

Axial and Centrifugal Compressors and Expander-compressors

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

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Axial and Centrifugal Compressors and Expander-compressors

Part 1—General Requirements

1 Scope

This standard specifies minimum requirements and gives recommendations for axial compressors, single-shaft and integrally geared process centrifugal compressors, and expander-compressors for special-purpose applications that handle gas or process air in the petroleum, chemical, and gas industries. This part of API 617 specifies general requirements applicable to all such machines.

API 617 does not apply to the following:

- fans (these are covered by API 673) or blowers that develop less than 34 kPa (5 psi) pressure rise above atmospheric pressure;
- integrally geared centrifugal plant and instrument air compressors, which are covered by API 672;
- axial inflow expanders, such as hot gas expanders.

This part of API 617 contains information pertinent to all equipment covered by the other parts of this document. It shall be used in conjunction with the following parts, as applicable to the specific equipment covered:

- *Part 2—Nonintegrally Geared Centrifugal and Axial Compressors;*
- *Part 3—Integrally Geared Centrifugal Compressors;*
- *Part 4—Expander-compressors.*

2 Normative References

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

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

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

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

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

API Standard 614, *Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries*, Fifth Edition

API Standard 616, *Gas Turbines for the Petroleum, Chemical, and Gas Industry Services*, Fifth Edition

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

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

API Technical Report 684-1, *API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing*, First Edition

API Recommended Practice 687, *Rotor Repair*, First Edition

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

API Recommended Practice 691, *Risk-based Machinery Management*, First Edition

API Standard 692, *Dry Gas Sealing Systems for Axial, Centrifugal, Rotary Screw Compressors and Expanders*, First Edition

ANSI ¹/AGMA ISO 1328-1-B14 ², *Cylindrical Gears—ISO System of Flank Tolerance Classification—Part 1: Definitions and Allowable Values of Deviations Relevant to Flanks of Gear Teeth*

ANSI/AGMA 2101-C95, *Fundamental Rating Factors And Calculation Methods For Involute Spur And Helical Gear Teeth*

AGMA 2101-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, 2004 (Reaffirmed 2010)

ASME B1.1-2003 (R2018) ³, *Unified Inch Screw Threads, UN and UNR Thread Form*

ASME B1.13M-2005 (R2020), *Metric Screw Threads: M Profile*

ASME B1.20.1-2013, *Pipe Threads, General Purpose (Inch)*

ASME B16.1-2015, *Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250*

ASME B16.5-2017, *Pipe Flanges and Flanged Fittings: NPS 1/2 Through NPS 24 Metric/Inch Standard*

ASME B16.11-2016, *Forged Fittings, Socket-Welding and Threaded*

ASME B16.42-2016, *Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300*

ASME B16.47-2017, *Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard*

ASME Boiler and Pressure Vessel Code (BPVC)-2017, Section V: *Nondestructive Examination*

ASME BPVC-2017, Section VIII, Division 1: *Rules for Construction of Pressure Vessels*

ASME BPVC-2017, Section IX: *Welding, Brazing, and Fusing Qualifications—Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators*

ASME PTC 10-1997, *Performance Test Code on Compressors and Exhausters*

ASME PTC 36, *Measurement of Industrial Noise*

¹ American National Standards Institute, 1899 L. Street, NW, 11th Floor, Washington, DC 20036, www.ansi.org.

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

³ American Society of Mechanical Engineers, Two Park Avenue, New York, New York 10016, www.asme.org.

ASTM A193/A193M ⁴, *Standard Specification for Alloy-Steel and Stainless Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

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

ASTM A247, *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings*

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

ASTM A307, *Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rods 60 000 PSI Tensile Strength*

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

ASTM A395/A395M, *Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*

ASTM A536, *Standard Specification for Ductile Iron Castings*

ASTM A563/A563M, *Standard Specification for Carbon and Alloy Steel Nuts (Inch and Metric)*

ASTM A578, *Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications*

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

ASTM E94/E94M, *Standard Guide for Radiographic Examination Using Industrial Radiographic Film*

ASTM E125-63 (2018), *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*

ASTM E165/E165M, *Standard Practice for Liquid Penetrant Testing for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

AWS D1.1/D1.1M:2015 ⁵, *Structural Welding Code—Steel*

DIN ISO 228-1⁶, *Pipe threads where pressure-tight joints are not made on the threads—Part 1: Dimensions, tolerances and designation*

EN 1092-1:2007+A1:2013 ⁷, *Flanges and their joints—Circular flanges for pipes, valves, fittings and accessories, PN designated—Part 1: Steel flanges*

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

⁵ American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166, www.aws.org.

⁶ German Institute for Standardization, Burggrafestraße 6, 10787 Berlin, Germany, www.din.de.

⁷ European Committee for Standardization (CEN), Rue de la Science 23, B-1040 Brussels, Belgium, www.cen.eu.

EN 1092-2:1997, *Flanges and their joints—Circular flanges for pipes, valves, fittings and accessories, PN designated—Part 2: Cast iron flanges*

EN 55011:2016+A1:2017, *Industrial, scientific and medical (ISM) radio-frequency equipment—Electromagnetic disturbance characteristics—Limits and methods of measurement*

EN 61000-6-2:2005, *Electromagnetic compatibility (EMC)—Part 6-2: Generic standards—Immunity for industrial environments*

IEC 60079-10-1:2015 ⁸, *Explosive atmospheres—Part 10-1: Classification of areas—Explosive gas atmospheres*

IEC 60529:2013, *Degrees of protection provided by enclosures (IP Code)*

IEEE 841:2009 ⁹, *IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)*

ISPM 15:2009 ¹⁰, *Regulation of Wood Packaging Material in International Trade*

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

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

ISO 3448, *Industrial liquid lubricants—ISO viscosity classification*

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

ISO 5389, *Turbocompressors—Performance test code, Second Edition*

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

ISO 8068, *Lubricants, industrial oils and related products (Class L) - Family T (Turbines) - Specification for lubricating oils for turbines*

ISO 8501, *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness*

ISO 9606, Parts 1–6, *Qualification testing of welders—Fusion welding*

ISO 14839-1, *Mechanical vibration—Vibration of rotating machinery equipped with active magnetic bearings—Part 1: Vocabulary*

ISO 14839-3, *Mechanical vibration—Vibration of rotating machinery equipped with active magnetic bearings—Part 3: Evaluation of stability margin*

⁸ International Electrotechnical Commission, 3 rue de Varembé, CH-1211 Geneva 20, Switzerland, www.iec.ch.

⁹ Institute of Electrical and Electronics Engineers, 3 Park Avenue, 17th Floor, New York, New York, 10016, www.ieee.org.

¹⁰ Food and Agriculture Organization of the United Nations, International Plant Protection Convention, Viale delle Terme di Caracalla, 00153 Rome, Italy, <http://www.fao.org/home/en>.

¹¹ International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

ISO 15614-1:2017, *Specification and qualification of welding procedures for metallic materials—Welding procedure test—Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO 21940-32:2012, *Mechanical vibration—Rotor balancing—Part 32: Shaft and fitment key convention*

NACE MR0103/ISO 17945 ¹², *Petroleum, petrochemical and natural gas industries—Metallic 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*

NACE SP0472-2015, *Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

NEMA 250–2014 ¹³, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

NFPA 70:2017 ¹⁴, *National Electrical Code*

SAE J518-2013 ¹⁵, *Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt Split Flange Type*

SSPC SP 6:2007 ¹⁶, *Commercial Blast Cleaning*

2.2 [●] The hierarchy of documents shall be specified.

NOTE Typical documents submitted as a user inquiry or orders are user specifications, industry specifications (such as API and ISO specifications), datasheets, meeting notes, and supplemental agreements.

3 Terms, Definitions, Acronyms, Abbreviations, and Symbols

3.1 Terms and Definitions

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

3.1.1

abradable seal

Seal design that anticipates rotor or rotor sleeve contact and possible stator element penetration maintaining acceptable sealing performance with no dimensional change to the labyrinth teeth.

NOTE An example of an abradable seal is rotating labyrinth teeth into a polytetrafluoroethylene (PTFE) stator strip.

3.1.2

anchor bolts

¹² NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

¹³ National Electrical Manufacturers Association, 1300 North 17th Street, Suite 900, Arlington, Virginia 22209, www.nema.org.

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

¹⁵ SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096, www.sae.org.

¹⁶ Society for Protective Coatings (now the Association for Materials Protection and Performance), 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, www.sspc.org.

Bolts used to attach the soleplate or baseplate to the support structure (concrete foundation or steel structure); cf. “hold-down bolts” (see 3.1.15).

3.1.3

axially split joint

Casing joint split with the principal face parallel to the shaft centerline.

3.1.4

baseplate

skid

Fabricated steel structure designed to support the driven and/or driver equipment and other ancillaries that may be mounted upon it.

3.1.5

buffer gas

Clean gas supplied to the process side of a double seal that is used to keep untreated process gas away from the seal.

NOTE Buffer gas is not intended to flow through dry gas seal faces.

3.1.6

capacity limit

Highest flow point at which the performance curve terminates on a given speed line or guide vane angle.

3.1.7

cartridge bundle assembly (centrifugal)

Assembly consisting of the complete compressor assembly minus the casing.

NOTE It includes the inner barrel assembly, end heads, seals, bearing housings, and bearings. It also includes the rotor assembly. It is designed to be shop assembled and ready for insertion into the casing to minimize installation work in the field.

3.1.8

certified point

Point to which the performance tolerances will be applied.

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

3.1.9

complex stiffness

Notation for the total equivalent stiffness and damping expression, including the cross-coupled terms as required for the hydrodynamic bearing or squeeze damper oil film.

3.1.10

compliant seal

A stationary seal that deflects during a rotor rub, and then returns back to its original shape or position.

3.1.11

compressor section

Series of one or more impellers with defined external process conditions (e.g. side streams, bypassing).

3.1.12

critical speed

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

3.1.13

design point

This is a term used by the equipment manufacturer to set various parameters such as power, pressure, temperature, or speed. It is not intended for the purchaser to define this point.

3.1.14**gear wheel****bull gear**

Lowest speed rotor in a gearbox; cf. “pinion(s)” (see 3.1.39).

3.1.15**hold-down bolts**

Bolts holding the equipment to the soleplate or baseplate; cf. “anchor bolts” (see 3.1.2).

3.1.16**hydrodynamic bearings**

Bearings that incorporate a fluid film to form an oil wedge, or wedges, that support the load without shaft-to-bearing contact.

3.1.17**informative**

Information only; cf. “normative” (see 3.1.37).

NOTE An informative reference or annex provides advisory or explanatory information. It is intended to assist the understanding or use of the document.

3.1.18**inlet volumetric flow**

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

3.1.19**inner barrel assembly**

Assembly consisting of the internal stationary parts that makes up the removable portion of the flow path, including the inner barrel, the diaphragms, the impeller eye labyrinths, and the diaphragm labyrinths.

3.1.20**internal friction**

A potentially destabilizing damping force produced from the phase difference between the stress and strain in any material under cyclic loading.

3.1.21**low temperature service**

Service where the specified minimum design metal temperature is below $-29\text{ }^{\circ}\text{C}$ ($-20\text{ }^{\circ}\text{F}$).

