

Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services

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Foreword

This standard is based on the accumulated knowledge and experience of manufacturers and users of reciprocating compressors. The objective of this publication is to provide a purchase specification to facilitate the procurement and manufacture of reciprocating compressors for use in petroleum, chemical, and gas industry services.

The primary purpose of this standard is to establish minimum requirements.

Energy conservation is of concern and has become increasingly important in all aspects of equipment design, application, and operation. Thus, innovative energy-conserving approaches should be aggressively pursued by the manufacturer and the user during these steps. Alternative approaches that may result in improved energy utilization should be thoroughly investigated and brought forth. This is especially true of new equipment proposals since the evaluation of purchase options will be based increasingly on total life costs as opposed to acquisition cost alone.

Equipment manufacturers, in particular, are encouraged to suggest alternatives to those specified when such approaches achieve improved energy effectiveness and reduced total life costs without the sacrifice of safety or reliability.

This standard requires the purchaser to specify certain details and features. Although it is recognized that the purchaser may desire to modify, delete, or amplify sections of this standard, it is strongly recommended that such modifications, deletions, and amplifications be made by supplementing this standard, rather than by rewriting or incorporating sections thereof into another standard.

A bullet (•) at the beginning of a subsection or paragraph indicates that either a decision by, or further information from, the purchaser is required. Further information should be shown on the data sheets (see example in Annex A) or stated in the quotation request and purchase order.

For effective use of this standard and ease of reference to the text, the use of the data sheets in Annex A is recommended.

The purchaser's checklist in Annex D can also be used for purchaser's specific requirements or decisions.

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

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

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

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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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Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services

1 Scope

This standard covers the minimum requirements for reciprocating compressors and their drivers for use in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or nonlubricated cylinders.

Compressors covered by this standard are low- to moderate-speed machines. Also included are related lubrication systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment. Compressors not covered by this standard are as follows:

- a) integral gas engine-driven compressors;
- b) compressors with single-acting trunk-type (automotive-type) pistons that also serve as crossheads;
- c) either plant or instrument-air compressors that discharge at a gauge pressure of 9 bar (125 psig) or below;
- d) diaphragm 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) issued at the time of purchase order applies.

API *Measurement of Petroleum Measurement Standards (MPMS) Chapter 15, Guidelines for the Use of Petroleum Industry-specific International System (SI) Units*

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

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

API Standard 547, *General-purpose Form-wound Squirrel Cage Induction Motors—185 kW (250 hp) through 2240 kW (3000 hp)*

API Standard 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

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

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

API Standard 613, *Special-purpose Gears for Petroleum, Chemical, and Gas Industry Services*

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

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

API Standard 660, *Shell-and-Tube Heat Exchangers*

API Standard 661, *Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers*

API Standard 670, *Machinery Protection Systems*

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

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

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

API Standard 688, *Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services*

API Recommended Practice 945, *Avoiding Environmental Cracking in Amine Units*

AGMA 9002 ¹, *Bores and Keyways for Flexible Couplings (Inch Series)*

ANSI B11.19 ², *Performance Requirements for Risk Reduction Measures: Safeguarding and Other Means of Reducing Risk*

ANSI B15.1, *Safety Standards for Mechanical Power Transmission Apparatus*

ASME Boiler and Pressure Vessel Code ³, Section V, *Nondestructive Examination*

ASME Boiler and Pressure Vessel Code, Section VIII: *Rules for Construction of Pressure Vessels, Division 1*

ASME Boiler and Pressure Vessel Code, Section IX: *Welding, Brazing, and Fusing Qualifications*

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

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

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

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

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

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

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

ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*

ASME PTC 36, *Measurement of Industrial Noise: Performance Test Codes*

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

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

ASTM A216, *Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service*

¹ American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, www.agma.org.

² American National Standards Institute, 1899 L Street, NW, Washington, DC 20036, www.ansi.org.

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

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

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

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

ASTM A320, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*

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

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

ASTM A503, *Standard Specification for Ultrasonic Examination of Forged Crankshafts*

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

ASTM A536, *Standard Specification for Ductile Iron Castings*

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

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

ASTM E165, *Standard Practice for Liquid Penetrant Examination for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E1417, *Standard Practice for Liquid Penetrant Testing*

AWS D1.1 ⁵, *Structural Welding Code—Steel*

IEC 60034 (all parts) ⁶, *Rotating Electrical Machines*

IEC 60079 (all parts), *Explosive Atmospheres*

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

IEC 60848, *GRAFCET Specification Language for Sequential Function Charts*

IEEE 841 ⁷, *IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty, Totally Enclosed Squirrel Cage Induction Motors from 0.75 kW to 370 kW (1 hp to 500 hp)*

ISO 7-1 ⁸, *Pipe threads where pressure-tight joints are made on the threads—Part 1: Dimensions, tolerances and designation*

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

⁶ International Electrotechnical Commission, 3 Rue de Varembé, CH-1211, Geneva 20, Switzerland, www.iec.ch.

⁷ Institute of Electrical and Electronics Engineers, 3 Park Avenue, 17th Floor, New York, New York 10016, www.ieee.org.

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

- ISO 261, *ISO general-purpose metric screw threads—General plan*
- ISO 262, *ISO general-purpose metric screw threads—Selected sizes for screws, bolts and nuts*
- ISO 281, *Rolling bearings—Dynamic load ratings and rating life*
- ISO 286-2, *Geometrical product specifications—(GPS)—ISO code system for tolerances on linear sizes—Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts*
- ISO 724, *ISO general-purpose metric screw threads—Basic dimensions*
- ISO 965 (all parts), *ISO general purpose metric screw threads—Tolerances*
- ISO 1217, *Displacement compressors—Acceptance tests*
- ISO 3740, *Acoustics—Determination of sound power levels of noise sources—Guidelines for the use of basic standards*
- 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 3746, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Survey method using an enveloping measurement surface over a reflecting plane*
- ISO 1940-1, *Mechanical vibration—Balance quality requirements for rotors in a constant (rigid) state—Part 1: Specification and verification of balance tolerances*
- ISO 6708, *Pipework components—Definition and selection of DN (nominal size)*
- ISO 7005-1, *Pipe flanges—Part 1: Steel flange for industrial and general service piping systems*
- ISO 7005-2, *Metallic flanges—Part 2: Cast iron flanges*
- ISO 8501 (all parts), *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness*
- ISO 13631, *Petroleum and natural gas industries—Packaged reciprocating gas compressors*
- ISO 14120, *Safety of machinery—Guards—General requirements for the design and construction of fixed and movable guards*
- NACE ⁹, *Corrosion Engineer's Reference Book*
- NACE MR0103, *Petroleum, Petrochemical and Natural Gas Industries—Metallic Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*
- NACE SP0403, *Avoiding Caustic Stress Corrosion Cracking of Carbon Steel Refinery Equipment and Piping*
- NEMA SM 23 (R2002) ¹⁰, *Steam Turbines for Mechanical Drive Service* (withdrawn)
- NFPA 70 ¹¹, *National Electrical Code (NEC)*
- SSPC SP 6 ¹²/NACE No. 3, *Commercial Blast Cleaning*

⁹ NACE International (now the Association for Materials Protection and Performance), 15835 Park Ten Place, Houston, Texas 77084, www.ampp.org.

¹⁰ National Electrical Manufacturers Association, 1300 17th St N 900, Arlington, Virginia 22209, www.nema.org.

¹¹ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

¹² Society for Protective Coatings (now the Association for Materials Protection and Performance), 15835 Park Ten Place, Houston, Texas 77084, www.ampp.org.

2.2 The NOTES following a section are informative.

- **2.3** The equipment supplied to this standard shall comply with either the applicable ISO standards or the applicable US standards, as specified.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

acoustic simulation

The process whereby the one-dimensional acoustic characteristics of fluids and the influence of the reciprocating compressor dynamic flow on these characteristics are modeled, taking into account the fluid properties and the geometry of the compressor and the connected vessels and piping.

NOTE See API 688 for additional information.

3.1.2

active analysis

A portion of the acoustic simulation in which the pressure pulsation amplitudes, due to imposed compressor operation for the anticipated loading, speed range, and state conditions, are simulated (see 3.1.1).

3.1.3

alarm point

A preset value of a measured parameter at which an alarm is actuated to warn of a condition that requires corrective action.

3.1.4

anchor bolts

Bolts used to attach the mounting plate or machine to the support structure (concrete foundation or steel structure).

NOTE See 3.1.15 for definition of hold-down bolts. Also see Figure K.1.

3.1.5

baseplate

A fabricated steel structure designed to provide support to the complete compressor and/or the drive equipment and other ancillaries that may be mounted upon it.

3.1.6

certified point

Point to which the performance tolerances will be applied.

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

3.1.7

crosshead pin load

The algebraic sum of gas load and inertia load on the crosshead pin parallel to the piston rod.

3.1.8

crosshead pin reversal

A change in direction of force in the piston rod loading (tension to compression or vice versa), which results in a load reversal at the crosshead pin during each revolution. This is commonly called "rod reversal."

3.1.9**design**

Manufacturer's calculated parameter.

NOTE A term used by the equipment manufacturer to describe various parameters such as design power, design pressure, design temperature, or design speed. It is not intended for the purchaser to use this term.

3.1.10**digital simulation**

A method using various mathematical techniques on digital computers to achieve the acoustic simulation (see 3.1.1).

3.1.11**drive train**

Includes all drive equipment up to the compressor shaft free-end and all components coupled to the free-end of the crankshaft.

3.1.12**fail safe**

A system that causes the equipment to revert to a permanently safe condition (shutdown and/or depressurized) in the event of a component failure or failure of the energy supply to the system.

3.1.13**gas load**

The force resulting from differential gas pressure acting on the piston differential area.

NOTE Based on internal cylinder pressure.

3.1.14**gauge board**

Bracket or plate used to support and display gauges, switches, and other instruments.

NOTE A gauge board is not a panel. A gauge board is open and not enclosed. A panel is an enclosure.

3.1.15**hold-down bolts (mounting bolts)**

Bolts holding the equipment to the mounting plate.

3.1.16**inertia load**

Force resulting from the acceleration and deceleration of a reciprocating mass.

NOTE The inertia force with respect to the crosshead pin is the summation of the products of all reciprocating masses (piston and rod assembly, and crosshead assembly, including pin) and their respective acceleration.

3.1.17**informative**

Describes part of the standard that is provided for information and is intended to assist in the understanding of use of the standard.

NOTE 1 Compliance with an informative part of the standard is not mandatory.

NOTE 2 An annex may be informative or normative as indicated. See 3.1.33 for definition of normative.

3.1.18

inlet volume flow

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

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

3.1.19

local

The location of a device when mounted on or near the equipment or console.

3.1.20

manufacturer

The organization responsible for the design and manufacture of the equipment.

