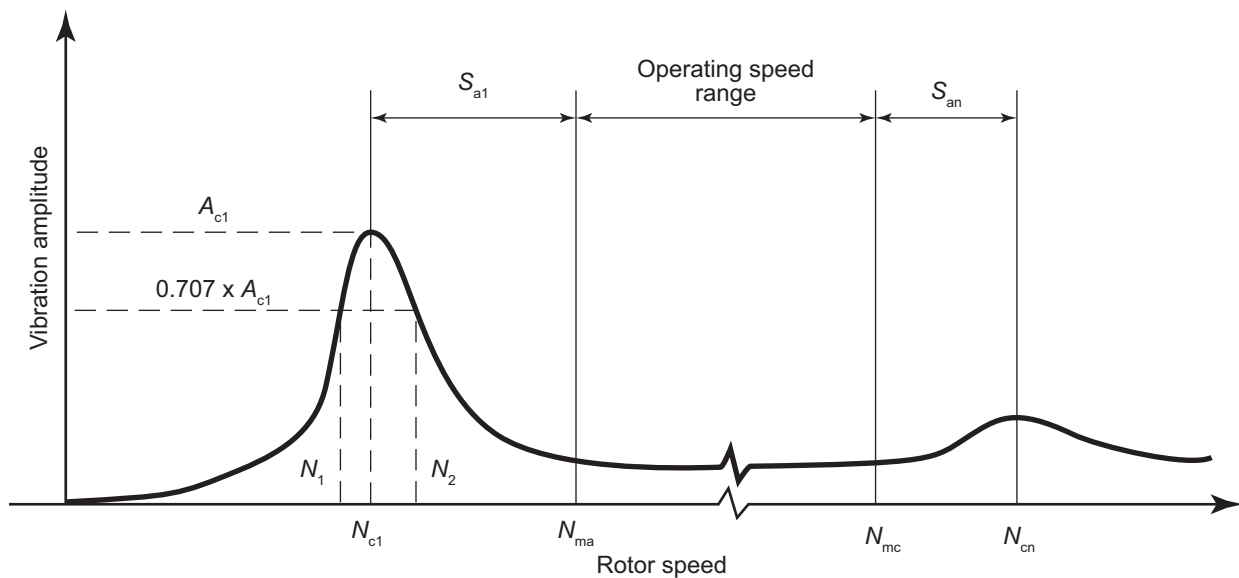
- a) unbalance in the rotor system,
- b) oil film instabilities (whirl),
- c) blade passing frequencies,
- d) gear tooth meshing and side bands,
- e) coupling misalignment,
- f) loose rotor system components,
- g) ball and race frequencies of rolling element bearings,
- h) VFD excitation frequencies.

NOTE The frequency of a potential source of excitation can be less than, equal to, or greater than the rotational speed of the rotor.

6.7.1.4 Resonances of structural support systems may adversely affect the rotor vibration amplitude. Therefore, resonances of structural support systems that are within the vendor's scope of supply and that affect the rotor vibration amplitude shall not occur within the specified operating speed range or the specified separation margins (see 6.7.2.1 and Annex D) unless the resonances are critically damped. The effective stiffness of the structural support shall be considered in the analysis of the dynamics of the rotor-bearing support system.

6.7.1.5 The vendor who is specified to have unit responsibility for the complete drivetrain shall communicate the existence of any undesirable running speeds in the range from zero to trip speed. This shall be illustrated by the use of Campbell (forced frequency) diagrams for individual machines and/or when specified for the complete train. These diagrams shall be submitted to the purchaser for his/her review and included in the instruction manual (see D.5).

NOTE Examples of undesirable speeds are those caused by the rotor lateral criticals of concern, system torsionals, and impeller resonant frequencies.



N_{c1} = rotor first critical speed
 N_{cn} = n^{th} critical speed
 N_{ma} = minimum allowable speed
 N_{mc} = maximum continuous speed

A_{c1} = amplitude at N_{c1}
 N_1 = initial (lesser) speed at $0.707 \times A_{c1}$
 N_2 = final (greater) speed at $0.707 \times A_{c1}$
 AF_1 = amplification factor of the first critical speed
 $= N_{c1} / (N_2 - N_1)$

S_{a1} = actual separation between N_{c1} and the operating speed range
 S_{an} = actual separation between N_{cn} and the operating speed range
 SM_{a1} = actual separation margin of first critical speed (%)
 $= 100 \times S_{a1} / N_{ma}$
 SM_{an} = actual separation margin of n^{th} critical speed (%)
 $= 100 \times S_{an} / N_{mc}$

NOTE The shape of the curve is for illustration only and does not necessarily represent any actual rotor response plot.