3.1.22**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) if handling the specified fluid at the specified maximum operating temperature.

3.1.23**maximum allowable working temperature****MAWT**

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

3.1.24**maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the machine, as-built and tested, is capable of continuous operation.

3.1.25**maximum inlet pressure**

Highest specified inlet pressure the equipment shall be subject to.

3.1.26**maximum operating pressure**

Highest continuous pressure expected for any specified operating condition over the entire operating performance map.

3.1.27**maximum operating temperature**

Highest continuous temperature expected for any specified operating condition over the entire operating performance map.

3.1.28**maximum sealing pressure**

Highest pressure the seals are required to seal during any specified operating conditions including start-up, shutdown, settle-out, and standby.

3.1.29**minimum allowable speed**

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

3.1.30**minimum design metal temperature**

Lowest mean metal temperature (through the thickness) expected in service, including operation upsets, auto refrigeration, and temperature of the surrounding environment for which the equipment is designed.

NOTE Adapted from the ASME BPVC.

3.1.31**modular rotor**

Rotor that is built up using stub shafts or similar devices and held together by one or more through bolts.

3.1.32**moment simulator**

Auxiliary device intended to create the moment of the mass of a half coupling.

NOTE A moment simulator can also be designated to serve as an idling adapter (solo plate).

3.1.33**nominal pipe size****NPS**

Value approximately equal to a diameter in inches.

EXAMPLE NPS $\frac{3}{4}$.

NOTE 1 Adapted from ASME B31.3.

NOTE 2 The letters NPS are followed by a value that is related to an approximate diameter of the bore, in inches, for piping up to and including 12 in. diameter. For piping over 12 in. (NPS 12), the NPS value is the nominal OD.

3.1.34

nominal pressure**PN**

Numerical designation relating to pressure that is a convenient round number for reference purposes.

EXAMPLE PN 100 (ISO 7268:1983).

NOTE The permissible working pressure associated with a PN designation depends upon materials, design, and working temperature and has to be selected from the pressure/temperature rating tables in corresponding standards.

3.1.35**normal operating point**

Point at which usual operation is expected and optimum efficiency is desired.

NOTE This point is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

3.1.36**normal speed**

Speed corresponding to the requirements of the normal operating point.

3.1.37**normative**

Required; cf. "informative" (see 3.1.17).

NOTE A normative reference or annex enumerates a requirement or mandate of the specification.

3.1.38**observed (tests and inspections)**

Inspection or test where the purchaser is notified of the schedule and the inspection is performed as scheduled even if the purchaser or purchaser's representative is not present; cf. "witnessed (tests and inspections)" (see 3.1.72).

3.1.39**pinion(s)**

High-speed rotor(s) in a gearbox; cf. "gear wheel" (see 3.1.14).

3.1.40**pressure casing**

Composite of all stationary pressure-containing parts of the unit, including all nozzles and other attached parts that isolates process gas from the atmosphere. Shaft end seals are not considered to be part of the pressure casing.

3.1.41**purchaser**

Agency that issues the order and specification to the vendor.

3.1.42**radially split**

Casing joint split with the principal face perpendicular to the shaft centerline.

3.1.43**rated point**

Rated point is the intersection on the 100 % speed line corresponding to the highest flow of any specified operating point for centrifugal compressors; rated point will be determined by the vendor for axial compressors and centrifugal compressors with variable inlet guide vanes (VIGVs).

NOTE This is generally a derived point rather than an actual operating point (see Figure 1 for a graphical representation).

3.1.44**rated power**

Power required at the rated point.

3.1.45**rated speed****100 % speed**

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

3.1.46**relief valve set pressure**

Pressure at which a relief valve starts to lift.

3.1.47**separation gas**

Air or inert gas used to isolate an atmospheric bearing housing from the seal housing.

3.1.48**service factor (gear)**

Factor used in the gear rating calculations that is applied to the tooth pitting index and the bending stress number, depending upon the characteristics of the driver and the driven equipment, to account for differences in potential overload, shock load, and/or continuous oscillatory torque characteristics (see Part 3, Annex F).

3.1.49**settle-out pressure**

Highest pressure that the compressor experiences while at standstill and equilibrium conditions.

NOTE Determination of settle-out pressure requires consideration of the trapped volume of gas throughout the compressor and its associated piping system.

3.1.50**shaft end seal**

Process gas seal on the shaft that restricts leakage of process gas to the atmosphere.

3.1.51**shutdown**

Condition as determined by the equipment user that requires action to stop the equipment; may be automated or manual.

3.1.52**slow roll**

Speed less than 5 % of the normal operating speed or the minimum speed permitted by the speed control.

3.1.53**soleplate**

A plate with a machined top surface that is grouted to a concrete foundation to support machinery.

3.1.54**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.

3.1.55**special tool**

Tool that is not a commercially available catalogue item.

3.1.56**stability analysis**

Determination of the natural frequencies and the corresponding logarithmic decrements (log decs) of the damped rotor/support system using a complex eigenvalue analysis.

3.1.57**standard volume flow**

Flow rate expressed in volume flow units at one of the standard conditions below.

ISO standard (normal) conditions:

Flow: normal cubic meters per hour (Nm³/h)
normal cubic meters per minute (Nm³/min)
Pressure: 1.01325 bar absolute
Temperature: 0 °C
Humidity: 0 %
Compressibility factor: 0 °C and 1.01325 bar absolute

US customary standard conditions:

Flow: standard cubic feet per minute (scfm)
million standard cubic feet per day (mmscfd)
Pressure: 14.7 psia
Temperature: 60 °F
Humidity: 0 %
Compressibility factor: 60 °F and 14.7 psia

NOTE 1 There are no universally accepted conditions for normal or standard cubic meters; therefore, their reference pressure and temperature are always spelled out, i.e. m³/h 0 °C, 1.013 bara.

NOTE 2 Due to the lack of uniformity on standard conditions, mass flow is typically provided in conjunction with standard flow rates to avoid confusion.

3.1.58**structure stiffness and damping**

Bearing housing to ground equivalent complex stiffness.

3.1.59**subsoleplate**

Separate plate/structure between the soleplate or baseplate and foundation/grout to provide levelling capability.

3.1.60**support stiffness**

Equivalent oil film to ground complex stiffness characteristics; pivot stiffness is typically included in the oil film characteristics.

3.1.61**surge****surge limit**

Flow instability that occurs in a centrifugal or axial compressor at low volumetric flow.

3.1.62**synchronous tilt pad coefficients**

Complex frequency dependent coefficient with the frequency equal to the rotational speed of the shaft.

3.1.63**tooth pitting index**

Corresponds to a contact surface stress number; the tooth pitting index is used to determine a load rating at which progressive pitting of the teeth does not occur during their design life.

3.1.64**total indicator runout****total indicator reading****TIR****runout**

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, indicated runout implies an out-of-squareness equal to the reading.

3.1.65**trip**

Automated shutdown to ensure personnel safety (safety critical).

3.1.66**trip speed****<electric motor driver>**

Speed corresponding to the synchronous speed of the motor at maximum intended supply frequency at the motor terminals plus a 2 % margin.

3.1.67**trip speed****<turbine, engine, expander>**

Speed at which the independent emergency overspeed device operates to shut down the driver.

3.1.68**turndown**

The difference between a specified operating point's capacity and surge capacity, divided by that specified capacity expressed as a percentage; for VIGV and variable-speed machines, the surge capacity shall be defined at that specified head (see Figure 1).

3.1.69**ultimate load rating (hydrodynamic thrust bearing)**

Load that will produce the minimum acceptable oil film thickness without inducing failure during continuous service, or the load that will not exceed the creep initiation or yield strength of the babbitt or bearing material.

3.1.70**unit responsibility**

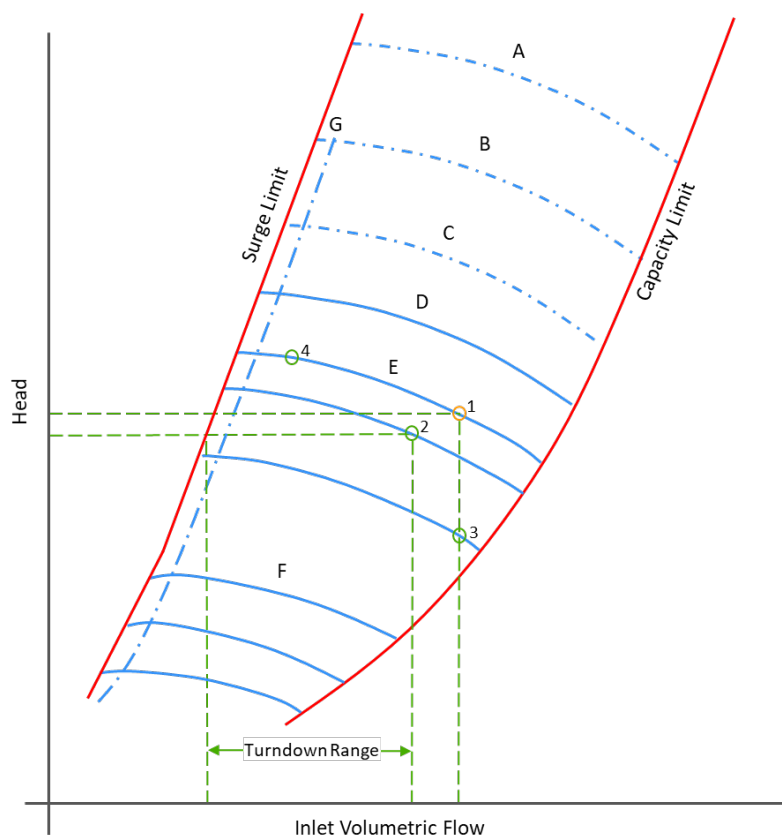
Obligation for coordinating the documentation, delivery, and technical aspects of the equipment and all auxiliary systems included in the scope of the order.

3.1.71**vendor**

Manufacturer or manufacturer's agent that supplies the equipment.

3.1.72**witnessed (tests and inspections)**

Inspection or test where the purchaser is notified of the schedule and a hold is placed until the purchaser or the purchaser's representative is in attendance; cf. "observed (tests and inspections)" (see 3.1.38).



Key

- A critical speed
- B trip speed steam turbine drive
- C trip speed gas turbine drive
- D maximum continuous speed (N_{mc}) variable-speed drive
- E rated (100 %) speed
- F minimum operating speed
- G anti-surge control line
- 1 compressor rated point
- 2 normal operating condition
- 3 specific operating condition
- 4 highest head operating condition

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 head; point 4 in the illustration.

NOTE 3 The compressor rated point (point 1) is the intersection on the 100 % speed line corresponding to the highest flow of any operating point (point 3 in the illustration). Point 1 is not a purchaser-specified point.

NOTE 4 The head-capacity curve at 100 % speed typically extends to at least 115 % of the capacity of the compressor rated point.

NOTE 5 Refer to the applicable standard for the compressor driver such as API 612 or API 616 for trip speed and minimum operating speed limits.

NOTE 6 Refer to 6.8.2.9 for allowable margins of critical speeds to operating speeds.