NOTE The manufacturer is often a different entity from the vendor.

3.1.21

manufacturer's rated capacity

The capacity used to size the compressor, which is the quantity of gas, taken into the compressor cylinder at the specified inlet conditions, while the compressor is operating at the specified discharge pressure.

3.1.22

maximum allowable speed

The highest rotational speed at which the manufacturer's design permits continuous operation.

3.1.23

maximum allowable temperature

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

3.1.24

maximum allowable working pressure

MAWP

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

3.1.25

maximum continuous speed

The highest rotational speed at which the machine, as built, is capable of continuous operation with the specified gas at any of the specified operating conditions.

3.1.26

minimum allowable speed

The lowest rotational speed at which the manufacturer's design permits continuous operation with the specified gas at any of the specified conditions.

3.1.27

minimum allowable suction pressure (for each stage)

The lowest pressure (measured at the inlet flange of the cylinder) below which the combined crosshead pin load, gas load, discharge temperature, or crankshaft torque load (whichever is governing) exceeds the maximum allowable value during operation at the set pressure of the discharge relief valve and other specified inlet gas conditions for the stage.

3.1.28**minimum allowable temperature**

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

3.1.29**mode shape (of an acoustic pulsation resonance)**

The description of the pulsation amplitudes and phase angle relationship at various points in the piping system. Knowledge of the mode shape allows the analyst to understand the pulsation patterns in the piping system (see 3.1.1).

3.1.30**mounting plate**

Baseplates, skids, soleplates, and rails.

3.1.31**normal operating point**

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

3.1.32**normally open and normally closed**

On-the-shelf state of a device (e.g. automatically activated switch or actuated valve).

NOTE 1 The following table gives examples of various devices and their on-the-shelf state.

Device	On-the-shelf State
Electrically activated devices	De-energized position of the device
Automatically activated pressure switch	State of the contacts at ambient pressure
Flow switch	State of the contacts at no flow
Level switch	State of the contacts at no level
Limit switch	State of the contacts at unactuated condition
Speed switch	State of the contacts at 0 rpm

NOTE 2 During operation of the equipment, these devices may be normally energized or actuated; therefore, the state of these devices during operation may not be the same as their on-the-shelf state.

3.1.33**normative**

A requirement to be met in order to comply with the standard.

3.1.34**observed**

An inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed, as scheduled, even if the purchaser or the purchaser's representative is not present.

3.1.35**owner**

The final recipient of the equipment.

NOTE In many instances the owner delegates another agent to be the purchaser of the equipment.

3.1.36**panel**

An enclosure used to mount, display, and protect gauges, switches, and other instruments.

3.1.37**passive analysis**

A portion of the acoustic simulation in which a constant flow amplitude modulation over an arbitrary frequency range is imposed on the system, normally at the cylinder valve locations. The resulting transfer function defines the acoustic natural frequencies and the mode shapes over the frequency range of interest (see 3.1.1).

3.1.38**piston rod drop**

A measurement of the position of the piston rod relative to the measurement probe mounting location(s) (typically oriented vertically at the piston rod pressure packing on horizontal cylinders).

3.1.39**piston rod runout**

The change in position of the piston rod in either the vertical or horizontal direction as measured at a single point (typically at or near the piston rod pressure packing case) while the piston rod is moved through the outbound portion of its stroke.

NOTE 1 In horizontal compressors, the piston rod runout is measured in both the vertical and horizontal directions. Horizontal runout is taken on the side of the rod to determine horizontal variations, while vertical runout is taken on the top of the rod to determine vertical variations.

NOTE 2 Practical considerations make it advisable to monitor the runout measurements while rotating the shaft through one complete revolution.

NOTE 3 See Annex C for a detailed discussion of piston rod runout.

3.1.40**pressure casing**

The composite of all stationary pressure-containing parts of the unit, including all nozzles and other attached parts.

3.1.41**pressure design code**

The recognized pressure vessel standard specified or agreed upon by the purchaser. For example, a recognized standard for pressure vessels is *ASME Boiler and Pressure Vessel Code (BPVC)* Section VIII.

3.1.42**purchaser**

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

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

3.1.43**R_a**

Arithmetic average of the absolute value of the profile height deviations recorded within the evaluation length and measured from the mean line.

NOTE 1 Adapted from ASME B46.1-2009, paragraph 1.4.1.1.

NOTE 2 It is the average height of the entire surface, within the sampling length, from the mean line.

3.1.44**rails**

Soleplates extending the full length of each side of the equipment.

3.1.45**rated discharge pressure**

The highest pressure required to meet the conditions specified by the purchaser for the intended service.

3.1.46**rated discharge temperature**

The highest predicted operating temperature resulting from any specified operating condition.

3.1.47**rated speed**

The highest rotational speed required to meet any of the specified operating conditions.

3.1.48**relief valve set pressure**

The pressure at which a relief valve starts to lift.

3.1.49**remote**

The location of a device when located away from the equipment or console, typically in a control room.

3.1.50**required capacity**

The process capacity specified by the purchaser to meet process conditions, with no-negative tolerance (NNT) permitted.

NOTE 1 The required capacity is the quantity of gas taken into the compressor cylinder at the specified inlet conditions, while the compressor is operating at the specified discharge pressure and speed.

NOTE 2 See Annex B for an explanation of the term “no-negative tolerance.”

3.1.51**rolled thread**

Thread produced by the action of a form tool that when pressed into the surface of a blank displaces material radially.

3.1.52**settling-out pressure**

The pressure within the compressor system when the compressor is shut down without depressuring of the system.

3.1.53**shutdown set point**

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

3.1.54**skid**

A baseplate that has sled-type runners for ease of relocation.

3.1.55**soleplates**

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

3.1.56**special tool**

A tool that is not a commercially available catalog item.

3.1.57**standard volume flow**

The flow rate expressed in volume flow units at one of the specified standard conditions as follows:

ISO 13443 Standard Conditions (Natural Gas Standard Reference Conditions)

Flow:	Cubic meters per hour (m ³ /h) Cubic meters per minute (m ³ /min)
Pressure:	1.01325 bar
Temperature:	15 °C
Relative humidity:	Dry

US Standard Conditions

Flow:	Standard cubic feet per minute (scfm) Million standard cubic feet per day (mmscfd)
Pressure:	14.696 psi
Temperature:	60 °F
Relative humidity:	Dry

NOTE Use of standard volume flow is discouraged due to the many various standard conditions in usage. Standard volume flow should be referenced to the appropriate standard conditions used or should also be supplied with mass flow to prevent conversion errors by those using the data.

3.1.58**total indicator reading (also known as total indicated runout)****TIR**

The 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 indicator reading implies an eccentricity equal to half the reading. For a perfectly flat face, the indicator reading gives an out-of-squareness equal to the reading. If the diameter in question is not cylindrical or flat, interpretation of the TIR is more complex and can be affected by ovality or lobing.

3.1.59**trip speed**

The speed at which the independent emergency overspeed device actuates to shut down a variable-speed prime mover. For the purposes of this standard, the trip speed of alternating current electric motors, except adjustable frequency drives, is the speed corresponding to the synchronous speed of the motor at the maximum supply frequency (see Table 2).

3.1.60**unit responsibility**

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

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

3.1.61 vendor

Manufacturer or manufacturer's agent that supplies the equipment.

NOTE The vendor can be the manufacturer of the equipment or the manufacturer's agent and normally is responsible for service support.

3.1.62 witnessed

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

3.2 Acronyms and Abbreviations

BPVC	<i>Boiler and Pressure Vessel Code</i>
EFRC	European Forum for Reciprocating Compressors
MAWP	maximum allowable working pressure
NNT	no-negative tolerance
SI	International System of Units
TIR	total indicator reading
USC	United States customary
VDDR	vendor drawing and data requirements

4 General

4.1 Unit Responsibility

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

4.2 Unit Conversion

The factors in API *MPMS* Ch. 15 were used to convert from United States customary (USC) units to International System of Units (SI). The resulting exact SI units were then rounded off.

4.3 Nomenclature

A guide to reciprocating compressor nomenclature is presented in Annex I.

5 Requirements

● 5.1 Units of Measure

The data, drawings, nameplates, hardware (including fasteners), and equipment supplied to this standard shall use either the SI or USC system of measurement, as specified.

● 5.2 Language

All vendor data, drawings, and nameplates shall be in English or other language, if specified.

5.3 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.

5.4 The hierarchy of documents shall be specified.

NOTE Typical documents include company and industry specifications, meeting notes, and modifications to these documents.

6 Basic Design

6.1 General

6.1.1 Equipment Reliability

- **6.1.1.1** Only equipment that is field proven, as defined by the purchaser, is acceptable.
- **6.1.1.2** If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

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

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

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

NOTE It is recognized that these are design criteria.

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

- **6.1.4** The purchaser shall specify all operating conditions for the equipment. The equipment's normal operating point shall be as specified. Unless otherwise specified, the capacity at the normal operating point shall have NNT.

NOTE 1 Operating conditions can include start-up, shutdown, commissioning, transient, and part-load.

NOTE 2 Operation with alternate gases such as nitrogen can have adverse effects on valves, pulsation suppression system, motor sizing, and capacity control system design.

NOTE 3 See Annex B for a discussion of capacity and the term "no-negative tolerance."

6.1.5 Compressors driven by induction motors shall be rated at the actual motor speed for the rated load condition, not at synchronous speed.

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

In order to determine compliance, the vendor shall provide both maximum sound pressure and sound power level data per octave band for the equipment. ISO 3740, ISO 3744, and ISO 3746 or ASME PTC 36 may be consulted for guidance.

6.1.8 Unless otherwise specified, cooling water system or systems shall be designed for the conditions of Table 1.

Table 1—Cooling System Conditions

Parameter	Requirement	
	SI Units	USC Units
For heat exchangers		
Water velocity over heat exchange surfaces	1.5 m/s to 2.5 m/s	5 ft/s to 8 ft/s
Maximum allowable working pressure (MAWP) (gauge)	≥ 700 kPa (7 bar)	≥ 100 psig
Test pressure (≥ 1.5 MAWP)	≥ 1050 kPa (10.5 bar)	≥ 150 psig
Maximum pressure drop	100 kPa (1 bar)	15 psi
Maximum inlet temperature	30 °C	90 °F
Maximum outlet temperature	50 °C	120 °F
Maximum temperature rise	20 K	30 °F
Minimum temperature rise	10 K	20 °F
Water side fouling factor	0.35 m ² K/kW	0.002 hr-ft ² -°F/Btu
Corrosion allowance for carbon steel shells	3 mm	1/8 in.
For cylinder jackets and packing cases		
Maximum allowable working pressure (MAWP) (gauge)	≥ 500 kPa (5 bar)	≥ 75 psig
Test pressure (≥ 1.5 MAWP)	≥ 750 kPa (7.5 bar)	≥ 115 psig

The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity over heat exchange surfaces results in a conflict. The criterion for velocity over heat exchange surfaces is intended to minimize water-side fouling. The criterion for minimum temperature rise is intended to minimize the use of cooling water. If such a conflict exists, the purchaser shall approve the final selection.