Figure 4—Rotor Response Plot

6.7.2 Lateral Analysis

6.7.2.1 Unless otherwise specified, the vendor's standard lateral critical speed values that have been analytically derived and proven by testing of identical fans, similar fans, or fans where the first bending critical speed is a minimum of 20 % above the maximum continuous speed are acceptable.

An identical fan is defined as one with the same size frame, aerodynamic design, rpm, size and type of shaft seal, size and type of bearings, and coupling mass and overhang.

Similarity between fans shall be established by agreement between the purchaser and vendor, considering the factors listed above.

- **6.7.2.2** If specified, a lateral analysis shall be carried out and the results assessed in accordance with Annex D.

6.7.3 Torsional Analysis

- **6.7.3.1** A torsional analysis shall be performed for any of the following:
 - a) electric motor or steam turbine driven fans with gears over 200 hp (150 kW),
 - b) units comprising three or more coupled machines (excluding any gears),
 - c) all VFD driven units,
 - d) internal combustion engine rated 325 hp (250 kW) or higher,
 - e) synchronous motor rated 700 hp (500 kW) or higher.

The vendor having unit responsibility shall ensure that the analysis is carried out and shall be responsible for directing any modifications necessary to meet the requirements of 6.7.3.2 through 6.7.3.7.

The analysis shall be for the train as a whole unless the train includes a device that has weak dynamic coupling, for example, a hydraulic coupling or torque converter.

The purchaser shall specify if a torsional analysis is required for motor driven units without gears.

6.7.3.2 Excitation of torsional natural frequencies may come from many sources that 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 such as unbalance, pitch line runout, and cumulative pitch error;
- b) cyclic process impulses;
- c) torsional transients such as start-up of synchronous electric motors;
- d) torsional excitation resulting from electric motors and reciprocating engines;
- e) control loop resonances from hydraulic, electronic governors, and VFDs;
- f) 1 and 2 times line frequency;
- g) running speed or speeds;
- h) harmonic frequencies from VFDs.

6.7.3.3 Excitation at the following frequencies shall be evaluated ("rpm" refers to rotor speed; " n " is an integer determined by the driver manufacturer):

- a) train with gear(s): 1 and 2 times rpm.
- b) synchronous motor: $n \times$ slip frequency or rpm (n = number of poles), 1 and 2 times line frequency.

- c) VFD: 1 and 2 times line frequency and harmonic excitations due to the VFD as determined by the manufacturer of the VFD.

The excitation frequencies for motor drives, Items b) and c), include transient and steady state conditions.

6.7.3.4 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).

6.7.3.5 Torsional natural frequencies at 2 or more times running speed shall be shown to have no adverse effect.

6.7.3.6 When torsional resonances are calculated to fall within the margin specified in 6.7.3.4 (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.

6.7.3.7 In addition to the torsional analyses required in 6.7.3.1 through 6.7.3.6, the vendor shall perform a transient torsional vibration analysis for synchronous motor driven units. The acceptance criteria for this analysis shall be mutually agreed upon by the purchaser and the vendor.

6.7.3.8 In addition to the parameters used to perform the torsional analysis specified in 6.7.3.1, the following shall be included:

- a) motor average torque, as well as pulsating torque (direct and quadrature axis) vs speed or time characteristics;
- b) load torque vs speed characteristics;
- c) electrical system characteristics affecting the motor terminal voltage or the assumptions made concerning the terminal voltage including the method of starting, such as across the line, or some method of reduced voltage starting.

6.7.3.9 The analysis shall generate the maximum torque as well as a torque vs time history for each of the shafts in the machinery train. The maximum torques shall be used to evaluate the peak torque capability of coupling components, gearing, and interference fits of components such as coupling hubs. The torque vs time history shall be used to develop a cumulative damage fatigue analysis of shafting, keys, and coupling components.

6.7.4 Vibration and Balancing

6.7.4.1 Prior to rotor assembly, the shaft shall be inspected for mechanical runout and concentricity at impeller mounting surface and bearing journals. Runout shall not exceed the following TIR.

Shaft Diameter (At Point Measured)		Total Indicator Reading Impeller Mounting Area/Journal	
in.	mm	in.	mm
≤6	≤150	0.002/0.001	0.05/0.025
>6, ≤14	>150, ≤360	0.003/0.0015	0.075/0.38
>14	>360	0.004/0.002	0.10/0.05

A runout recheck adjacent to the hub shall be made after rotor assembly and prior to balancing. Certified runout reports shall be furnished by the vendor.

6.7.4.2 Balance weights, if required, shall not exceed $\frac{1}{4}$ in. (6 mm) in thickness or exceed the thickness of the member to which the weight is attached and shall be continuously welded onto the impeller in two or three defined balancing planes. Those balance weights required in the gas passage shall be ground to the impeller surfaces at a fillet angle not exceeding 20° .