Figure 1—Centrifugal Compressor Performance Map—Illustration of Terms

3.2 Acronyms, Abbreviations, and Symbols

For the purposes of this document, the following acronyms, abbreviations, and symbols apply.

A_{c1}	amplitude at N_{c1} , μm (mil)
AF	amplification factor (refer to API 684, Third Edition, and Figure 3)
AF_1	amplification factor of the first critical speed defined as: $AF_1 = N_{c1} / (N_2 - N_1)$
A_{max}	maximum probe response amplitude (p - p) considering all vibration probes, over the range of N_{ma} to N_{mc} , for the unbalance amount/case being considered, μm (mil)
AFD	adjustable frequency drive
AMB	active magnetic bearing
A_{vl}	mechanical test vibration limit defined in 6.8.2.10, μm (mil)
CCW	counterclockwise (rotation)
CFD	computational fluid dynamics
CW	clockwise (rotation)
DN	nominal diameter
FCSR	first undamped critical speed on rigid supports, rpm
FLFPS	full-load/full-pressure/full-speed
MAWP	maximum allowable working pressure
N	operating speed, rpm
N_{c1}	rotor first critical speed, rpm
N_{cn}	rotor n^{th} critical speed, rpm
N_{ma}	minimum allowable speed, rpm
N_{mc}	maximum continuous speed, rpm
N_1	initial (lesser) speed at $0.707 \times$ peak amplitude, rpm
N_2	final (greater) speed at $0.707 \times$ peak amplitude, rpm
OEM	original equipment manufacturer
PMI	positive material identification
PTFE	polytetrafluoroethylene

Q_A	anticipated cross coupling for the rotor, kN/mm (klbf/in.); defined as:
	$Q_A = \sum_{i=1}^S q_{Ai}$
Q_0	minimum cross coupling needed to achieve a log decrement equal to zero for either minimum or maximum component clearance, kN/mm (klbf/in.)
q_a	cross coupling defined in Equation (10) or Equation (11) for each stage or impeller, kN/mm (klbf/in.)
R_{out}	combined mechanical and electrical runout, μm (mil)
S	number of stages or impellers
S_{a1}	actual separation for first critical speed, rpm
S_{an}	actual separation for n^{th} critical speed, rpm
SI	International System of Units
SM	separation margin (see Figure 3)
SM_1	separation margin for the first critical speed, % $= 100 \times S_{a1} / N_{ma}$
SM_a	forced response analysis actual separation margin, %
SM_{an}	separation margin for n^{th} critical speed, %
SM_r	the forced response analysis required separation margin, %
U_a	input unbalance for the rotordynamic response analysis, g-mm (oz-in.) $= 2 \times U_r$
U_r	maximum allowable residual unbalance, g-mm (oz-in.)
USC	United States customary
VDDR	vendor drawing and data requirements
VIGV	variable inlet guide vane
δ	logarithmic decrement
δ_A	minimum log decrement at the anticipated cross coupling for either minimum or maximum component clearance
δ_b	basic log decrement of the rotor, oil film seals if used and support system only
δ_f	log decrement of the complete rotor support system

4 Dimensions and Units

4.1 Drawings and maintenance dimensions shall be in the International System of Units (SI) or United States customary (USC) units.

4.2 Use of an SI datasheet indicates that SI units shall be used.

4.3 Use of an USC datasheet indicates that USC units shall be used.

5 Requirements

5.1 Statutory Requirements

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

5.2 Unit Responsibility

The vendor shall assume unit responsibility and shall ensure that all subvendors comply with the requirements of this standard and all reference documents for all equipment and all auxiliary systems included in the scope of the order.

6 Basic Design

6.1 General

6.1.1 [●] Only equipment that is field proven is acceptable. The purchaser shall specify the TRL level from API 691 for qualified equipment.

NOTE Purchasers can use their engineering judgment in determining what equipment is field proven.

6.1.1.1 [●] If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

6.1.1.2 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.

6.1.2 Performance

6.1.2.1 The equipment shall be capable of operating within the entire performance map at all specified operating conditions including transient conditions (e.g. momentary surge, settle-out, trip, and start-up).

6.1.2.2 [●] The purchaser shall specify all operating conditions for the equipment.

NOTE Special operating conditions such as start-up conditions, air dry-out, field commissioning test run, catalyst regeneration, etc. are specified in order to ensure that operation at off-design points can satisfactorily be met.

6.1.2.3 [●] Normal operating point and certified point shall be indicated.

6.1.2.4 The compressor shall be designed to deliver normal head at the normal inlet volumetric flow.

NOTE 1 The purchaser can furnish mass flow that will then be converted to volumetric flow by the vendor.

NOTE 2 See 8.3 of the applicable part for performance tolerances.

6.1.2.5 The section capacity limit shall be at least 115 % of the rated condition.

6.1.2.6 [●] The purchaser shall supply a gas analysis.

6.1.2.7 Gas properties used shall be agreed.

6.1.3 Unit Operation

6.1.3.1 [●] The purchaser shall specify the period of uninterrupted continuous operation.

6.1.3.2 Shutting down the equipment to perform vendor required maintenance or inspection during the specified uninterrupted operation period is not acceptable.

6.1.3.3 The vendor shall advise in the proposal any component designed for finite life or that would result in the need to shut down the equipment within the uninterrupted operational period.

6.1.3.4 Cooling water systems including those on process heat exchangers shall be in accordance with API 614.

6.1.3.5 [●] The purchaser shall specify any requirements for liquid injection.

6.1.3.6 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor at or before the coordination meeting.

6.1.3.7 [●] The applicable electrical codes and hazardous area classification shall be specified.

6.1.3.8 Local electrical codes that apply shall be provided by the purchaser.

6.1.3.9 Motors, generators, instrumentation, electrical components, and electrical installations shall be suitable for the area classification (class, group, and division or zone) as specified by the purchaser in 6.1.3.7.

6.1.3.10 Motors, generators, instrumentation, electrical components, and electrical installations shall meet the requirements of IEC 60079-10-1 or NFPA 70, Articles 500 through 505 as applicable, as well as local codes specified and furnished by the purchaser in 6.1.3.8.

6.1.3.11 All components, which are specific as to rotational direction, top or bottom casing half location, or axial location in the machine shall be designed to prevent incorrect installation.

6.1.3.12 [●] The equipment including all auxiliaries shall be suitable for operation under the environmental conditions specified by the purchaser.

NOTE These conditions normally include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, humidity, dusty or corrosive conditions, wind loads, and seismic zone.

6.1.3.13 Control of the sound pressure level of all equipment furnished shall be a joint effort of the purchaser and the vendor having unit responsibility.

6.1.3.13.1 [●] The equipment furnished by the vendor shall conform to the maximum allowable sound pressure level specified.

6.1.3.13.2 The vendor shall provide expected values for maximum sound pressure level per octave band for the equipment.

6.1.3.13.3 [●] If specified, sound power levels shall be supplied based on calculation methods.

NOTE ASME PTC 36 or ISO 3740, ISO 3744, and ISO 3746 can be consulted for guidance. ISO 10494 can be consulted for gas turbine drive packages.

6.1.3.14 [●] The purchaser shall specify oil for manufacturer's approval.

6.1.3.15 The preferred mineral oil shall correspond to ISO 3448 Grade 32.

NOTE Operating conditions can require higher viscosity oil.

6.1.4 Speed Requirements

6.1.4.1 The equipment's basis for maximum continuous speed (N_{mc}) shall not be less than 105 % of the rated speed for variable-speed machines [including adjustable frequency drives (AFDs)] and shall be equal to the synchronous speed for constant-speed motor drives.

6.1.4.2 The equipment's trip speed shall not be less than the limiting speed of the emergency overspeed device furnished with the driver.

6.1.4.2.1 Table 1 provides typical values for various drivers.

6.1.4.2.2 The purchaser and the vendor shall agree whether turbine overspeed based on loss of inertial load applies to the compressor.

6.1.4.3 Equipment shall be designed to operate simultaneously at the maximum allowable working pressure (MAWP) and trip speed without damage.

6.1.4.4 Equipment driven by induction motors shall be rated based on the actual motor speed for the rated load condition.

Table 1—Driver Trip Speeds

Driver Type	Trip Speed (Times Maximum Continuous Speed)
Steam turbine— Maximum speed rise ^a (% of N_{mc})	
> 7	1.15
≤ 7	1.10
Gas turbine	1.05
Variable-speed motor	1.02
Variable-speed gear	1.02
Constant-speed motor	1.02
Expander/Compressor	1.05
Expander/Generator	1.02
Reciprocating engine	1.10
^a See API 612 12.2.6 c).	

6.1.5 Additional Requirements

6.1.5.1 [●] If specified, the vendor shall review and comment on the purchaser's piping and foundation drawings.

NOTE Many factors (such as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site) can adversely affect site performance.

6.1.5.2 [●] If specified, the vendor's representative shall witness:

- a) a check of the piping alignment performed by unfastening the main process connections of the equipment;
- b) the initial shaft alignment check at ambient conditions (cold alignment);
- c) check shaft alignment at the operating temperature (hot alignment).

NOTE Refer to API 686 for basic guidelines for conducting piping alignments, shaft hot and cold alignments.

6.1.5.3 Spare and replacement parts for the machine and all furnished auxiliaries shall meet all the criteria of this standard.

6.1.5.4 [●] If specified, the machine or machines shall be suitable for field run on air.

6.1.5.4.1 Performance parameters, including any required precautions, shall be agreed.

6.2 Materials

6.2.1 General

6.2.1.1 Materials of construction shall be the vendor's standard for the specified operating and site environmental conditions, except as required or prohibited by the datasheets or by this standard.

NOTE Annex F lists material specifications that, when used with appropriate heat treatment or impact testing requirements, or both, are generally considered acceptable for major component parts.

6.2.1.2 The materials of construction of all major components shall be clearly stated in the vendor's proposal.

6.2.1.2.1 Materials shall be identified by reference to applicable international standards, including the material grade.

6.2.1.2.2 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.

NOTE Where international standards are not available, internationally recognized national or other standards can be used.

6.2.1.3 [●] The purchaser shall specify any agents (including trace quantities) present in the motive and process fluids and in the site environment, including constituents, that may cause corrosion or erosion.

NOTE 1 Typical agents of concern are hydrogen sulfide, amines, chlorides, cyanide, fluoride, naphthenic acid, mercury, monoethylene glycol, and polythionic acid.

NOTE 2 Selection of materials is a joint effort between the manufacturer and the vendor.

6.2.1.4 The vendor shall specify the tests and inspection procedures that are necessary to ensure that materials are satisfactory for the service.

6.2.1.5 Only fully killed, normalized steels made to fine grain practice are acceptable for pressure-containing machine components. Steel made to a coarse austenitic grain size (e.g. ASTM A515/A515M) shall not be used.

NOTE Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or lower temperatures.

6.2.1.6 If hydrogen sulfide or chlorides have been identified in the gas composition, materials exposed to that gas shall be selected in accordance with the requirements of NACE MR0103/ISO 17945 and where applicable, the referenced NACE SP0472.

NOTE 1 NACE MR0103/ISO 17945 requires restrictive hardness limits, more restrictive weld qualification procedures, and limits to the carbon equivalent levels of materials vs NACE MR0175/ISO 15156 (see 6.2.1.7).