6.1.9 Provisions shall be made for complete venting and draining of the jacket water system.

6.1.10 Equipment shall be designed to run simultaneously at the relief valve and trip speed settings without damage.

NOTE There can be insufficient driver power to operate under these conditions (see 7.1.1).

6.1.11 The equipment's trip speed shall not be less than the values in Table 2.

6.1.12 Reciprocating compressors should normally be specified for constant-speed operation in order to avoid excitation of torsional, acoustic, and/or mechanical resonances. When adjustable-speed drivers are used, all equipment shall be designed to run safely throughout the operating speed range, up to and including the trip speed. For adjustable-speed drives, a list of undesirable running speeds shall be furnished to the purchaser by the vendor. The occurrence of undesirable speeds in the operating range shall be minimized.

NOTE Valve life may be affected if a wide operating speed range is specified.

6.1.13 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance.

Table 2—Driver Trip Speeds

Driver Type	Trip Speed (% of Maximum Continuous Speed)
Steam turbine	
NEMA Class A ^a	115 %
NEMA Class B, C, D ^a	110 %
Gas turbine	105 %
Adjustable-speed motor	110 %
Constant-speed motor	102 %
Reciprocating engine	110 %
^a Indicates governor class as specified in NEMA SM 23.	

- **6.1.14** Motors, electrical components, and electrical installations shall be suitable for the area classification (Class, Group, Division, or Zone and Temperature Code) specified and shall meet the requirements of IEC 60079 and IEC 60529 (or NFPA 70, Articles 500, 501, 502, and 504), as well as any local codes as specified. On request the purchaser will furnish copies of local codes.

6.1.15 Oil reservoirs and housings that enclose moving lubricated parts such as bearings, shaft seals, highly polished parts, instruments, and control elements shall be designed to minimize contamination by moisture, dust, and other foreign matter during periods of operation and idleness.

6.1.16 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as cylinders, distance pieces, and compressor frames shall be designed and manufactured to ensure accurate alignment on reassembly. This can be accomplished by methods such as shouldering, using cylindrical dowels, or keys.

6.1.17 The purchaser is responsible for the civil design of the compressor system.

- **6.1.18** If specified, an initial installation check by the vendor's representative and an operating temperature alignment check at a later date shall be performed. The details and scope of the check shall be agreed. Such checks shall include, but not be limited to, initial alignment check, grouting, crankshaft web deflection, piston-rod runout, driver alignment, motor air gap, outboard bearing insulation, bearing checks, and piston end clearance.

6.1.19 The power required by the compressor at the normal operating point shall not exceed the stated power by more than 3 %.

6.1.20 Compressors shall be capable of developing the maximum differential pressure specified.

- **6.1.21** The equipment, including all auxiliaries, shall be suitable for operation under the environmental conditions specified. These conditions shall include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions. The scope of winterization and/or tropicalization (e.g. allowances for insulation) shall be agreed.
- **6.1.22** The equipment, including all auxiliaries, shall be suitable for operation using the utility stream conditions specified.

- **6.1.23** The purchaser shall specify flow, gas composition, dew point, and gas conditions. The purchaser can also specify molecular weight, ratio of specific heats (C_p/C_v), and compressibility factors (Z).

NOTE Specified flow at discharge conditions is the mass flow minus any condensation that occurs in the interstage(s).

6.1.24 Unless otherwise specified, the vendor shall use the specified values of flow, the specified gas composition, and the specified gas conditions to calculate molecular weight, ratio of specific heats (C_p/C_v), and compressibility factors (Z). The compressor vendor shall indicate values on the data sheets with the proposal and use them to calculate performance data.

NOTE The dew point of the gas is particularly important in nonlubricated applications.

6.1.25 If any of the compressor cylinders are to be operated partially or fully unloaded for extended periods of time, the purchaser and the vendor shall jointly determine the method to be used (e.g. periodic, momentary loading to purge accumulation of lube oil in the compressor cylinders) to prevent heat and liquid damage.

- **6.1.26** The compressor vendor shall confirm that the unit is capable of continuous operation at any full-load, part-load, or fully unloaded conditions (see 6.1.25) and that the unit is capable of start-up in accordance with 7.1.1.6. If specified, 100 % unloading shall be furnished as part of the system by the supplier.

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

NOTE See E.3.4 for parts list requirements.

6.2 Bolting

6.2.1 Details of threading shall conform to ISO 261, ISO 262, ISO 724, and ISO 965 or ASME B1.1. The use of fine pitch threads shall be avoided in external fasteners subject to routine maintenance, fasteners for pressure retaining parts, and fasteners in cast iron. Fasteners of diameters equal to or greater than 24 mm (1 in.) shall be of the constant 3 mm pitch (8 threads/in.) series.

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

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

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

6.2.4 Manufacturer's marking shall be located on all fasteners 6 mm ($1/4$ in.) and larger (excluding washers and headless setscrews). For studs, the marking shall be on the exposed stud end. Fasteners manufactured in accordance with NACE material requirements shall be clearly and permanently marked as such, and their correct locations shall be identified in the installation and maintenance manuals.

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

6.2.5 Bolting on reciprocating or rotating parts shall be positively locked mechanically (spring washers, tab washers, and anaerobic adhesives shall not be used as positive locking methods) unless preload is achieved by hydraulic tensioning or other well-defined methods that generates the exact prestress (see 6.10.1 or 6.10.2.1).

NOTE Locking device is not a substitute for proper preload.

6.2.6 External studs for hydraulic tensioning shall have a protective cover on exposed threads.

6.2.7 Thread engagement in tapped holes shall be at least 1.5 times the fastener nominal diameter.

6.3 Calculating Cold Runout

6.3.1 For horizontal compressors, the vendor shall provide the expected horizontal and vertical cold runout before the shop bar-over test. The manufacturer shall disclose the assumptions used in the calculations.

The vertical tolerance applied to the expected runout shall not exceed ± 0.015 % of stroke. The horizontal tolerance shall not exceed 0.064 mm (0.0025 in.), regardless of length of stroke. The expected cold horizontal and vertical rod runout shall be confirmed during the shop bar-over test and shown on the rod runout table. Piston rod runout shall be measured adjacent to the cylinder packing case flange.

NOTE See Annex C for clarification of rod runout and typical rod runout table.

6.3.2 For nonhorizontal cylinders, the procedures and tolerances for runout measurements shall be agreed.

● **6.4 Allowable Speeds**

Compressors shall be conservatively rated at a speed less than or equal to that known by the manufacturer to result in low maintenance and trouble-free operation under the specified service conditions. The maximum acceptable average piston speed and the maximum acceptable rotating speed can be specified where experience indicates that specified limits should not be exceeded for a given service.

NOTE Generally, the rotating speed and piston speed of compressors in nonlubricated services may be less than those in equivalent lubricated services.

6.5 Allowable Discharge Temperature

6.5.1 Unless otherwise specified, the maximum predicted discharge temperature shall not exceed 135 °C (275 °F). This limit applies to all specified operating and load conditions. The vendor shall provide the purchaser with both the predicted and adiabatic discharge temperature rise.

For hydrogen-rich services (molecular weight less than or equal to 12) or nonlubricated cylinders, the predicted discharge temperature shall not exceed 120 °C (250 °F).

The discharge temperature shall be reviewed at all loading points.

NOTE 1 The predicted discharge temperature can differ from the adiabatic discharge temperature depending on factors such as the power input to a cylinder, the ratio of compression, the size of the cylinder, and the effect of the coolant. Hydrogen services generally have higher discharge temperatures because of internal leakage and the unusual characteristic of hydrogen, which can release heat when it expands.

NOTE 2 Temperature limits apply to specified operating conditions. Relief valve settings are not included.

6.5.2 A high discharge temperature alarm device shall be provided for each compressor cylinder. The set points and the mode of operation shall be agreed.

The recommended discharge temperature high and high-high alarms are 20 K (40 °F) and 30 K (50 °F) above the maximum predicted discharge temperature. Temperature shutdown, if applied, shall not exceed 175 °C (350 °F). To prevent autoignition, lower temperature limits should be considered for oxygen-bearing gasses.

NOTE A risk assessment may require a high temperature shutdown.

6.6 Crosshead Pin and Gas Loads

6.6.1 The crosshead pin load shall not exceed the manufacturer's maximum allowable continuous crosshead pin load at any specified operating load step. These crosshead pin loads shall be calculated on the basis of the set point pressure of the discharge relief valve of each stage and of the lowest specified suction pressure corresponding to each load step.

6.6.2 The gas load shall not exceed the manufacturer's maximum allowable continuous gas load for the compressor static frame components (cylinders, heads, distance pieces, crosshead guides, crankcase, and bolting) at any specified operating load step. These loads shall be calculated on the basis of the set point pressure of the discharge relief valve of each stage and of the lowest specified suction pressure corresponding to each load step.

6.6.3 The crosshead pin loads and the gas loads shall be calculated for each 5-degree interval of one crankshaft revolution for each specified load step on the basis of internal cylinder pressures using valve and gas passage losses and gas compressibility factors corresponding to the internal cylinder pressure and temperature conditions at each crank angle increment.

6.6.4 For all specified operating load steps, fully unloaded condition and at relief valve set pressures, the crosshead pin loading shall fully reverse between the crosshead pin and bushing during each complete revolution of the crankshaft. The machine shall be designed for continuous operation at a minimum reversal of 15 degrees of crank angle and a 3 % load magnitude. The 3 % load magnitude is based on the peak crosshead pin load in the opposite direction.

NOTE This reversal is required to maintain proper lubrication between the crosshead pin and bushing.

6.7 Critical Speeds

6.7.1 The compressor vendor shall perform the necessary torsional studies to demonstrate the elimination of any torsional vibrations that may hinder the operation of the complete unit within the specified operating speed range in any specified loading step. The vendor shall provide copies of the studies and shall inform the purchaser of all critical speeds from zero to trip speed or synchronous speed that occur during acceleration or deceleration (see E.2.3.3, item m).

6.7.2 With the exception of belt-driven units, the vendor shall provide a torsional analysis of all machines furnished. Torsional natural frequencies of the complete driver-compressor system (including couplings and any gear unit) shall not be within 10 % of any operating shaft speed and within 5 % of any multiple of operating shaft speed in the rotating system up to and including the tenth multiple.

6.7.3 For drive trains that include a turbine and gear, the requirements of API 611, API 612, API 613, and API 616, as applicable, shall govern in calculation and evaluation of critical speeds. For units requiring the use of a low-speed quill shaft and coupling, a separate lateral critical speed analysis shall be performed. Any lateral critical speed of a quill shaft shall be separated by at least 20 % from any operating speed of any shaft in the system.