6.7.4.3 Impellers and similar major rotating components shall be dynamically balanced to ISO 1940, Grade 2.5. The rotating element shall be multiplane dynamically balanced. When spare rotors are supplied, they shall be dynamically balanced to the same tolerance as the main rotor.

6.7.4.4 During the shop test of the assembled machine, operating at maximum continuous speed or at any other speed within the specified operating speed range, the maximum allowable unfiltered peak amplitude of vibration in any plane measured on the bearing housing shall not exceed the value given in Table 3. At the trip speed of the driver, the vibration shall not exceed 150 % of these values.

Table 3—Vibration Limits for Fans ^a

	Point of Measurement			
	Bearing Housing		Shaft ^b	
	All Fan Bearings		Hydrodynamic Fan Bearings (J/B)	
	mm/s (rms)	in./s (rms)	micron	mils (pk/pk)
Unfiltered	<2.8	<0.11	<50	<2
Filtered ^c	<1.8	<0.07	<40	<1.6

^a At any flow within the specified operating envelope.

^b Applies when optional API 670 proximity type probes are purchased and installed adjacent to hydrodynamic bearings.

^c At discrete frequencies.

6.7.5 Additional Requirements for Special Purpose Fans

6.7.5.1 A lateral analysis shall be performed for all special purpose applications.

- **6.7.5.1.1** If specified, the effects of other equipment in the train shall be included in the damped unbalanced response analysis (i.e. a train lateral analysis shall be performed). A train lateral analysis need not be considered unless one or more rigid couplings are employed in the drivetrain.

NOTE This analysis should be considered for machinery trains with long coupling spacers [more than 36 in. (91 cm)], rigid couplings, or both.

6.7.5.1.2 In addition to the damped unbalanced response analysis requirements of Annex D, for machines equipped with rolling element 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.

6.7.5.1.3 The maximum allowable residual unbalance per plane (journal) shall be calculated as follows: a separate damped unbalanced response analysis shall be conducted for each critical speed within the speed range of 0 to $1.5 \times N_{mc}$. Unbalance shall analytically be placed at the locations defined in Figure D.2. For the translatory (symmetric) modes, the unbalance shall be based on the sum of the journal static loads. For conical (asymmetric) modes, these unbalances shall be 180° out of phase and of a magnitude based on the static load on the adjacent bearing. For overhung modes, the unbalances shall be based on the overhung mass. Section D.2 shows the typical mode shapes and indicates the location and definition of U_a for each of the shapes. The magnitude of the unbalances shall be 2 times the value of U_r as calculated by Equations (1) or (2).

In SI units:

$$U_r = 6350W/N_{mc} \quad (1)$$

In USC units:

$$U_r = 4W/N_{mc} \quad (2)$$

where

$U_a = 2 \times U_r$ is the input unbalance for the rotordynamic response analysis in oz-in. (g-mm);

U_r is the maximum allowable residual unbalance in oz-in. (g-mm);

N_{mc} is the maximum continuous operating speed, rpm;

W is the journal static load in lbm (kg), or for bending modes where the maximum deflection occurs at the shaft ends, the overhung mass (i.e. the mass of the rotor outboard of the bearing) in lbm (kg) (see Figure D.2).

NOTE 1 Refer to Annex D of this standard for more detailed explanations of the lateral critical speed analysis required.

NOTE 2 ISO Grade 1.0 is approximately equivalent to $4W/N$.

NOTE 3 If the components for the equipment are relatively light in weight and/or operates at high speed, the limits given in this paragraph may not be achievable with commercial balancing machines.

- **6.7.5.1.4** For fans over 500 hp (370 kW) supplied with baseplates that provide an integral support for the drive and fan bearings, a finite element analysis or equivalent shall be performed to determine the baseplate stiffness to be used in the critical speed analysis and to determine baseplate resonant frequencies and mode shapes that could be excited by operational forces.

6.7.5.2 Vibration and Balance for Special Purpose Fans

6.7.5.2.1 On rotors with keyways, the keyway shall be filled with a fully crowned half-key. The weight of all half-keys used during final balancing of the assembled element shall be recorded on the residual unbalance worksheet (see Annex E). The maximum allowable residual unbalance per plane (journal) shall be calculated as follows:

In SI units:

$$U_{max} = 6350W/N \quad (3)$$

In USC units:

$$U_{max} = 4W/N \quad (4)$$

where

U_{max} is the residual unbalance, in oz-in. (g-mm);

W is the journal static weight load, in lb (kg);

N is the maximum continuous speed, in rpm.

NOTE 1 ISO Grade 1.0 is approximately equivalent to $4W/N$.

NOTE 2 If the components for the equipment are relatively light in weight and/or operates at high speed, the limits given in this paragraph may not be achievable with commercial balancing machines.