NOTE 2 It is the responsibility of the purchaser to determine the amount of H₂S that can be present, considering normal operation, start-up, shutdown, idle standby, upsets, or unusual operating conditions such as catalyst regeneration.

6.2.1.7 [●] If specified, NACE MR0175/ISO 15156 shall be used in place of NACE MR0103/ISO 17945.

NOTE 1 NACE MR0175/ISO 15156 applies to material potentially subject to sulfide and chloride stress-corrosion cracking in oil and gas production facilities. These are upstream facilities; however, NACE MR0175/ISO 15156 earlier editions have been applied to compressors in downstream facilities since the Fifth Edition of API 617 (1988) prior to the introduction of NACE MR0103.

NOTE 2 A survey conducted of units built in accordance with NACE MR0175/ISO 15156 in previous API 617 editions has indicated no failures. The more restrictive requirements of NACE MR0103/ISO 17945 can therefore not be required to provide sufficient protection against corrosion.

6.2.1.8 For process gas conditions known to cause sulfide stress cracking as identified by NACE MR0103/ISO 17945 or NACE MR0175/ISO 15156, ferrous materials not covered by these standards shall have maximum yield strength of 620 N/mm² (90,000 psi) and a maximum Rockwell hardness of HRC 22.

NOTE Shafts in compressors of between-bearing design can exceed the stated limits of yield strength and hardness.

6.2.1.9 For wet H₂S services, components fabricated by welding shall meet the hardness requirements in both the weld and heat-affected zones per NACE SP0472.

6.2.1.10 Austenitic stainless steel parts that are fabricated, hard faced, overlaid, or repaired by welding shall be made of low-carbon or stabilized grades if exposed to conditions that can promote intergranular corrosion.

NOTE Overlays or hard surfaces that contain more than 0.10 % carbon can sensitize both low-carbon and stabilized grades of austenitic stainless steel, unless a buffer layer that is not sensitive to intergranular corrosion is applied.

6.2.1.11 In services where stress-corrosion cracking is a possibility, austenitic stainless steels shall be used only as allowed by NACE MR0103/ISO 17945 or NACE MR0175/ISO 15156.

6.2.1.12 Materials that have a yield strength in excess of 827 MPa (120,000 psi) or hardness in excess of Rockwell C 34 are prohibited for use in hydrogen gas service where the partial pressure of hydrogen exceeds 689 kPa (100 psi gauge) or the hydrogen concentration exceeds 90 molar percent at any pressure.

6.2.1.13 External parts that are subject to rotary or sliding motions (such as control linkage joints and adjusting mechanisms) shall be of corrosion-resistant materials suitable for the site environment.

6.2.1.14 Minor parts such as nuts, springs, washers, gaskets, and keys shall have corrosion resistance suitable for its environment.

6.2.1.15 Where mating parts such as studs and nuts of austenitic stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound suitable for the process temperature and compatible with the specified process fluid(s).

NOTE Anti-seizure compounds can alter friction factors and are considered in specifying the torque value in order to achieve the necessary preload.

6.2.1.16 O-ring and gasket materials shall be compatible with all specified conditions.

6.2.1.16.1 O-rings shall not be damaged during gas decompression rates less than that stated in 6.2.1.16.2.

6.2.1.16.2 The maximum gas decompression rate for the equipment shall be stated by the vendor.

NOTE Susceptibility to rapid gas decompression depends on the gas to which the O-ring is exposed, the compounding of the elastomer, temperature of exposure, the rate of decompression, and the number of cycles.

6.2.1.17 [●] If specified, copper or copper alloys shall not be used for parts of machines or auxiliaries in contact with process fluids. Nickel-copper alloy (UNS N04400), bearing babbitt, and precipitation hardened stainless steels are excluded from this requirement.

NOTE Certain corrosive fluids in contact with copper alloys have been known to form explosive compounds.

6.2.2 Coatings

6.2.2.1 [●] If specified, acceptable coatings shall be applied to the rotating and/or stationary components in the gas path.

6.2.2.2 If coatings are applied to rotating components, the final balance check shall be after coatings have been applied.

6.2.2.3 The sequence of procedures for balancing and coating of rotating components shall be agreed.

NOTE 1 It is advisable to prebalance in order to minimize balance corrections and subsequent repair to coating areas for the final acceptance balance. By minimizing the area repaired, a final check balance after repair could possibly not be required.

NOTE 2 API 687 has an informative tutorial appendix on coatings.

6.2.3 Positive Material Identification

6.2.3.1 [●] The purchaser shall specify the extent of positive material identification (PMI) testing for materials, welds, fabrications, and piping, including any sampling requirements.

6.2.3.2 If PMI is specified, techniques providing quantitative results shall be used.

6.2.3.3 PMI testing shall not be considered a substitute for mill test reports, material composite certificates, visual stamps, or markings.

6.2.3.4 PMI results shall be within governing standard limits with allowance for the accuracy of the PMI device as specified by the device manufacturer.

6.2.3.5 If PMI testing has been specified for a fabrication, the components comprising the fabrication, including welds, shall be checked after the fabrication is complete except as permitted in 6.2.3.5.2.

6.2.3.5.1 Testing may be performed prior to any heat treatment.

6.2.3.5.2 Unique (non-stock) components such as impellers, blading, and shafts may be tested after manufacturing and prior to rotor assembly.

6.2.3.5.3 The purchaser and the vendor shall agree upon what criteria to use for PMI testing.

6.2.4 Low Temperature Service

NOTE See definition 3.1.21.

6.2.4.1 Pressure casings and rotating elements shall be designed for the prevention of brittle fracture.

6.2.4.2 [●] The purchaser shall specify the minimum temperature and concurrent pressure including any transient operation.

6.2.4.3 Vendor shall establish the minimum design metal temperature, impact test, and other material requirements based on the information supplied by the purchaser.

NOTE Normally, this will be the lower of the minimum surrounding ambient temperature or minimum fluid pumping temperature; however, the purchaser can specify a minimum temperature based on operating properties of the pumped fluid, such as auto refrigeration at reduced pressures.

6.2.4.4 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 A good design practice will include the selection of fabrication methods, welding procedures, and materials for vendor-furnished steel pressure retaining parts that could be subject to temperatures below the ductile-brittle transition temperature. The published design-allowable stresses for materials in internationally recognized standards such as the ASME *BPVC* and ANSI standards are based on minimum tensile properties.

6.2.4.5 All carbon and low-alloy steel pressure-containing components for low temperature service including nozzles, flanges, and weldments shall be impact tested in accordance with the requirements of Section VIII, Division 1, Sections UCS-65 through 68 of the ASME *BPVC*, appropriate European standards, or other purchaser-approved code.

6.2.4.6 High-alloy steels shall be tested in accordance with Section VIII, Division I, Section UHA-51 of the ASME *BPVC*, European standards, or other purchaser-approved code.

NOTE In some situations, impact testing of a material will not be required depending on the minimum design metal temperature, thermal, mechanical and cyclic loading, and the governing thickness. Refer to requirements of Section VIII, Division I, Section UG-20F of the ASME *BPVC*, for example.

6.2.4.7 Governing thickness used to determine impact testing requirements shall be the greater of the following:

- a) the nominal thickness of the largest butt-welded joint;
- b) the largest nominal section for pressure containment, excluding:
 - 1) structural support sections such as feet or lugs,
 - 2) sections with increased thickness required for rigidity to mitigate shaft deflection, and
 - 3) structural sections required for attachment or inclusion of mechanical features such as jackets or seal chambers;
- c) one fourth of the nominal flange thickness, including parting flange thickness for axially split casings (in recognition that the predominant flange stress is not a membrane stress).

6.2.4.8 The results of the impact testing shall meet the minimum impact energy requirements of Section VIII, Division I, Section UG-84 of the ASME *BPVC*, appropriate European standards, or other purchaser-approved code.

6.2.4.9 [●] For materials and thicknesses not covered by Section VIII, Division I of the ASME *BPVC*, European standards, or other purchaser-approved code, the purchaser shall specify requirements.

6.2.5 Castings

6.2.5.1 Castings shall comply with material specification requirements regarding porosity, hot tears, shrink holes, blow holes, cracks, scale, blisters, and similar defects.

6.2.5.2 Surfaces of castings shall be cleaned by sandblasting, shot blasting, chemical cleaning, or other standard methods.

6.2.5.3 Mold-parting fins and the remains of gates and risers shall be chipped, filed, or ground flush.

6.2.5.4 Where chaplets are necessary, they shall be clean and corrosion free (plating is permitted) and of a composition compatible with the casting.

6.2.5.5 Pressure-containing ferrous castings shall only be repaired as specified in 6.2.5.5.1 through 6.2.5.5.6.

6.2.5.5.1 Weldable grades of steel castings shall be repaired, using a qualified welding procedure based on the requirements of the appropriate pressure vessel code such as Section VIII, Division 1 and Section IX of the ASME *BPVC* or appropriate European standards.

6.2.5.5.2 After major weld repairs and before hydro test, the complete repaired casting shall be given a post-weld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal and dimensional stability during subsequent machining operations.

6.2.5.5.3 Post-weld heat treatment on individual minor weld repairs after final machining may be performed by local heat treatments.

6.2.5.5.4 Ductile iron may be repaired by plugging within the limits specified in ASTM A395/A395M. The holes drilled for plugs shall be carefully examined, using liquid penetrant, to ensure that all defective material has been removed.

6.2.5.5.5 All repairs that are not covered by ASTM or appropriate European specifications shall be subject to the purchaser's approval.

6.2.5.5.6 If either NACE MR0103/ISO 17945 (per 6.2.1.6) or NACE MR0175/ISO 15156 (per 6.2.1.7) has been specified, the completed weld repairs shall meet the requirements of the applicable standard.

6.2.5.6 Cored voids, which become fully enclosed by methods such as plugging, welding, or assembly, are prohibited.

6.2.5.7 All ductile (nodular) iron castings shall be produced in accordance with ASTM A395/A395M or other internationally recognized standard as approved.

6.2.5.8 Brinell hardness tests shall be made on the actual casting at feasible critical sections such as section changes, flanges, and other accessible locations.

6.2.5.8.1 Sufficient surface material shall be removed before hardness tests are made to eliminate any skin effect.

6.2.5.8.2 Tests shall also be made at the extremities of the casting at locations that represent the sections poured first and last.

6.2.5.8.3 These shall be made in addition to hardness test on keel or Y blocks in accordance with 6.2.5.9.1.

6.2.5.9 The production of the ductile (nodular) iron castings shall conform to the conditions specified in 6.2.5.9.1 through 6.2.5.9.4.

6.2.5.9.1 The keel or Y block cast at the end of the pour shall have a thickness not less than the thickness of critical sections of the main casting.

NOTE Critical sections are typically heavy section changes, high-stress points such as flanges. Normally, bosses and similar sections are not considered critical sections of a casting. If critical sections of a casting have different thicknesses, average size keel or Y blocks can be selected in accordance with ASTM A395/A395M.