6.7.4 When torsional resonances are calculated to fall within the margin specified in 6.7.2, and the purchaser and the vendor have agreed that all efforts to remove the critical from within the limiting frequency range have been exhausted, a stress analysis shall be performed to demonstrate that the resonances have no adverse effect on the driver-compressor system. The assumptions and acceptance criteria for this analysis shall be agreed.

6.8 Compressor Cylinders

6.8.1 General

6.8.1.1 The maximum allowable working pressure (MAWP) of the cylinder shall be at least equal to the specified relief valve set pressure. If a set pressure is not specified, the MAWP of the cylinder shall exceed the maximum stage discharge gauge pressure by at least 10 % or 1.7 bar (25 psig), whichever is greater.

6.8.1.2 Unless otherwise specified, horizontal cylinders shall be used for compressing saturated gases or for gases carrying injected flushing liquids. All horizontal cylinders shall have bottom discharge connections. Other cylinder arrangements may be considered with the approval of the purchaser. In these cases, manufacturer shall provide the purchaser with an experience list for similar services.

NOTE Liquid in any form has detrimental effect on cylinder valve life and potentially on piston rod pressure packing and piston ring life.

6.8.1.3 Cylinders shall be spaced and arranged to permit access for operating and removal for maintenance of all components (including water jacket access covers, distance piece covers, packing, crossheads, pistons, valves, unloaders, or other controls mounted on the cylinder) without removing the cylinder, the process piping, or pulsation suppression devices.

6.8.1.4 Single-acting, step piston, or tandem cylinder arrangements may be provided if accepted by the purchaser at the time of purchase. For such cylinder arrangements, special consideration shall be given to ensure crosshead pin load reversal (see 6.6.4).

6.8.1.5 Unless otherwise specified, each cylinder shall have a replaceable dry-type liner, not contacted by the coolant. Liners shall be at least 9.5 mm ($\frac{3}{8}$ in.) thick for bore diameters up to and including 250 mm (10 in.). For bore diameters larger than 250 mm (10 in.), the minimum liner thickness shall be 12.5 mm ($\frac{1}{2}$ in.).

Liners shall be secured to prevent axial movement or rotation. The liner fit to the cylinder bore shall be designed to enhance heat transfer and dimensional stability.

NOTE 1 Liners may be replaced if damaged or worn during operation.

NOTE 2 Replaceable dry-type liners allow the use of alternate materials as a wear surface to maximize piston ring and rider band performance. See 6.8.1.8.

NOTE 3 Noncontacting vertical labyrinth type pistons do not necessarily need a replaceable liner.

6.8.1.6 The surface finish of the running bore of the cylinder liners and cylinders without liners shall be 0.1 μm to 0.6 μm (4 $\mu\text{in.}$ to 24 $\mu\text{in.}$) Ra (arithmetic average roughness). The actual surface finish requirement is dependent on the choice of cylinder liner material, coatings, operating conditions, and the degree of lubrication.

- **6.8.1.7** If specified, the running bore of cylinders shall be honed using a hone surface of the same material as the rider bands and/or piston rings. The hone surface material and the method of application shall be mutually agreed.

NOTE During commissioning of cylinders, particularly nonlubricated cylinders, monitor excessive early rider band wear to prevent damage to the cylinder liner. After the initial run-in period, rider band wear normally decreases significantly.

6.8.1.8 The walls of cylinders without liners (see 6.8.1.5) shall be thick enough to provide for reboring to a total of 3.0 mm ($\frac{1}{8}$ in.) increase over the original diameter. The increase in piston diameter shall not affect the cylinder MAWP, the maximum allowable continuous gas load, and the maximum allowable continuous crosshead pin load.

NOTE 1 If a liner is not used, the piston wear surface is part of the pressure containment boundary.

NOTE 2 Unlined cylinders may be over-bored or may require replacement.

6.8.1.9 The use of tapped bolt holes in pressure parts shall be minimized. To prevent leakage in pressure sections of casings, metal equal in thickness to at least half the nominal bolt diameter, in addition to the allowance for corrosion shall be left around and below the bottom of drilled and tapped holes.

6.8.1.10 Bolting shall be furnished as specified in 6.2.

6.8.1.11 Cylinder heads, stuffing boxes for piston rod pressure packing, clearance pockets, and valve covers shall be fastened with studs. The fastening configuration shall be designed so that these component parts can be removed without removing any studs.

6.8.1.12 Cylinder supports shall be designed to avoid misalignment and resulting excessive rod runout during the warm-up period and at actual operating temperature. The support shall not be attached to the outboard cylinder head, unless agreed. The cylinder support design shall be flexible in the direction of the piston rod center line to allow for the thermal growth and axial stretch of the cylinder along this line. The pulsation suppression devices shall not be used to support the compressor cylinder.

6.8.1.13 Where valve covers with radial captured O-rings are used, two extra-long studs 180 degrees apart shall be provided for each cover to ensure the cover O-ring clears the cylinder valve-port bore before the valve cover clears the studs. Extra-long studs shall be capable of having a full-threaded nut when the O-ring is clear of cylinder valve-port sealing bore.

6.8.1.14 Valve cage designs shall be of the cylindrical type held in place by a circular contact cover. Center-bolt design shall not be furnished (see Annex I for preferred approach).

6.8.1.15 The surface finish of valve port O-ring sealing surfaces shall not exceed an arithmetic average roughness Ra of 1.6 μm (64 $\mu\text{in.}$). Valve ports shall include an entering bevel for the O-ring.

6.8.1.16 Drain connections shall be supplied on external bottles used as clearance pockets.

6.8.2 Cylinder Connections

6.8.2.1 General

6.8.2.1.1 All openings or nozzles for piping connections on cylinders shall be DN 20 ($3/4$ NPS) or larger and shall be in accordance with ISO 6708. Sizes DN 32, DN 65, DN 90, DN 125, DN 175, and DN 225 ($1\frac{1}{4}$ NPS, $2\frac{1}{2}$ NPS, $3\frac{1}{2}$ NPS, 5 NPS, 7 NPS, and 9 NPS) shall not be used.

6.8.2.1.2 All connections shall be flanged or machined and studded, except where threaded connections are permitted by 6.8.2.1.5. All connections shall be suitable for the MAWP of the cylinder. Flanged connections may be integral with the cylinder or, for cylinders of weldable material, formed by butt-welded pipe nipple or transition piece and shall terminate with a welding-neck flange. Socket welded connections shall not be used.

6.8.2.1.3 Connections welded to the cylinder shall meet the material requirements of the cylinder, including impact values. All welding of connections shall be completed before the cylinder is hydrostatically tested (see 8.3.2).

6.8.2.1.4 Butt-welded connections, size DN 40 ($1\frac{1}{2}$ NPS) and smaller, shall be reinforced or gusseted.

6.8.2.1.5 For connections other than main process connections, threaded connections for pipe sizes not exceeding DN 40 ($1\frac{1}{2}$ NPT) may be used with purchaser's approval in the following cases:

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

6.8.2.1.6 Pipe nipples screwed or welded to the cylinder should be no more than 150 mm (6 in.) long and shall be a minimum of Schedule 160 seamless for sizes DN 25 (1 NPS) and smaller and a minimum of Schedule 80 for DN 40 ($1\frac{1}{2}$ NPS).

6.8.2.1.7 The nipple and flange materials shall meet the requirements of 6.14.7.9.

- **6.8.2.1.8** Pipe threads, where permitted, shall be taper threads in accordance with ISO 7-1 or ASME B1.20.1 as specified. If ISO 7-1 has been specified, tapered or straight internal threads shall also be specified.

6.8.2.1.9 Threaded connections shall not be seal welded.

6.8.2.1.10 Threaded openings not to be connected to piping shall be plugged with solid, round-head steel plugs in accordance with ASME B16.11. As a minimum, these plugs shall meet the material requirements of the pressure casing (or cylinder). Plugs with the possibility of later removal shall be of a corrosion-resistant material. Plastic plugs shall not be used. A process compatible thread lubricant of proper temperature specification shall be used on all threaded connections. Thread tape shall not be used.

6.8.2.1.11 Machined and studded connections shall conform to the facing and drilling requirements of ISO 7005-1 or ISO 7005-2 or ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47. Studs and nuts shall be furnished installed.

6.8.2.1.12 Machined and studded connections and flanges not in accordance with ISO 7005-1 or ISO 7005-2 or ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47, except for noncircular cylinder connections described in 6.8.2.2.1, shall be approved by the purchaser. Unless otherwise specified, the vendor shall supply mating flanges, studs, and nuts for these nonstandard connections.

6.8.2.1.13 Studded connections shall be furnished with studs installed. Threads at both ends of each stud shall be removed to allow the stud end to bottom in the hole. Anaerobic adhesive or similar epoxy bonding agents shall not be used.

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

6.8.2.1.15 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.

6.8.2.1.16 The finish of the gasket contact surfaces shall conform to ISO 7005-1 or ISO 7005-2 or ASME B16.5.

- **6.8.2.1.17** Each cylinder shall be provided with a DN 12 (NPT $1/2$) indicator tap at each end. If specified, each cylinder shall be provided with a flanged indicator tap at each end.
- **6.8.2.1.18** If specified, indicator valves shall also be provided. If indicator valves are not furnished, the tapped indicator holes shall be plugged in accordance with 6.8.2.1.10 and flanged connections shall be blinded.
- **6.8.2.1.19** Lube oil injection passages to the cylinder bore shall be drilled through a metal boss provided in the cylinder water jacket casting or weldment. If specified, cylinders for nonlubricated service shall not be drilled and tapped for lube oil injection.

6.8.2.2 Flanges

6.8.2.2.1 Flanges shall conform to ISO 7005-1 or ISO 7005-2 or ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 Series B as applicable, except as specified in 6.8.2.2.2 through 6.8.2.2.7 (see 6.8.2.1.16 for facing finish requirements). The details of any special connections, such as a lens joint, shall be submitted to the purchaser for review (see Annex E). For low-pressure cylinders, where noncircular connections are used, the vendor shall supply inlet and discharge transition pieces with the termination flange consistent with the agreed flange standards. The transition pieces shall be of the same grade of material as, or of a higher grade of material than the cylinder. The vendor shall supply all gaskets, studs, and nuts between the cylinder and transition piece.

6.8.2.2.2 Cast, ductile, and malleable iron flanges shall be flat faced and conform to the dimensional requirements of ASME B16.1 or ASME 16.42 or ISO 7005-2 as specified. PN 20 (Class 125) flanges shall have a minimum thickness equal to PN 50 (Class 250) for sizes DN 200 (NPS 8) and smaller.

6.8.2.2.3 Steel flanges shall conform to the dimensional requirements of ISO 7005-1, ASME B16.5, or ASME B16.47.

6.8.2.2.4 Nonferrous flanges shall conform to agreed standards.

6.8.2.2.5 Flat-face flanges with full raised face thickness are permitted on cylinders of all materials. Flanges in all materials that are thicker or have a larger outside diameter than required by the applicable flange standards are permitted. The dimensions of nonstandard (oversized) flanges shall be shown on the arrangement drawing in full detail.

NOTE Flat-faced flanges, in lieu of recessed or female face flanges, are typically needed to permit removal of the cylinder without removing or springing piping or pulsation suppression devices. Ring type joints and lens type joints should be discussed between the purchaser and the vendor on a special requirement basis.

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

6.8.2.2.7 The flange gasket contact surface shall not have mechanical damage that penetrates the root of the grooves for a radial length of more than 30 % of the gasket contact width.

6.8.3 External Forces and Moments

The vendor shall define the maximum allowable nozzle loads at the vendor interfaces. These loads shall be referred to a coordinate system as shown on a drawing.

6.9 Valves and Unloaders

6.9.1 Valves

6.9.1.1 Average valve gas velocity shall be calculated as shown in Equation (1):

In SI units

$$W = F \times c_m / f \quad (1)$$

where

- W is the average gas velocity in m/s;
- F is the effective area of the cylinder bore; the area of the cylinder bore nearest the compressor crankshaft is the area of the crank-end of the cylinder bore less the cross-sectional area of the compressor piston rod in cm²;
- f is the product of the valve geometric lift area and the number of inlet or discharge valve per cylinder in cm²;
- c_m is the average piston speed in m/s.

In USC units

$$V = 288 \times D/A$$

where

- V is the average gas velocity in ft/min;
- D is the piston displacement per cylinder in ft³/min;
- A is the product of the valve geometric lift area and the number of inlet or discharge valves per cylinder in in.²

The valve lift used in Equation (1) shall be shown on the data sheets.

If the lift area is not the smallest area in the flow path of the valve, that condition shall be noted on the data sheet and the velocity shall be computed on the basis of the smallest area. Velocities calculated from Equation (1) should not be confused with effective velocities based on crank angle, degree of valve lift, unsteady flow, and other factors.

NOTE The velocity computed from Equation (1) is not necessarily a representative index for valve power loss or disk/plate impact.

6.9.1.2 Valve and unloader designs shall be suitable for operation with all gases specified. Each individual unloading device shall be provided with a visual indication of its position and its load condition (loaded or unloaded).

6.9.1.3 The valve design shall be such that valve assemblies cannot be inadvertently interchanged or reversed. For example, it shall not be possible to fit a suction valve assembly into a discharge port, nor a discharge valve assembly into a suction port, nor shall it be possible to insert a valve assembly upside down.

6.9.1.4 Valve assemblies (seat and guard) shall be removable for maintenance. Valve-to-cylinder gaskets shall be solid metal. Valve-cover-to-cylinder sealing may be achieved with gaskets (either solid metal, flexible graphite type, or metal jacketed) or with O-ring type seals.

6.9.1.5 The valve and cylinder designs shall be such that neither the valve guard nor the assembly bolting can fall into the cylinder even if the valve assembly bolting breaks or unfastens. Hanging-guard type valves require purchaser approval.

6.9.1.6 All under-slung valves shall be provided with a retention device to hold the complete valve assembly in position while the cover is removed or installed.

6.9.1.7 The ends of coil-type valve springs shall be squared and ground to protect the plate against damage from the spring ends.

6.9.1.8 The vendor shall conduct a valve dynamic study to optimize the valve element motion, impacts, and efficiencies. The study shall include a review of all operating gas densities and load conditions. The report shall define the assumptions used in the study.

6.9.1.9 When nonmetallic valve plates or disks are furnished, flatness and surface finish shall be controlled so that adequate sealing occurs in operation. The vendor shall provide the properties of nonmetallic valve element materials. These properties shall include usable temperature range, chemical compatibility, and material type. Metal valve disks or plates, nonmetallic valve plates or disks, when furnished, shall be suitable for installation with either side sealing and shall be finished on both sides to an Ra of 0.4 μm (16 $\mu\text{in.}$) or better. Valve seats and sealing surfaces shall also be finished to an Ra of 0.4 μm (16 $\mu\text{in.}$) or better.

6.9.2 Unloaders

- **6.9.2.1** If cylinder valve unloading is required, the type of unloader provided (finger-, port-, or plug-type) shall be specified. Valve assembly lifters shall not be used. When finger-type valve unloaders are used for capacity control, all inlet valves of the cylinder end involved shall be so equipped. Use of less than a full complement of suction valve finger-type unloaders requires the purchaser's approval.

6.9.2.2 Where plug-type unloaders are used for capacity control, the number of unloaders is determined by the area per plug opening, the total of which shall be equal to or greater than half of the total geometric lift area of all suction valves on that end. The unloader assembly shall positively guide the plug to the seat.

6.9.2.3 When unloaders are used only for start-up and not for capacity control, consideration should be given to using a reduced number of unloaders.

- **6.9.2.4** Unloaders shall be pneumatically, hydraulically, or electromechanically actuated as specified. Individual hand-operated unloaders or manual overrides on actuated unloaders shall not be used. The vendor shall provide the user with information regarding the proper sequencing for unloader operation. See 7.8.2.4.

NOTE Malfunctioning and/or incorrect sequencing of unloaders can result in compressor damage.

6.9.2.5 For turbine-driven, geared applications, cylinder unloaders shall be provided on each cylinder end for emergency shutdown.

6.9.2.6 Unloaders shall be designed so that the operating fluid used for unloading cannot mix with the gases being compressed, even in the event of failure of the diaphragm or another sealing component. A threaded gas vent connection shall be provided at the stem packing.

6.9.2.7 Unloader sliding push rods exposed to atmospheric conditions shall be of corrosion-resistant material.

6.10 Pistons, Piston Rods, and Piston Rings

6.10.1 Connection of Piston-to-Piston Rod

Pistons that are removable from the rod shall be attached to the rod by a shoulder and nut(s) design or a multi-through-bolt design. Other proven attachment methods may be used, and in such cases, they shall be noted in the proposal. Mechanical or hydraulic methods are acceptable for tightening piston nuts. Slugging (hammer) wrenches shall not be used for this procedure.

As a basic requirement, the manufacturer's tightening procedure shall ensure a minimum preload in the connection of 1.5 times the maximum allowable continuous gas loading.

6.10.2 Connection of Piston Rod to Crosshead

6.10.2.1 Piston rods shall be connected to the crosshead by the following:

- a) a direct connection, where the rod is threaded into the crosshead (e.g. jam nut design or a multi-jackbolt jam nut design), or
- b) an indirect connection, where the rod is not threaded into the crosshead.

The attachment method shall be described in the proposal. Mechanical or hydraulic methods are acceptable for tightening. Slugging wrenches for this procedure shall not be used.

6.10.2.2 Positive locking of the nut shall be provided for direct connection methods. Where preload is achieved by hydraulic or multi-jackbolt tensioning methods, which ensure the proper preload, positive locking is not required.

6.10.2.3 The manufacturer's tightening procedure shall ensure a minimum preload in the connection equal to 1.5 times the maximum allowable continuous pin load minus the inertial effects of the crosshead.

6.10.3 Pistons

6.10.3.1 Hollow pistons (single piece or multi-piece) shall be continuously self-venting; i.e. they shall depressure when the cylinder is depressurized. Acceptable methods of venting include a hole located in the head-end face of the piston in the form of a single hole 3 mm ($\frac{1}{8}$ in.) in diameter, a hole at the bottom of the piston ring groove, or a spring-loaded relief plug in the outer-end face of the piston.

6.10.3.2 All pistons shall be supplied with nonmetallic rider bands. Rider bands shall be designed to prevent them acting as piston rings.

NOTE Vertical cylinders with labyrinth pistons may not require rider bands.

- **6.10.3.3** Piston ring grooves shall be wear-resistant.

6.10.3.4 For nonlubricated, horizontal cylinders, the bearing load calculated from Equation (2) on rider bands shall not exceed 0.035 N/mm² (5 lbf/in.²) based on the mass of the entire piston assembly plus half the mass of the rod divided by the projected area of a 120° arc of all rider bands [see Equation (2)].

For lubricated horizontal cylinders, the bearing load calculated from Equation (2) on rider bands, if used, shall not exceed 0.07 N/mm² (10 lbf/in.²).

$$L_B = \frac{M_{PA} + (M_R/2)}{(0.866 \times D \times W)} \quad (2)$$

where

L_B is the bearing load on rider band in N/mm² (lbf/in.²);

M_{PA} is the weight of piston assembly in N (lbf);

M_R is the weight of piston rod in N (lbf);

D is the cylinder bore diameter in mm (in.);

W is the total width of all rider bands in mm (in.).

NOTE When meeting the bearing load requirement results in an excessively wide rider band, multiple rider bands are preferred.

6.10.3.5 Rider bands shall not overrun single-hole valve ports or liner counter-bores by more than half the width of the rider band. When the cylinder configuration leads the rider band to overrun the valve ports by more than half the band width, the port design shall be of the multiple-drilled-hole type to provide sufficient support for the rider band.

6.10.4 Piston Rods

6.10.4.1 Unless otherwise specified, all piston rods, regardless of base material, shall be coated with a wear-resistant material. The material and surface treatment of piston rods shall be chosen to maximize rod and piston rod pressure packing life and shall be proposed by the vendor at the time of purchase for the purchaser's acceptance. Coatings shall comply with 6.10.4.2. Piston rod base material and coatings for use in corrosive environments shall be suitable for the service and operating conditions specified.

Uncoated piston rod may be proposed when the expected life equals or exceeds that of a coated rod for the specified operating conditions. Uncoated piston rods shall be surface-hardened in the packing area to a hardness of at least Rockwell C50 and shall be inspected for cracking by magnetic particle examination.

6.10.4.2 When coatings are used, piston rods shall be continuously coated from the piston rod packing through the oil wiper travel areas. The coating material shall be properly sealed to prevent corrosion of the base material at the interface of the coating. Techniques that require temperatures high enough to permanently affect the mechanical characteristics of the base material shall not be used. High-velocity and high-impact thermal coating processes are acceptable for the coating of piston rods. Metal spray techniques requiring roughening of the surface of the base metal shall not be used. Use of a subcoat (other than a binder layer) under the main coating shall not be used.

Piston rods that have been previously induction-hardened shall not be coated with a wear-resistant material over the induction-hardened case.

6.10.4.3 The base material of piston rods used in H₂S service shall be in accordance with NACE MR0103 (see 6.14.1.9). When this requirement results in insufficient surface hardness for wear resistance, a proven surface treatment or coating shall be proposed for purchaser's approval.