6.2.5.9.1.1 This test block shall be tested for tensile strength and hardness and shall be microscopically examined.

6.2.5.9.1.2 Classification of graphite nodules under microscopic examination shall be in accordance with ASTM A247.

6.2.5.9.1.3 There shall be no intercellular flake graphite.

6.2.5.9.2 A minimum of one set (three samples) of Charpy V-notch impact specimens at one-third the thickness of the test block shall be made from the material adjacent to the tensile specimen on each keel or Y block.

6.2.5.9.2.1 All three specimens shall have an impact value not less than 12 J (9 ft-lbf).

6.2.5.9.2.2 The mean of the three specimens shall not be less than 14 J (10 ft-lbf) at room temperature.

6.2.5.9.3 If purchaser approved, nonpressurized ductile (nodular) iron castings may be produced in accordance with ASTM A536 or other equivalent internationally recognized standard.

6.2.5.9.4 An “as-cast” sample from each ladle shall be chemically analyzed.

6.2.6 Forgings

6.2.6.1 The forging material should be selected from those listed in Annex F as applicable.

6.2.6.2 Pressure-containing ferrous forgings shall not be repaired except as specified in 6.2.6.2.1 through 6.2.6.2.4.

6.2.6.2.1 Weldable grades of steel forgings shall be repaired by welding using a qualified welding procedure based on the requirements of the appropriate pressure vessel code such as Section VIII, Division I and Section IX of the ASME *BPVC* or other purchaser-approved code.

6.2.6.2.2 After major weld repairs, and before hydro test, the complete forging shall be given a post-weld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal.

6.2.6.2.3 Post-weld heat treatment on individual minor weld repairs after final machining may be performed by local heat treatments.

6.2.6.2.4 All repairs that are not covered by ASTM or appropriate European specifications shall be subject to the purchaser's approval.

6.2.7 Welding

6.2.7.1 Nonpressurized component welding, such as welding on baseplates, nonpressure ducting, lagging, and control panels, shall be performed and inspected by personnel and procedures qualified in accordance with AWS D1.1/D1.1M or ASME *BPVC* Section IX or ISO 9606 Parts 1–6 or other purchaser-approved standard.

6.2.7.2 Welding of piping, pressure-containing parts and rotating parts, weld repairs, and any dissimilar-metal welds shall be performed and inspected by personnel and procedures qualified in accordance with Section VIII, Division I and Section IX of the ASME *BPVC* or purchaser-approved standard, such as ISO 9606 and ISO 15607 and ISO 15614-1 for welder qualifications, or procedures.

6.3 Casings

6.3.1 Pressure-containing Casings

6.3.1.1 The pressure casing may be designed with the aid of numerical methods and shall be designed in accordance with 6.3.1.1.1 through 6.3.1.1.4.

6.3.1.1.1 The allowable tensile stress used in the design of the pressure casing for any material shall be less than 0.25 times the minimum ultimate tensile strength and less than 0.67 times the minimum yield strength at the maximum allowable temperature for that material.

NOTE This is intended to apply to the average hoop stress of the casing.

6.3.1.1.2 For cast materials, the allowable tensile stress shall be multiplied by the appropriate casting factor as shown in Table 2.

Table 2—Casting Factors

Type of Nondestructive Examination	Casting Factor
Visual, magnetic particle and/or liquid penetrant	0.8
Spot radiography	0.9
Ultrasonic	0.9
Full radiography	1.0

NOTE In general, deflection is the determining consideration in the design of casings. Ultimate tensile or yield strength is seldom the limiting factor.

6.3.1.1.3 A corrosion allowance of at least 3 mm (0.125 in.) shall be added to the casing thickness used in 6.3.1.1.1. This corrosion allowance applies to all auxiliary connections exposed to the same fluid as the pressure-containing casing.

6.3.1.1.4 The vendor may propose alternative corrosion allowances for consideration if materials of construction with superior corrosion resistance are employed without affecting functionality, safety, and reliability.

6.3.1.2 The casing joint bolting shall be in accordance with 6.3.1.2.1 through 6.3.1.2.4.

6.3.1.2.1 For casing joint bolting, the allowable tensile stress (as determined in 6.3.1.1.1) shall be used to determine the total bolting area based on hydrostatic load and gasket preload as applicable.

6.3.1.2.2 The preload stress shall not exceed 75 % of the bolting material minimum yield strength.

6.3.1.2.3 During hydro test, the bolting stress shall not exceed 90 % of the bolting material minimum yield strength.

6.3.1.2.4 Torque values shall not be used to determine bolt elongation.

NOTE Thread stress in the nut or case can be the limiting factor in the strength of the bolting.

6.3.1.3 For flammable or toxic gases, casings shall be steel or purchaser-approved alloy.

6.3.1.4 For air or nonflammable gases, casings may be steel, ductile iron, or cast iron materials depending on the following ratings.

a) Ductile iron casings can be used up to the flange rating in accordance with ASME B16.42, Class 300.

b) Cast iron casings can be used up to the flange rating in accordance with ASME B16.1, Class 250.

6.3.1.5 Jackscrews, guide rods, cylindrical casing-alignment dowels, and/or special tools shall be provided to facilitate disassembly and reassembly.

NOTE "Special tools" could be extraction rigs for radially split equipment, or rollers on the bundles of these machines.

6.3.1.5.1 Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly.

6.3.1.5.2 Lifting lugs or eyebolts/safety hoist rings shall be provided for lifting only the top half of the casing of axially split casings.

6.3.1.5.3 If jackscrews are used as a means of parting contacting faces, the load bearing face shall be relieved (counter bored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

6.3.1.6 The use of threaded holes in pressure parts of cast iron casings is allowed and shall be per the following.

6.3.1.6.1 To prevent leakage in pressure sections of casings, metal equal in thickness to at least 12 mm ($\frac{1}{2}$ in.), in addition to the allowance for corrosion, shall be left around and below the bottom of drilled and threaded holes.

6.3.1.6.2 The depth of the threaded holes shall be at least 1.5 times the diameter of the threaded insert (stud, plug, etc.).

6.3.1.7 The sealing of stud clearance holes to prevent leakage is not permitted.

6.3.1.8 Bolting shall be furnished as specified in 6.3.1.8.1 through 6.3.1.8.9.

6.3.1.8.1 The details of threading shall conform to ASME B1.1, ASME B1.13M, or ISO 261.

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

NOTE 2 Glossary of terms for screw threads can be found in ASME B18.12.

6.3.1.8.2 Studs shall be supplied on the main joint of axially split casings and bolted end covers of radially split casings.

6.3.1.8.3 Studs shall be used instead of cap screws, on all other external joints, except where hexagonal head cap screws are essential for assembly purposes and have been approved by the purchaser.

6.3.1.8.4 Clearance shall be provided at bolting locations to permit use of tools to install and remove bolting.

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

6.3.1.8.6 Vendor shall advise whether bolting that needs to be disassembled for maintenance is metric or USC thread series.

6.3.1.8.7 The minimum quality bolting material for pressure joints shall be carbon steel (such as ASTM A307, Grade B) for cast iron casings and high-temperature alloy steel (such as ASTM A193, Grade B7) for steel casings.

6.3.1.8.7.1 Carbon steel nuts (such as ASTM A194, Grade 2H) shall be used.

6.3.1.8.7.2 Where space is limited, case-hardened carbon steel nuts (such as ASTM A563, Grade A) shall be used.

NOTE For low temperature requirements, see 6.2.4.

6.3.1.8.8 Fasteners (excluding washers and headless set-screws) shall have the material grade and manufacturer's identification symbols applied to one end of studs $\frac{3}{8}$ in. (10 mm) in diameter and larger and to the heads of bolts $\frac{1}{4}$ in. (6 mm) in diameter and larger. If the available area is inadequate, the grade symbol may be marked on one end and the manufacturer's identification symbol marked on the other end.

6.3.1.8.9 Studs shall be marked on the exposed end.

6.3.1.9 Materials, casting factors, and the quality of any welding shall be equal to those required by Section VIII, Division 1 of the ASME *BPVC* or other purchaser-approved standard.

6.3.1.10 The manufacturer's data report forms, as specified in the ASME *BPVC*, are not required unless required by regulation.

6.3.1.11 To prevent the buildup of potential voltages, residual magnetism of the free air gauss level in the casings and all stationary components, except bearing and seal assemblies, shall not exceed ± 4 gauss when measured with a calibrated Hall effect probe on the surface of the part.

6.3.2 Casing Repairs and Inspections

6.3.2.1 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 the applicable qualified procedures (see 6.3.1.9).

6.3.2.2 Weld repairs shall be nondestructively tested by the same method used to detect the original flaw.

6.3.2.3 The minimum level of inspection after the repair shall be by the magnetic particle method in accordance with 8.2.5 for magnetic material and by the liquid penetrant method in accordance with 8.2.6 for nonmagnetic material.

6.3.2.4 The purchaser shall be notified before making a major repair to a pressure-containing part.

6.3.2.4.1 Major repair, for the purpose of purchaser notification only, is any defect that equals or exceeds any of the three criteria defined below:

- a) the depth of the cavity prepared for repair welding exceeds 50 % of the component wall thickness;
- b) the length of the cavity prepared for repair welding is longer than 150 mm (6 in.) in any direction;
- c) the total area of all repairs to the part under repair exceeds 10 % of the surface area of the part.

6.3.2.4.2 Procedures for major repairs shall be subject to review by the purchaser prior to any repair.

6.3.2.5 Actual repairs to pressure-containing parts shall be made as required by the following documents.

- a) The repair of plates, prior to fabrication, shall be performed in accordance with the material standard to which the plate was purchased.
- b) The repair of castings or forgings shall be performed prior to final machining in accordance with the material standard to which the casting or forging was purchased.
- c) The repair of a fabricated casing or the defect in either a weld or the base metal of a cast or fabricated casing, uncovered during preliminary or final machining, shall be performed in accordance with Section VIII of the ASME *BPVC* or other purchaser-approved standard. A weld map of all repaired areas shall be provided by the vendor.
- d) If NACE MR0103/ISO 17945 (per 6.2.1.6) or NACE MR0175/ISO 15156 (per 6.2.1.7) is applicable, the material and welding requirements of the specified NACE document shall apply to the repairs.

6.3.2.6 Pressure-containing casings made of wrought materials or combinations of wrought and cast materials shall conform to the conditions specified in 6.3.2.6.1 through 6.3.2.6.7.

6.3.2.6.1 Before welding, plate edges shall be examined by the magnetic particle method to confirm the absence of laminations.

6.3.2.6.2 Accessible surfaces of welds shall be inspected by magnetic particle or liquid penetrant examination after back chipping or gouging and again after post-weld heat treatment.

6.3.2.6.3 [●] If specified, the quality control of welds that will be inaccessible on completion of the fabrication shall be agreed on by the purchaser and vendor prior to fabrication.

6.3.2.6.4 Pressure-containing welds, including welds of the case to axial or radial joint flanges, shall be full penetration (complete joint) welds.

NOTE For auxiliary connections, refer to 6.4.3.

6.3.2.6.5 Casings and fabrications shall be stress relieved by heat treating regardless of thickness.

6.3.2.6.6 All pressure-containing welds shall be examined as required by Section VIII, Division 1 of the ASME *BPVC*.

6.3.2.6.7 Requirements for additional examination shall be agreed.

NOTE See 6.3.3 for required procedures and acceptance criteria.