6.10.4.4 Tolerances for finished rods shall be 12.5 µm (0.0005 in.) for roundness and 25 µm (0.001 in.) for diametral variation over the length of the rod.

The surface finish in the packing areas for lubricated and nonlubricated services shall be 0.15 µm to 0.4 µm (6 µin. to 16 µin.) Ra.

NOTE Smoother finishes can be considered for high pressures or for particular material combinations where experience indicates that such finishes can result in improved performance.

6.10.4.5 Piston rods with threads shall be furnished with rolled threads having a polished thread relief area.

6.10.4.6 The vendor shall state in the proposal the rod material and type of connection (see Figure F.5, Figure F.6, and Figure F.7).

6.10.4.7 Threads shall be rolled after heat treatment. If NACE MR0103 is applied, the rod material will be considered acceptable as long as the base hardness and yield strength remain within the specified NACE values. An increase in hardness around thread surface due to thread rolling is acceptable as long as the base hardness meets NACE requirements.

6.10.4.8 The use of tail rods requires purchaser's written approval. When tail rods are deemed acceptable, tail rod packing assemblies shall be equal in design and quality to packing assemblies for piston rods. Tail rod surface treatment and finish shall be the same as for the piston rod. Tail rod design shall include a device to positively prevent the tail rod from being ejected in the event that it becomes disconnected from the piston/piston rod. Rod runout measured at the tail rod packing assembly shall not exceed the limits defined in 6.3.1.

6.11 Crankshafts, Bearings, Connecting Rods, Crossheads, and Crankcases

6.11.1 Crankshafts

For compressors above 150 kW (200 hp), crankshafts shall be forged in one piece and shall be heat treated and machined on all working surfaces and fits. The use of removable counterweights is acceptable. For compressors less than or equal to 150 kW (200 hp), ductile iron is acceptable for crankshafts. The crankshafts shall be free of sharp corners. Main and crankpin journals shall be ground to size. Drilled holes or changes in section shall be finished with generous radii and shall be highly polished. Forced lubrication passages in crankshafts shall be drilled. See 8.2.2.3.2 for ultrasonic testing of crankshafts.

6.11.2 Bearings

6.11.2.1 For compressors above 150 kW (200 hp), replaceable, precision-bored shell (sleeve) crankpin bearings and main bearings shall be used. For compressors equal to or less than 150 kW (200 hp), tapered roller type bearings are acceptable for main bearings. Cylindrical, roller, or ball type bearings may be used only with the purchaser's approval.

NOTE The use of rolling element bearings can affect the service life of the compressor.

6.11.2.2 When rolling element bearings are allowed, they shall be supplied in compliance with 6.11.2.3 and 6.11.2.4.

6.11.2.3 Rolling element bearing's basic rating life, L_{10h} , shall be at least 50,000 hours with a continuous operation at rated conditions, and at least 32,000 hours at maximum radial and axial loads at rated speed. The basic rating, L_{10h} life, shall be calculated in accordance with ISO 281.

6.11.2.4 Rolling element bearings shall be secured to the shaft by a shrink fit and fitted into housings in accordance with the vendor recommendations.

6.11.3 Connecting Rods

6.11.3.1 For compressors above 150 kW (200 hp), connecting rods shall be forged steel with removable caps on the crankpin end. For compressors less than or equal to 150 kW (200 hp), ductile iron, steel plate, or cast steel connecting rods are acceptable.

6.11.3.2 Connecting rods shall be free of sharp corners. Forced lubrication passages shall be drilled. Drilled holes or changes in section shall be finished with generous radii and shall be highly polished.

6.11.3.3 Crosshead pin bushings shall be of the replaceable precision-bored type and shall be securely locked in place.

6.11.3.4 Connecting rod bolts shall have rolled threads.

6.11.4 Crossheads

6.11.4.1 Crossheads shall be made of steel or ductile iron.

6.11.4.2 The crosshead top and bottom shoes shall be replaceable. Facilities shall be provided for the adjustment of crosshead clearance and alignment. Field machining for adjustment of clearances shall not be used. Crossheads without replaceable or adjustable shoes shall be approved by the purchaser.

6.11.4.3 Adequate openings shall be provided to service crosshead assemblies.

6.11.5 Crankcases

- If specified, the crankcase shall be provided with one or more device(s) to protect against rapid pressure rise. These devices shall incorporate a flame-arresting mechanism and a rapid closure device to minimize reverse flow and be directed away from the personnel area. Sizing criteria shall be agreed considering crankcase environments, oil mist only or hydrocarbon gas, and potential pressure rise within the crankcase.

When not an integral part of the frame, crosshead housings shall be attached to the crankcase with studs. A metal-to-metal joint, prepared with suitable sealant, shall be used between the crosshead housing and crankcase, the crosshead housing and distance piece, and the distance piece and cylinder.

6.12 Distance Pieces

6.12.1 Distance Piece Types

- **6.12.1.1** The purchaser shall specify the type of distance piece to be supplied. The types are listed in 6.12.1.2 through 6.12.1.5 (see Figure F.2).

6.12.1.2 Type A—Short, single-compartment distance piece used only for lubricated service when oil carryover (at the wiper packing and piston rod pressure packing) is acceptable. In this application, part of the piston rod may alternately enter the crankcase (crosshead housing) and the piston rod pressure packing. This arrangement shall not be used when cylinders are lubricated with oils not compatible with the crankcase oil (see 7.5.3.1.11).

NOTE Type A distance pieces are used only for nonflammable or nonhazardous gases.

6.12.1.3 Type B—Long single-compartment distance piece used for nonlubricated service or for lubricated service where oil carryover is not acceptable. No part of the piston rod shall alternately enter the crankcase (crosshead housing) and the piston rod pressure packing. The piston rod shall be fitted with an oil slinger of spark resistant material and of a split design for easy access to the piston rod pressure packing.

- **6.12.1.4** Type C—Long/long two-compartment distance piece designed to contain flammable, hazardous, or toxic gases. No part of the piston rod shall alternately enter the wiper packing and partition packing or the partition packing and piston rod pressure packing. The piston rod shall be fitted with a frame-end compartment oil slinger of spark resistant material and of a split design for easy access to the packing. A segmental packing shall be provided between the two compartments. If necessary, provisions for lubrication of the partition packing shall be furnished by the vendor. If specified, provisions for the injection of buffer gas shall also be provided.

NOTE The Type C distance piece with two oil slingers, one in each compartment, is not normally used on process compressors. This type of distance piece is used only for special services such as oxygen service. This distance piece design causes the overall length of the gas end assembly to become excessively large, thus causing the overall width of the compressors to become large and therefore increasing foundation requirements. Uses of such distance pieces can cause piston-rod diameters to increase because of the column effect of excessively long piston rods.

- **6.12.1.5** Type D—Long/short two-compartment distance piece designed to contain flammable, hazardous, or toxic gases. No part of the piston rod shall alternately enter the wiper packing and the intermediate partition packing. The rod shall be fitted with a frame-end compartment oil slinger of spark resistant material and of a split design for easy access to the packing. Segmental packing shall be provided between the two compartments. Provisions for lubrication of this segmental packing, if necessary, and, if specified, for the injection of buffer gas shall be furnished by the vendor.

NOTE The buffer gas should be a nonflammable, nonreactive, or inert gas such as nitrogen.

6.12.2 Distance Piece Requirements

- **6.12.2.1** Access openings of adequate size shall be provided in all distance pieces to permit removal of the assembled piston rod pressure packing case. On Type D, two-compartment distance pieces, the compartment adjacent to the cylinder (the outboard compartment) may be accessible through a removable partition. Distance piece compartments shall be equipped with gasketed solid metal covers. If specified, screened safety guards or louvered weather covers may be used for nonflammable or nonhazardous gases.

6.12.2.2 Distance piece design shall be such that the packing rings can be removed and replaced without removal of the piston rod.

NOTE In the case of small compressors, it can be easier to remove the piston rod.

6.12.2.3 For distance pieces with solid metal covers, the distance piece, partitions, covers, bolting, and partition packing shall be designed for a minimum of 3 bar (45 psig) MAWP. For Types C and D, each compartment shall be capable of the full MAWP independently. The vendor shall indicate the MAWP of the distance piece.

6.12.2.4 The purchaser shall specify the maximum operating pressure on the vent system. Vendor shall propose corrective measures if the distance piece MAWP is lower than the specified maximum operating vent pressure.

- **6.12.2.5** Each distance piece compartment shall be provided with the following connections (see Figure F.2):
 - a) top vent connection at least DN 40 (NPT 1½);
 - b) bottom drain connection;
 - c) if specified, a purge or vacuum connection;
 - d) a piston rod pressure packing vent connection below the piston rod to facilitate liquid draining of the piston rod pressure packing case;
 - e) when required, piston rod pressure packing lubrication;
 - f) where piston rod pressure packing case cooling is required or specified, inlet and outlet connections on the distance piece suitably arranged to facilitate draining and venting.

See Annex H for vent and purge system schematics. Closed, sealed, or purged distance pieces not utilizing the DN 40 (NPT 1½) free vent connection shall be equipped with a relief device. The vendor shall provide the sizing criteria for the vent connection.

6.12.2.6 Double compartment distance pieces shall be equipped with a buffer gas connection on the inboard distance piece. The inboard distance piece shall preferably be buffered with a pressure of at least 0.5 bar (7 psi) above the outboard distance piece pressure to avoid leakage of toxic or hazardous gas toward inboard compartment.

The buffer gas purge pressure shall be limited to the maximum allowable pressure for the distance piece components (see 6.12.2.3). Some buffer gas will flow into the compressor frame. Frame venting shall allow an outlet for this flow.

6.12.2.7 All external connections, except the top vent, shall be at least DN 25 (NPT 1).

6.12.2.8 Distance piece compartments with internal reinforcing ribs shall have internal drain provisions through the ribs.

6.12.2.9 Unless otherwise specified, all external drain, vent, and purge piping and equipment shall be provided by the purchaser.

6.12.2.10 For Type A and Type B distance pieces with solid metal covers, positive seal rings shall be provided at the wiper packing. For Type C and Type D distance pieces with solid metal covers, positive seal rings shall be provided at both the wiper packing and the intermediate partition packing. These seal rings shall be of the segmental type that effectively seal at atmospheric pressure (without purge) to prevent contamination of the crankcase oil by leakage from the piston rod pressure packing (see 6.13.1.5).

6.13 Packing Cases and Piston Rod Pressure Packing

6.13.1 General

- **6.13.1.1** All oil-wiper packing, partition packing, and piston rod pressure packing shall be segmental rings with garter springs of a nickel chromium alloy (such as Inconel 600 or X750). If specified, shields shall be provided in the crosshead housings over the oil return drains from the wiper-packing stuffing boxes to prevent splash flooding.