6.3.3 Material Inspection of Pressure-containing Parts

NOTE Refer to 8.2.2 for inspection of non-pressure-containing parts.

6.3.3.1 Regardless of the generalized limits presented in this section, it shall be the vendor's responsibility to review the design limits of all materials and welds in the event that more stringent requirements are specified.

6.3.3.2 Defects that exceed the limits imposed in 6.3.3.3 and 6.3.3.4 shall be removed to meet the quality standards cited, as determined by additional magnetic particle or liquid penetrant inspection as applicable prior to repair welding.

6.3.3.3 [●] If radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds or materials is required or specified, the procedures and acceptance criteria in Table 3 shall apply, except as noted in 8.2.2.

Table 3—ASME Materials Inspection Standards

Type of Inspection	Methods	Acceptance Criteria	
		For Fabrications	For Castings
Radiography	Section V, Articles 2 and 22 of the ASME BPVC	Section VIII, Division 1, UW-51 (for 100 % radiography) and UW-52 (for spot radiography) of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC
Ultrasonic inspection	Section V, Articles 4, 5, and 23 of the ASME BPVC	Section VIII, Division 1, UW-53 and Appendix 12 of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC
Magnetic particle inspection	Section V, Articles 7 and 25 of the ASME BPVC	Section VIII, Division 1, Appendix 6 of the ASME BPVC	See acceptance criteria in 6.3.3.4 and Table 4
Liquid penetrant inspection	Section V, Articles 6 and 24 of the ASME BPVC	Section VIII, Division 1, Appendix 8 of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC

6.3.3.3.1 Spot radiography shall consist of a minimum of one 150 mm (6 in.) spot radiograph for each 7.5 m (25 ft) of weld on each casing. As a minimum, one spot radiograph is required for each welding procedure and welder used for pressure-containing welds.

6.3.3.3.2 For magnetic particle inspections, linear indications shall be considered relevant only if the major dimension exceeds 1.5 mm ($1/16$ in.).

6.3.3.3.3 Individual indications that are separated by less than 1.5 mm ($1/16$ in.) shall be considered continuous.

6.3.3.4 Cast steel casing parts shall be examined by magnetic particle methods.

6.3.3.4.1 Acceptability of defects shall be based on a comparison with the photographs in ASTM E125.

6.3.3.4.2 For each type of defect, the degree of severity shall not exceed the limits specified in Table 4.

Table 4—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

6.4 Pressure Connections

6.4.1 General

6.4.1.1 All connections shall be flanged or machined and studded, except where threaded connections are permitted by 6.3.1.6 or 6.4.3.

6.4.1.2 All process gas connections to the casing shall be suitable for the MAWP.

6.4.1.3 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.

6.4.1.4 All openings or nozzles for piping connections on pressure casings shall be in accordance with ASME B1.20.1 (ISO 6708) and at least NPS $\frac{1}{2}$ (DN 15) for equipment with a main process connection NPS 2 (DN 50) and smaller, or NPS $\frac{3}{4}$ (DN 20) for equipment with all main process connections larger than NPS 2 (DN 50).

6.4.1.5 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.

NOTE NPS designates pipe per ASME B1.20.1.

6.4.1.6 Connections welded to the casing shall meet the material requirements of the casing, including impact values, rather than the requirements of the connected piping.

6.4.1.7 All welding of connections shall be completed before the casing is hydrostatically tested (see 8.3.2).

6.4.1.8 Casing drain connections shall be per 6.4.1.8.1 through 6.4.1.8.5.

6.4.1.8.1 For axially split pressure casings, the vendor shall provide connections for complete drainage of all gas passages.

6.4.1.8.2 For radially split pressure casings, the drains shall be located at the lowest point of each inlet section, the lowest point of the section between the inner and outer casings, and the lowest point of each discharge section.

6.4.1.8.3 Number and size of drain connections shall be provided.

6.4.1.8.4 [●] If specified, individual stage drains for radially split pressure casings, including a drain for the balance piston cavity, shall be provided.

NOTE If the vendor can show that their standard design provides complete drainage of all gas passages, individual stage drains would not be required.

6.4.1.8.5 [●] If specified, if casing drains are provided, the individual drains shall be manifolded into a common drain connection.

6.4.2 Main Process Connections

6.4.2.1 [●] Main process connections shall be flanged or machined and studded. Orientation shall be as specified.

NOTE Main process connections include all process inlets and outlets including those for side loads and intermediate cooling.

6.4.2.2 The CLASS system applies, and all flanges shall conform to ASME B16.1, B16.5, B16.42, or B16.47 Series B, as applicable.

6.4.2.3 [●] If the PN system is specified, all flanges shall conform to EN 1092-1 or EN 1092-2 as applicable, except as specified in 6.4.2.4 through 6.4.2.18.

NOTE EN 1092 flanges are PN 6, 10, 16, 25, 40, 63, 100, 160, 250, 320, and 400.

6.4.2.4 Steel flanges shall conform to the dimensional requirements of ASME B16.5 or B16.47 Series B or EN 1092-1, as applicable.

6.4.2.5 [●] If specified, ASME B16.47 Series A steel flanges shall be provided.

NOTE ASME B16.47 covers flange diameters from NPS 26 through NPS 60.

6.4.2.6 Machined and studded connections and flanges not in accordance with ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 or EN 1092-1, EN 1092-2 require purchaser's approval.

6.4.2.7 The vendor shall supply mating flanges, studs, and nuts for the nonstandard connections in 6.4.2.6.

6.4.2.8 The vendor shall state the particular flange standard and provide details of the flanges that are being provided.

6.4.2.9 Cast, ductile, and malleable iron flanges shall be flat faced and conform to the dimensional requirements of ASME B16.1 or ASME B16.42 or EN 1092-2, as applicable.

- a) Class 125 flanges shall have a minimum thickness equal to Class 250 for sizes NPS 8 and smaller.
- b) PN 20 (Class 125) flanges shall have a minimum thickness equal to PN 50 (Class 250) for sizes DN 200 (NPS 8) and smaller.
- c) PN16 flanges shall have a minimum thickness equal to PN25 for sizes DN 200 and smaller.

6.4.2.10 Flat face flanges with full raised face thickness are acceptable on casings of all materials.

6.4.2.11 Flanges in all materials that are thicker or have a larger outside diameter than required by ASME (EN) are acceptable.

6.4.2.11.1 Nonstandard (oversized) flanges shall be completely dimensioned on the arrangement drawing.

6.4.2.11.2 If oversized flanges require studs or bolts of nonstandard length, this requirement shall be identified on the arrangement drawing.

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

6.4.2.13 The concentricity of the bolt circle and the bore of all casing 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.

6.4.2.14 For steel flanges imperfections in the flange gasket surface shall not exceed that permitted in ASME B16.5 or ASME B16.47, as applicable.

6.4.2.15 [●] Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 or EN 1092-1, EN 1092-2, as specified.

6.4.2.16 Studs and nuts shall be provided installed, and the first 1.5 threads at both ends of each stud shall be removed.

NOTE Threads are removed at the end of the stud to allow the stud to bottom without damaging the end threads in the hole. Threads are removed from both ends of the stud to allow either end of the stud to be inserted into the threaded hole.

6.4.2.17 To minimize nozzle loading, and facilitate installation of piping, machine flanges shall be parallel to the plane of the flange as shown on the general arrangement drawing to within 0.5°.

6.4.2.18 Studs or bolt holes shall straddle centerlines parallel to the main axes of the flange.

6.4.3 Auxiliary Connections

6.4.3.1 Auxiliary connections may include but are not limited to those for vents, liquid injection, drains (see 6.4.1.8), water cooling, lube and seal oil, flushing, seal and buffer gas, and balance piston cavity.

6.4.3.2 Auxiliary connections shall conform to ASME B16.1, ASME B16.5, or ASME B16.42 (EN 1092-1), or SAE J518, as applicable.

6.4.3.3 Auxiliary connections other than lube oil, seal oil, or dry gas seal connections shall be socket-welded and flanged or machined and studded.

6.4.3.4 Auxiliary connections for lube oil, seal oil, or dry gas seal operation shall use weld-neck flanges or be machined and studded.

6.4.3.5 Socket-welds shall not be used for auxiliary connections for lube oil, seal oil, or dry gas seal operation.

6.4.3.6 Pipe nipples screwed or welded to the casing, preferably not more than 150 mm (6 in.) long, shall be a minimum of Schedule 160 seamless for sizes DN 40 (NPS 1 1/2) and smaller and a minimum of Schedule 80 for DN 50 (NPS 2).

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

6.4.4 Requirements for Threaded Connections

6.4.4.1 [●] Threaded openings for tapered pipe threads shall conform to ASME B1.20.1 or ISO 7-1 or DIN ISO 228-1, as specified.

6.4.4.1.1 If ISO 7-1 has been specified, tapered or straight internal threads shall also be specified.

6.4.4.1.2 Bosses for pipe threads shall conform to ASME B16.5.

6.4.4.1.3 Threaded connections shall be brought to a remote flange that can be disassembled for maintenance so as to require the least amount of assembly/disassembly of the threaded connection.

NOTE ISO 7-1 and ASME B1.20.1 are not equivalent for tapered threads; however, they are sufficiently close that stripped threads and/or sealing problems can result in installing incorrect parts (including later in the field). Caution is therefore taken in specifying a standard that agrees with the standard used within the plant.

6.4.4.2 [●] Pipe threads shall be taper thread conforming to ASME B1.20.1 or ISO 7-1, as specified.

6.4.4.3 Threaded connections shall not be seal welded.

6.4.4.4 For threaded connections that are connected to pipe, a pipe nipple, preferably not more than 150 mm (6 in.) long, schedule 160 seamless minimum shall be installed in the threaded opening.

6.4.4.4.1 Each pipe nipple shall be terminated with a welding-neck or socket-weld flange.

6.4.4.4.2 The nipple and flange materials shall meet the requirements of 6.4.1.5.

6.4.4.5 Threaded openings not required to be connected to piping shall be plugged with solid, round-head steel plugs in accordance with ASME B16.11.

6.4.4.5.1 As a minimum, these plugs shall meet the material requirements of the pressure casing.

6.4.4.5.2 Plugs that may later require removal shall be of a corrosion-resistant material.

6.4.4.5.3 Plastic plugs are not permitted.

6.4.4.6 A process-compatible thread sealant/lubricant rated for the maximum allowable temperature shall be used on all threaded connections.

6.4.4.7 Thread tape shall not be used.

6.5 Stationary Components

6.5.1 Casing Support Structures

Machines requiring alignment shall meet the following criteria.