6.13.1.2 Packing case flanges shall be bolted to the cylinder head or to the cylinder with no less than four bolts. Flanges shall be of steel for flammable, hazardous, or toxic gas service. Packing cases shall be pressure rated at least to the MAWP of the cylinder. Packing case assemblies shall have positive alignment features to align all stationary components (e.g. pilot fits, body-fitted tie bolts).

6.13.1.3 For flammable, hazardous, toxic, or wet gas service, the piston rod pressure packing case shall be provided with a common vent and drain, below the piston rod, piped by the vendor to the lower portion of the distance piece. See Annex F.

6.13.1.4 Adequate radial clearance shall be provided between the piston rod and all adjacent stationary components to prevent contact when the maximum allowable wear occurs on the piston rider bands.

6.13.1.5 Oil wiper packing shall be supplied to effectively minimize oil leakage from the crankcase. Oil wiper leakage shall not exceed 5 drops per minute.

6.13.1.6 Unless otherwise specified, the manufacturer shall provide suitable devices and instructions to enable the piston rod to be passed through the completely assembled piston rod pressure packing without damage.

NOTE There is a risk of packing damage when using entering sleeves. However, when the outside diameter of the entering sleeve is equal to the outside diameter of the rod, the risk is reduced when the manufacturer's instructions are followed.

6.13.1.7 Unused connections in the packing cases shall be plugged with threaded steel plugs.

6.13.2 Piston Rod Pressure Packing Case Cooling Systems

6.13.2.1 Unless otherwise specified, the criteria given in 6.13.2.2 through 6.13.2.9 shall be followed for the cooling of piston rod pressure packing cases.

6.13.2.2 Packing cases shall be designed for liquid cooling with totally enclosed cooled cups for the following applications:

- a) all nonlubricated packing rings above 17 bar (250 psig);
- b) lubricated nonmetallic rings, when the cylinder MAWP is above 35 bar (500 psig);
- c) all materials, lubricated or nonlubricated, when the cylinder MAWP is above 100 bar (1500 psig).

6.13.2.3 When liquid cooled packing cases are furnished:

- a) O-rings shall be used to seal coolant passages between cups;
- b) O-rings shall be fully captured in grooves, both on the inside and outside diameter of the O-ring; a small relief recess of 0.5 mm to 1 mm (0.015 in. to 0.030 in.) shall be provided around the captured O-ring to detect gas leakage; O-rings that encircle the piston rod are not allowed;
- c) cases are to be tested for leakage on the coolant side to a gauge pressure not less than 8 bar (115 psig).

6.13.2.4 When the packing case is cooled by forced circulation, the vendor shall supply internal tubing and fittings of austenitic stainless steel.

6.13.2.5 When cooling of piston rod pressure packing is required, the vendor shall be responsible for determining and informing the purchaser of minimum requirements such as flow, pressure, pressure drop, and temperature, as well as any filtration and corrosion protection criteria. The inlet packing case coolant temperature should not exceed 35 °C (95 °F). The coolant pressure drop through the packing case shall not exceed 1.7 bar (25 psig).

NOTE Packing efficiency increases with low coolant temperature.

- **6.13.2.6** If specified, the vendor shall supply a closed liquid cooling system.

NOTE See Figure F.1 and Figure F.3 for typical drawing on packing case cooling systems.

- **6.13.2.7** If specified, and for all sour or toxic gas services, this system shall be separate from the cylinder jacket cooling system.

6.13.2.8 A coolant filter having a 125 µm (125 microns) nominal rating or better and located external to the distance piece shall be provided. If external tubing is provided by the vendor, it shall be austenitic stainless steel.

- **6.13.2.9** If specified, the packing vent temperature shall be monitored.

6.13.3 Buffer Gas System

- **6.13.3.1** If specified, a buffer gas system shall be supplied to reduce process gas emissions. The buffer gas should be a nonflammable, nonreactive, or inert gas such as nitrogen. The buffer system scope and design shall be agreed.

- **6.13.3.2** If specified, the piston rod pressure packing shall include venting and buffer gas cups with side-loaded packing rings in the adjacent sealing cups. The packing vent/drain shall be routed to a liquid collection pot.

NOTE See the arrangement in Figure H.7.

6.13.3.3 The piston rod pressure packing buffer gas supply pressure shall be at least 1 bar (15 psi) higher than the vent system pressure at connection points A or G in Annex F, Figure F.2 (in the outboard distance piece), whichever is higher.

- **6.13.3.4** A liquid collection pot shall be supplied. The purchaser shall specify the vent and drain locations and conditions. The collection pot shall not be combined with the distance piece drains.
- **6.13.3.5** If specified, intermediate partition packing shall be buffered in addition to the piston rod pressure packing.
- **6.13.3.6** If specified, the distance piece shall be buffered. On dual compartment distance pieces, the purchaser shall specify which compartment shall be buffered and which compartment shall be vented.
- **6.13.3.7** If specified, the distance piece vent pressure shall be monitored.

6.14 Materials

6.14.1 General

6.14.1.1 Unless otherwise specified, the materials of construction shall be selected by the manufacturer based on the operating and site environmental conditions specified.

NOTE Table G.1 lists material typically used.

6.14.1.2 The materials of construction for all major components shall be clearly stated in the vendor's proposal. Materials shall be identified by reference to applicable international standards, including the material grade. Where international standards are not available, internationally recognized national standards (such as AISI or ASTM) or other standards may be used. 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.

6.14.1.3 Copper and copper alloys shall not be used for parts of compressors or auxiliaries in contact with corrosive gas or with gases capable of forming explosive copper compounds. Nickel-copper alloys (UNS N04400 Monel or its equivalent), bearing babbitt, bearings, and precipitation-hardened stainless steels, are excluded from this requirement. Where agreed, copper-containing materials may be used for packing on lubricated compressors or other specific purposes.

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

- **6.14.1.4** The vendor shall specify the tests and inspection required to ensure that materials selected are satisfactory for the service intended. Such tests and inspections shall be listed in the proposal. Additional tests and inspections shall be specified by the purchaser.

NOTE Additional tests and inspections can be specified, especially for materials used in critical components or in critical services.

6.14.1.5 Minor parts such as nuts, springs, washers, gaskets, and keys shall have corrosion resistance at least equal to that of specified parts in the same environment.

- **6.14.1.6** The purchaser shall specify the presence of any agents (including trace quantities) in the motive and process fluids and in the site environment that may cause corrosion.

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

NOTE 2 If amines are present, refer to API 945 for information on amine cracking and its prevention.

NOTE 3 Guidelines to avoid caustic stress corrosion cracking can be found in NACE SP0403.

When the purchaser has specified the presence of chlorides in any fluid, materials exposed to that fluid shall be selected and processed in accordance with the requirements of API 571. Chloride concentrations greater than 50 ppm may require alternate material selection.

6.14.1.7 If austenitic stainless steel parts exposed to conditions that may promote intergranular corrosion are to be fabricated, hard faced, overlaid, or repaired by welding, they shall be made of low-carbon or stabilized grades.

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.

6.14.1.8 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-seize compound suitable for the process temperatures and compatible with the material(s) and specified process fluid(s).

NOTE The required torque values to achieve the necessary bolt preload will vary considerably depending if anti-seize compound is used on the threads.

- **6.14.1.9** All materials exposed to H₂S gas service shall be in accordance with the requirements of NACE MR0103. Ferrous materials not covered by NACE MR0103 shall not have a yield strength exceeding 620 N/mm² (90,000 psi) nor a hardness exceeding Rockwell C22. When there are trace quantities of wet H₂S known to be present, or if there is any uncertainty about the amount of wet H₂S that may be present, the purchaser shall note on the data sheets that materials resistant to sulfide stress corrosion cracking are required.

Hardness requirements for valve seats and piston rod surface can be in excess of NACE provisions (see 6.10.4.3). Similar exceptions can be made for valve plates, springs, and unloader components, where greater hardness has been proven necessary. Agreement shall be reached on requirements for alternative alloys or special heat treatment.

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

6.14.1.10 Components that are fabricated by welding shall be post-weld heat treated, if required, so that both the welds and the heat-affected zones meet the tensile strength and ductility requirements and, when required, hardness and impact requirements.

6.14.1.11 On multiple service and multistage machines, NACE requirements shall apply to all fasteners and other interchangeable parts of all cylinders to avoid possible inadvertent interchange of parts.

6.14.1.12 The vendor shall select materials to avoid conditions that can result in electrolytic corrosion. Where such conditions cannot be avoided, the purchaser and the vendor shall agree on the material selection and any other precautions necessary.

NOTE When dissimilar materials with significantly different electrical potentials are placed in contact in the presence of an electrolytic solution, galvanic couples that can result in serious corrosion of the less noble material can be created. The NACE *Corrosion Engineer's Reference Book* is one resource for selection of suitable materials in these situations.

6.14.1.13 Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or lower temperatures. Therefore, only steels made to fine-grain practice are acceptable. Steel made to a coarse austenitic grain size practice (such as ASTM A515) shall not be used.

6.14.1.14 O-ring materials shall be compatible with all specified services. O-rings for high-pressure services shall not be damaged upon rapid depressurization (explosive decompression).

NOTE Susceptibility to explosive 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.

6.14.1.15 Bolting shall be in accordance with ASTM A193 Grade B7 or Grade B7M. Carbon steel nuts such as ASTM A194, Grade 2H shall be used.

Bolting and nuts in accordance with ASTM A320 shall be used for temperatures below $-30\text{ }^{\circ}\text{C}$ ($-20\text{ }^{\circ}\text{F}$). The grade of ASTM A320 will depend on design, service conditions, mechanical properties, and low-temperature characteristics.

6.14.2 Pressure-containing Parts

6.14.2.1 Materials for pressure-containing cylinder parts shall be used in conjunction with the MAWP in Table 3. All material selections shall be subject to review by the purchaser.

NOTE Higher design pressures can be permitted based on detailed engineering analysis.

Table 3—Maximum Gauge Pressures for Cylinder Materials

Material	Maximum Allowable Working Pressure	
	barg	psig
Gray cast iron	70	1000
Ductile iron	100	1500
Cast steel	180	2500
Forged steel	No limitation	
Fabricated steel	85	1250

6.14.2.2 Steel compressor cylinders shall be equipped with steel heads.

6.14.2.3 The use of fabricated cylinders shall be stated in the proposal and shall be approved by the purchaser.

6.14.3 Castings

6.14.3.1 General

6.14.3.1.1 Castings shall be free from porosity, hot tears, shrink holes, blowholes, cracks, scale, blisters, and similar injurious defects. Surfaces of castings shall be cleaned by sandblasting, shot-blasting, chemical cleaning, or other standard methods. Mold-parting fins and the remains of gates and risers shall be chipped, filed, or ground flush. Castings shall not be impregnated or surface sealed.