- a) Mounting surfaces shall be machined to a finish of 6 μm (250 $\mu\text{in.}$) arithmetic average roughness (Ra) or better.
- b) Each mounting surface shall be machined within a flatness of 40 μm per linear meter (500 $\mu\text{in.}$ per linear ft) of mounting surface.
- c) Different mounting planes shall be parallel to each other within 50 μm (0.002 in.) over the distance between mounting surfaces.
- d) The upper machined or spot-faced surface shall be directionally parallel to the mounting surface.
- e) Hold-down bolt holes shall be drilled directionally perpendicular to the mounting surfaces.
- f) The mounting hole in the equipment feet shall be at least 12 mm ($1/2$ in.) larger in diameter than the hold-down bolt.
- g) Mounting holes in equipment feet shall be machined or spot faced to a diameter suitable for a washer positioned eccentrically around the bolt to allow for equipment alignment. Holes shall not be slotted.
- h) The equipment feet shall be provided with vertical jack-screws and shall be drilled with pilot holes that are accessible for use in final doweling.

NOTE 1 Mounting requirements for equipment mounting feet are covered in Parts 2, 3, and 4.

NOTE 2 Expander-compressors as covered in Part 4 do not require alignment since driver and compressor are on the same shaft.

NOTE 3 Refer to 7.2.1.2.1 for horizontal jackscrew requirements.

6.5.2 External Forces and Moments

External forces and moment information can be found in the applicable parts of this standard.

6.5.3 Guide Vanes, Stators, and Stationary Internals

Refer to subsequent parts of this standard for specific requirements.

6.6 Rotating Elements

6.6.1 General

6.6.1.1 Shaft ends for couplings shall conform to the requirements of API 671.

6.6.1.2 All shaft sensing areas (both radial vibration and axial position) shall be free from stencil or scribe marks or any other surface discontinuity for a minimum of one probe tip diameter on each side of the probe.

6.6.1.3 The final surface finish of sensing areas observed by radial and axial proximity probes shall be a maximum of 0.8 μm (32 $\mu\text{in.}$) rms.

6.6.1.3.1 These areas shall be demagnetized (see API 670) or otherwise treated so that the required combined total electrical and mechanical runout can be met.

6.6.1.3.2 For areas observed by radial vibration probes, the combined total electrical and mechanical runout shall not exceed the value from Equation (1) or 6.35 μm (0.25 mil), whichever is greater.

In SI units:

$$R_{\text{out}} = \frac{25.4}{4} \sqrt{\frac{12,000}{N_{\text{mc}}}} \quad (1a)$$

In USC units:

$$R_{\text{out}} = \frac{1}{4} \sqrt{\frac{12,000}{N_{\text{mc}}}} \quad (1b)$$

where

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

R_{out} is the allowable runout ($\mu\text{m}/\text{mils}$).

For areas observed by axial proximity probes, the combined total electrical and mechanical runout shall not exceed 0.5 mil (12.7 μm).

NOTE 1 If all reasonable efforts fail to achieve the limits noted in 6.6.1.3.2, the vendor and the purchaser can agree on alternate acceptance criteria.

NOTE 2 Diamond burnishing of probe areas has been shown to be effective in reducing electrical runout.

NOTE 3 The use of magnetic holders or chucks in the probe areas during manufacture or handling will cause electrical runout.

NOTE 4 Shaft materials such as 17-4 PH frequently exhibit excessive electrical runout. Some vendors have successfully reduced electrical runout to acceptable levels with treatments such as the application of 1 mm (0.04 in.) radial thickness of metalized aluminum.

6.6.1.4 To prevent the buildup of potential voltages in the shaft, residual magnetism of the rotating element free air gauss level shall not exceed ± 2 gauss when measured with a calibrated Hall effect probe on the surface of the part.

NOTE The free air gauss level is measured while suspending the rotor from nonconductive straps with no influence from stray magnetic fields.

6.6.1.5 Integral thrust collars are preferred.

6.6.1.5.1 Removable thrust collars shall be furnished only if they are required for removal of shaft end seals.

6.6.1.5.2 If removable collars are furnished (for assembly and maintenance purposes), they shall be locked to the shaft to prevent movement axially and tangentially and mounted to the shaft with an interference fit to minimize fretting.

6.6.1.5.3 If integral collars larger than 125 mm (5 in.) diameter are furnished, they shall be provided with at least 3 mm (0.125 in.) of additional thickness to enable refinishing if the collar is damaged.

6.6.1.6 Both faces of thrust collars shall have a surface finish of not more than 0.4 μm (16 $\mu\text{in.}$) rms, and the axial total indicator runout of either face shall not exceed 12.7 μm (0.5 mils).

6.6.1.7 Stationary labyrinth seals shall have replaceable shaft sleeves or be designed so that major rotating parts need not be replaced.

6.6.1.8 Labyrinth-type seals with the teeth on the rotating element shall have a replaceable nonrotating element of an abradable material.

6.6.1.9 Metal plating or metal spray (HVOF) is not permitted on the coupling fits.

6.6.1.10 Any axial clearance requirement between shaft sleeves to allow for expansion shall be clearly indicated on the rotor drawing.

6.6.2 Impellers

6.6.2.1 Impellers shall be of welded, brazed, milled, electro-eroded, or cast construction.

6.6.2.1.1 Other manufacturing methods may be permitted if approved by the purchaser.

6.6.2.1.2 Each impeller shall be marked with a unique identification number.

6.6.2.2 Impellers may consist of forged and cast components.

6.6.2.2.1 Other component manufacturing methods may be permitted if approved by the purchaser.

6.6.2.2.2 Welds in the gas passageway shall be smooth and free of weld spatter.

6.6.2.2.3 Impellers shall be heat treated and stress relieved after welding.

6.6.2.2.4 Impeller blade entrance and exit tips shall not have knife edges.

6.6.2.3 All accessible weld surfaces on welded impellers and finish machined surfaces of electro-eroded impellers shall be inspected by visual and magnetic particle or liquid penetrant examination.

6.6.2.3.1 Impeller fabrications resulting in joints that are not visually accessible, such as brazed joints, shall be subjected to ultrasonic examination to verify joint integrity.

6.6.2.3.2 Refer to 8.2.2 for material inspection methods and 8.2.2.1.2 for acceptance criteria.

6.6.2.4 Cast impellers hubs and covers shall be inspected by radiographic or ultrasonic means prior to finish machining.

6.6.2.4.1 Details of inspection techniques and acceptance criteria shall be agreed.

6.6.2.4.2 Refer to 8.2.2 for material inspection methods and 8.2.2.1.2 for acceptance criteria.

6.6.2.5 Upgrade or repair welding of impellers after overspeed testing may be permitted only with the purchaser's approval.

6.6.2.6 Welding as a means of balancing an impeller is not permitted.

6.6.2.7 After the overspeed test described in 8.3.3, each impeller shall be fully examined by means of magnetic particle or liquid penetrant methods.

NOTE Refer to 8.2.2 for material inspection methods and 8.2.2.1.2 for acceptance criteria.

6.6.2.8 Plating or coating of the impeller bore is not permitted without purchaser's approval.

6.7 Bearings and Bearing Housings

6.7.1 General

6.7.1.1 Radial and thrust bearings shall be as specified in the subsequent parts of this standard.

6.7.1.2 Hydrodynamic bearings shall be inspected to ensure babbitt to backing material contact of not less than 99 %.

6.7.1.3 The bond contact check shall be performed by ultrasonic testing flaw detection methods in the main part or body of the part.

6.7.1.4 A PT (dye penetrant) inspection shall be required to ensure that no side separation exists.

6.7.1.5 For machines using active magnetic bearings (AMBs), refer to Annex D for requirements.

6.7.2 Hydrodynamic Radial Bearings

Hydrodynamic radial bearings shall be in accordance with the applicable parts of this standard.

6.7.3 Hydrodynamic Thrust Bearings

6.7.3.1 For gear couplings, the external thrust force shall be calculated from Equation (2).

In SI units:

$$F = \frac{(0.25)(9550)P_r}{N_r D} \quad (2a)$$

In USC units:

$$F = \frac{(0.25)(63,300)P_r}{N_r D} \quad (2b)$$

where

F is the external thrust force, in kilonewtons (lb);

P_r is the rated power, in kW (hp);

N_r is the rated speed, in rpm;

D is the shaft diameter at the coupling, in mm (in.).

6.7.3.2 Thrust forces for flexible-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

6.7.3.3 If the thrust forces from two or more rotors are carried by one thrust bearing (such as from a gear box or motor), the resultant of the forces shall be used, provided the directions of the forces make them numerically additive; otherwise, the largest of the forces shall be used.

6.7.3.4 Hydrodynamic thrust bearings shall be selected at no more than 50 % of the bearing manufacturer's ultimate load rating. In sizing thrust bearings, consider the following for each specified application:

- a) shaft speed;
- b) temperature of the bearing babbitt;
- c) deflection of the bearing pad;
- d) minimum oil film thickness;
- e) feed rate, viscosity, and supply conditions of the oil over the specified allowable oil supply condition range;
- f) design configuration of the bearing;
- g) babbitt or other bearing surface material alloy and pad material;
- h) turbulence of the oil film;
- i) load changes due to process changes over the specified operating range.

6.7.3.5 Thrust bearings shall be sized for continuous operation under the most adverse specified operating conditions.

6.7.3.6 Calculations of the thrust forces shall include, but shall not be limited to, the following factors:

- a) seal nominal design clearances and twice the maximum design clearances;
- b) pressurized rotor diameter step changes;
- c) stage maximum differential pressures;
- d) specified extreme variations in inlet, interstage, and discharge pressures;
- e) any anticipated transient loading (i.e. from valve opening or closing);
- f) maximum thrust force that may be transmitted to the compressor thrust bearing by other equipment in the train (i.e. couplings, gears, or a motor without a thrust bearing);
- g) maximum thrust force from the sleeve bearing type drive if the motor or generator is directly connected.

6.7.4 Bearing Housings

6.7.4.1 Bearing housings shall be equipped with replaceable labyrinth-type end seals and deflectors where the shaft passes through the housing.

6.7.4.1.1 Lip-type seals shall not be used.

6.7.4.1.2 Bearing housing seals and deflectors shall be made of spark-resistant materials.

6.7.4.1.3 Bearing housing shall be designed to retain oil in the housing and prevent entry of foreign material into the housing without the requirement for external service such as an air purge or grease.

6.7.4.2 The drain system shall maintain the oil and foam level below shaft seals.

6.7.4.3 Provisions for the installation of required instrumentation shall be provided.

6.7.4.4 Where practical, oil and instrument connections shall be in the lower half of the bearing housing to eliminate the need for their removal during bearing inspections and sealed to prevent leakage.

6.7.4.5 Instrument connections shall be above the oil level.

6.7.4.6 [●] If specified, provisions for locally disconnecting bearing temperature sensors' wiring within the bearing housing shall be provided.

6.7.4.7 Oil flow control orifices used within the housing shall be replaceable and identified on contractual drawings.

6.7.4.8 To prevent the buildup of potential voltages in the bearing housing, residual magnetism of the free air gauss level shall not exceed ± 4 gauss when measured with a calibrated Hall effect probe.

6.8 Dynamics

6.8.1 General

NOTE Refer to API 684 for more information on rotordynamics.

6.8.1.1 In the design of rotor-bearing systems, consideration shall be given to all potential sources of excitation and force such as, but not limited to, the following:

- a) unbalance in the rotor system;
- b) fluid forces from bearings, seals, and aerodynamics;
- c) internal rubs;
- d) blade, vane, nozzle, and diffuser passing frequencies;
- e) gear-tooth meshing and side bands;
- f) coupling misalignment;
- g) loose rotor-system components;
- h) internal friction within the rotor assembly;
- i) synchronous excitation from complimentary geared elements;
- j) control loop dynamics such as those involving AMBs;
- k) driver-induced dynamics.

NOTE 1 The frequency of a potential source of excitation or force can be less than, equal to, or greater than the rotational speed of the rotor.

NOTE 2 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 can 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, is related to the amount of damping in the system.

6.8.1.2 Resonances of structural support systems that are within the vendor's scope and that affect the rotor vibration amplitude shall not occur within the specified operating speed range or the required separation margins (SM_r) (see 6.8.2.9).

6.8.1.3 The dynamic characteristics of the structural support shall be considered in the analysis of the rotor-support system [see 6.8.2.4 d)].

6.8.1.4 The vendor with unit responsibility shall communicate the existence of any undesirable running speeds in the range from zero to 150 % N_{mc} .

6.8.1.5 These undesirable running speeds shall be illustrated by the use of a Campbell diagram, submitted to the purchaser for review, and included in the instruction manual [see vendor drawing and data requirements (VDDR) in Annex B of the applicable part].

NOTE 1 Examples of undesirable running speeds are those associated with rotor lateral critical speeds with amplification factors (AFs) greater than or equal to 2.5, train torsionals, and vane and blading modes.

NOTE 2 See Annex C for examples of Campbell diagrams.

6.8.1.6 Lateral and stability analyses specified in 6.8.2 through 6.8.5 shall be reported per 6.8.1.6.1 through 6.8.1.6.3 and Annex B.

6.8.1.6.1 The standard rotordynamics report shall be provided (see B.1).

6.8.1.6.2 [●] If specified, the data requirements identified for independent audit of the results shall be provided.

6.8.1.6.3 [●] If specified, provisions shall be made to provide the purchaser with access to drawings to develop independent models of the rotor, bearings, and seals.

6.8.1.6.4 These data shall be made available in electronic format.

6.8.1.7 Torsional analysis requirements specified in 6.8.6 shall conform to 6.8.1.7.1 through 6.8.1.7.4 and Annex C.

6.8.1.7.1 The torsional reports shall be provided as described in Annex C.

6.8.1.7.2 [●] If specified, the data requirements identified for independent audit of the results shall be provided.

6.8.1.7.3 [●] If specified, provisions shall be made to provide the purchaser with access to drawings to develop independent models of the rotors.

6.8.1.7.4 These data shall be made available in electronic format.

6.8.2 Lateral Analysis

6.8.2.1 Critical speeds and their associated AFs shall be determined by means of a damped unbalanced rotor response analysis.

6.8.2.2 The vendor shall conduct an undamped analysis to identify the undamped critical speeds and determine their mode shapes.

6.8.2.3 The analysis shall identify the first four undamped critical speeds and cover as a minimum the stiffness range to produce free-free to rigid support rotor modes.

6.8.2.4 The lateral analysis shall include, but not be limited to, the following:

- a) rotor stiffness, mass and polar and transverse moments of inertia, including coupling halves, and rotor stiffness changes due to shrunk on components;
- b) bearing lubricant-film stiffness and damping values including changes due to speed, load, minimum to maximum preload, range of oil inlet temperature and pressure, maximum to minimum clearances resulting from accumulated assembly tolerances, and the effect of asymmetrical loading that may be caused by gear forces (including the changes over range of maximum to minimum torque), side streams, eccentric clearances, volutes, etc.;
- c) for tilt-pad bearings, the pad pivot stiffness;
- d) structure stiffness, mass, and damping characteristics, including effects of excitation frequency over the required analysis range; for machines whose dynamic structural stiffness values are less than or equal to 3.5 times the maximum bearing stiffness value at N_{mc} , the structure characteristics shall be incorporated as an adequate dynamic system model, calculated frequency dependent structure stiffness and damping values (impedances), or structure stiffness and damping values (impedances) derived from modal or other testing; the vendor shall state the structure characteristic values used in the analysis and the basis for these values (for example, modal tests of similar rotor structure systems or calculated structure stiffness values);
- e) rotational speed, including the various starting-speed detents, operating speed and load ranges (including agreed test conditions if different from those specified), trip speed, and coastdown conditions;
- f) the influence, of the casing shaft end oil seals over the operating range; minimum and maximum stiffness shall be considered taking into account the tolerance on the component clearance and the oil inlet temperature;
- g) the location and orientation of the radial vibration probes that shall be the same in the analysis as in the machine;
- h) squeeze film damper mass, stiffness and damping values considering the component clearance and centering tolerance, oil inlet temperature range, and operating eccentricity;
- i) the vendor shall state the bearing stiffness and damping values used for the analysis; the basis for these values or the assumptions made in calculating the values shall be presented;
- j) dry gas seals shall be assumed to have no stiffness or damping;
- k) the influence over the operating range of the damper seal's stiffness and damping considering the tolerance on the component's clearance and operating conditions.

6.8.2.5 [●] If specified, the vendor with unit responsibility shall provide a train lateral analysis.

6.8.2.6 The vendor with unit responsibility shall provide a train lateral analysis for machinery trains with rigid couplings.

6.8.2.7 A separate damped unbalanced response analysis shall be conducted within the speed range of 0 to 150 % of N_{mc} .

6.8.2.7.1 Unbalance shall analytically be placed at the locations defined in Figure 2.

6.8.2.7.2 For the translatory (symmetric) modes, the unbalance shall be based on the sum of the journal static loads.

6.8.2.7.3 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.

6.8.2.7.4 For overhung modes, the unbalances shall be based on the overhung mass.

6.8.2.7.5 Figure 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 Equation (3).

In SI units:

$$U_r = 6350 \frac{W}{N_{mc}} \quad (\text{for } N_{mc} < 25,000 \text{ rpm}) \quad (3a)$$

$$U_r = \frac{W}{3.937} \quad (\text{for } N_{mc} \geq 25,000 \text{ rpm})$$

In USC units:

$$U_r = 4 \frac{W}{N_{mc}} \quad (\text{for } N_{mc} < 25,000 \text{ rpm}) \quad (3b)$$

$$U_r = \frac{W}{6250} \quad (\text{for } N_{mc} \geq 25,000 \text{ rpm})$$

where

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

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

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

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

NOTE Above 25,000, the limit is based on 0.254 μm (10 $\mu\text{in.}$) mass displacement, which is in general agreement with the capabilities of conventional balance machines, and is necessary to invoke for small rotors running at high speeds.

6.8.2.7.6 For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall be 2 times the maximum of the following assembly check balance values:

$$U_{ac1} = \frac{K_1 \times W}{N_{mc}} \quad (4a)$$

$$U_{ac2} = K_2 \times W \quad (4b)$$

$$U_{ac3} = K_3 \quad (4c)$$

where

$$K_1 = 63,500 \text{ (40);}$$

$$K_2 = 12.7 \text{ (0.008);}$$

$$K_3 = 72 \text{ (0.1);}$$

U_{ac} is the coupling unbalance used in the response analysis, in g-mm (oz-in.);

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

W is the mass portion of the respective coupling end in kg (lbm) (see Figure 2).

6.8.2.7.7 For rotors with damper seals, an unbalance response with and without the effects of the damper seal shall be provided.

6.8.2.8 Additional analyses shall be made for use with the verification test specified in 6.8.3.

6.8.2.8.1 The location of the unbalance shall be determined by the vendor.

6.8.2.8.2 Any test stand parameters that influence the results of the analysis shall be included.

6.8.2.8.3 For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall not be less than 2 times or greater than 8 times the maximum value of Equation (4).

NOTE For most machines, there will only be one plane readily accessible for the placement of an unbalance; for example, the coupling flange on a single ended drive machine, or the impeller hub or disk on an integrally geared machine, or expander-compressors. However, some compressor types (axial compressors, for example) can provide additional externally accessible balance planes.

6.8.2.8.4 For other unbalance placement, the unbalance shall not be less than 2 times or greater than 8 times the maximum value of Equation (3).

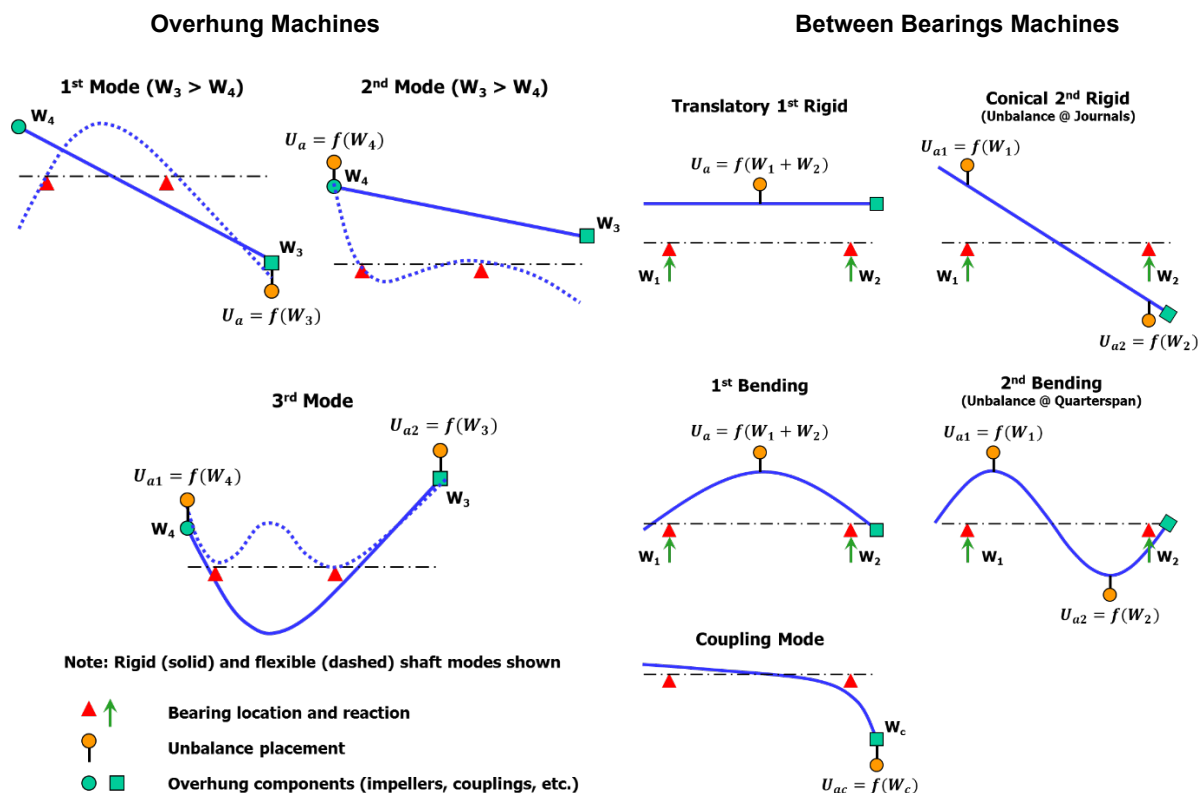


Figure 2—Typical Mode Shapes and Corresponding Unbalance