6.14.3.1.2 The use of chaplets in pressure castings shall be held to a minimum. Where chaplets are necessary, they shall be clean and corrosion free (plating is permitted) and of a composition compatible with the casting.

6.14.3.1.3 Fully enclosed cored voids, which become fully enclosed by methods such as plugging, welding, or assembly, shall not be used.

6.14.3.1.4 Pressure-retaining castings of gray iron shall be produced in accordance with ASTM A278.

6.14.3.1.5 Pressure-retaining castings of steel shall be produced in accordance with ASTM A216.

6.14.3.2 Ductile Iron Castings

6.14.3.2.1 Pressure-retaining castings of ductile iron shall be produced in accordance with ASTM A395. The production of these castings shall conform to the conditions specified in 6.14.3.2.2 through 6.14.3.2.4. Ductile iron castings for non-pressure-retaining components, such as crossheads, shall be produced in accordance with either ASTM A395 or ASTM A536.

6.14.3.2.2 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. All three specimens shall have an impact value not less than 12 J (9 ft-lb) and the mean of the three specimens shall not be less than 14 J (10 ft-lb) at room temperature.

6.14.3.2.3 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. This test block shall be tested for tensile strength and hardness and shall be microscopically examined. Classification of graphite nodules under microscopic examination shall be in accordance with ASTM A247.

6.14.3.2.4 Brinell hardness readings shall be made on the actual castings at feasible critical sections such as section changes, flanges, and other accessible locations such as the cylinder bore and valve ports. Sufficient surface material shall be removed before hardness readings are made to eliminate any skin effect. Readings shall also be made at the extremities of castings at locations that represent the sections poured first and last. These readings shall be made in addition to Brinell readings on the keel and Y-blocks.

6.14.4 Forgings

Pressure-containing forgings shall be in accordance with ASTM A668.

6.14.5 Fabricated Cylinders and Cylinder Heads

6.14.5.1 When fabricated cylinders are allowed, they shall be designed based on an infinite fatigue life. The vendor shall conduct an engineering analysis that addresses the applicable loads, materials, weldments, and the geometry of the cylinder. The analysis shall ensure that the alternating stresses are limited to values that preclude the propagation of an existing internal defect.

6.14.5.2 Gas pressure-containing parts of cylinders and cylinder heads made of wrought materials or combinations of wrought and cast materials shall conform to the conditions specified in 6.14.5.3 through 6.14.5.13.

6.14.5.3 Plate subjected to alternating pressure loads used in cylinders and cylinder heads shall be subjected to the procedures in 6.14.5.4 through 6.14.5.6 after being cut to shape and before weld joint preparation.

6.14.5.4 If the plate is loaded in tension in the through-thickness direction, the piece shall be 100 % ultrasonically inspected in the area one plate-thickness on each side of the load-imposing member (see Figure 1).

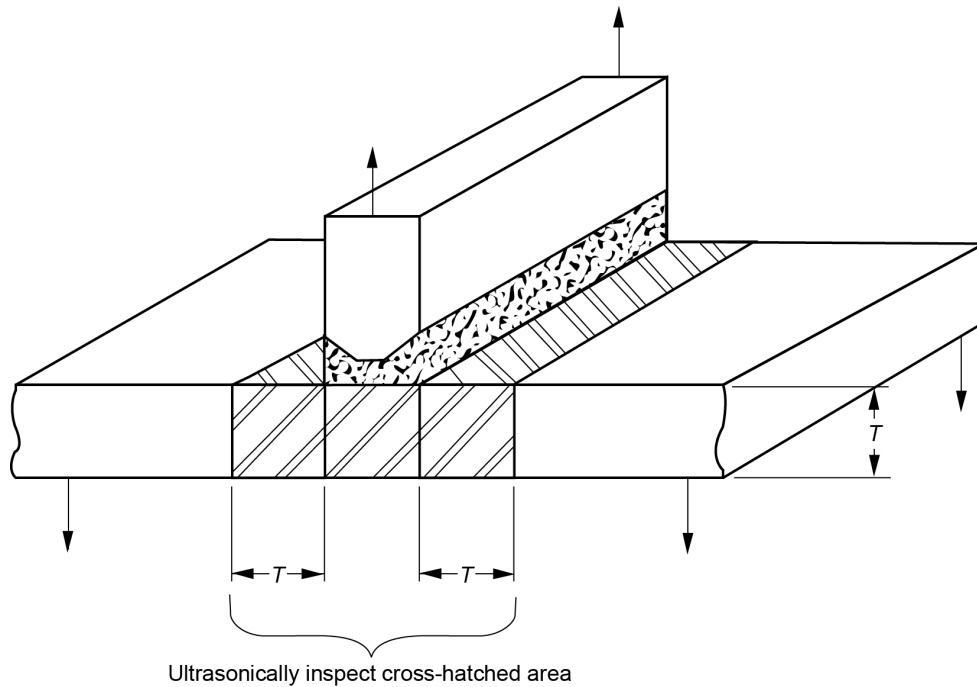


Figure 1—Plate Loaded in Tension in the Through-thickness Direction and Its Area Requiring Ultrasonic Inspection

6.14.5.5 If the plate is loaded in bending, the piece shall be 100 % ultrasonically inspected in the area one plate-thickness on each side of the load-imposing member (see Figure 2).

NOTE These procedures are intended to discover laminations or inclusions that can affect the load-carrying ability of the components.

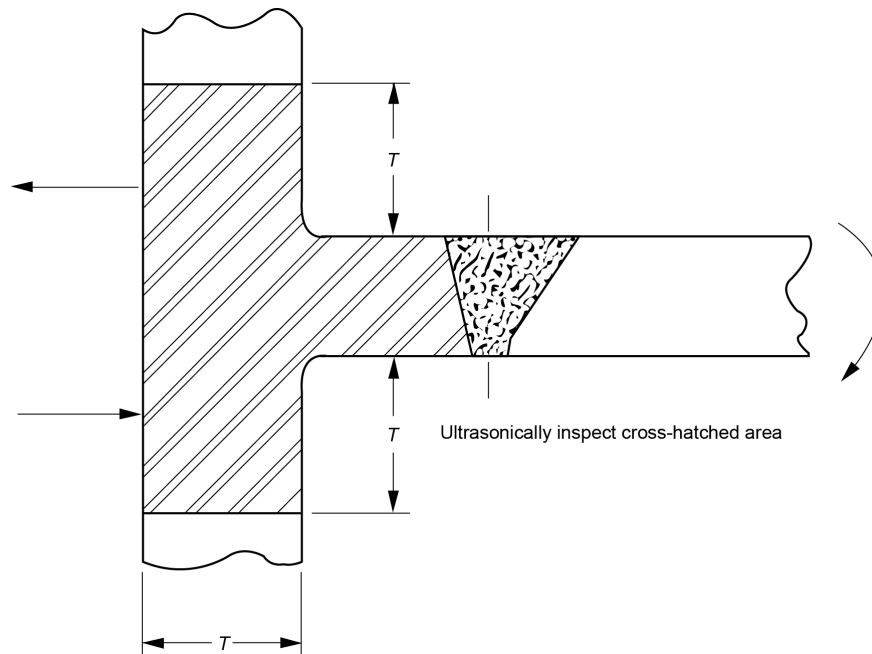


Figure 2—Plate Loaded in Bending and Its Area Requiring Ultrasonic Inspection

6.14.5.6 If the plate is axially loaded, ultrasonic inspection is not required (see Figure 3).

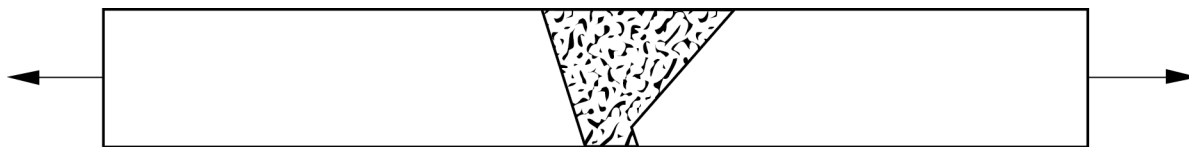


Figure 3—Axially Loaded Plate

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

- **6.14.5.8** Accessible surfaces of welds shall be inspected by magnetic particle or liquid penetrant examination after chipping or back-gouging and again after post-weld heat treatment. If specified, the quality control of welds that will be inaccessible on completion of the fabrication shall be agreed prior to fabrication.

6.14.5.9 Pressure-containing welds, including welds to horizontal- and vertical-joint flanges, shall be full-penetration (complete-joint) welds.

6.14.5.10 All fabricated cylinders and cylinder heads shall be post-weld heat treated, regardless of thickness (see 6.14.7.7).

6.14.5.11 All butt welds on the inner barrel of welded cylinders shall be 100 % examined radiographically. Other welds to the inner barrel shall be inspected radiographically where possible. If radiography is not possible, other methods such as ultrasonic examination shall be approved.

- **6.14.5.12** If specified, in addition to the requirements of 6.14.7.1, specific welds shall be subjected to 100 % radiography, magnetic particle inspection, or liquid penetrant inspection.
- **6.14.5.13** If specified, proposed cylinder, cylinder-head, and connection designs shall be made available for review and approval by the purchaser before fabrication. The drawings shall show weld designs, size, materials, and preweld and post-weld heat treatments.

6.14.6 Repairs to Castings and Forgings

6.14.6.1 Major repairs to pressure-containing parts, all repairs to moving parts subject to load reversals, and all repairs to crankshafts shall be undertaken only with the purchaser's written authorization. This requirement applies, but is not necessarily limited to, cylinder parts, piston and rod assembly components, and crosshead assembly components.

6.14.6.2 A major repair, for the purpose of purchaser notification, is any defect that equals or exceeds any of the following criteria:

- a) any repair of a pressure-containing part in which the depth of the cavity prepared for repair welding exceeds 50 % of the component wall thickness, and/or is longer than 150 mm (6 in.) in any direction;
- b) any situation where the total area of all repairs to the part under repair exceeds 10 % of the surface area of the part;
- c) any repairs to pressure-containing parts carried out after hydrostatic testing.

6.14.6.3 Before performing major repairs to pressure-containing parts, the vendor shall submit the following for the purchaser's written approval:

- a) sketches or photographs showing the defective area;
- b) proposed method of repair;
- c) materials to be used;
- d) welding procedure;
- e) proposed extent of testing or re-testing to prove the effectiveness of the repair.

All such repairs shall be properly documented for the purchaser's permanent record.

6.14.6.4 For non-pressure-containing components, the vendor shall make repairs in accordance with their internal quality procedures. These procedures shall be available for review by the purchaser at the manufacturer's plant.

When repairs of non-pressure-containing components are done, they shall be documented by the vendor. No repair is to be made without written approval of the vendor's engineering, quality-control, and manufacturing departments.

- **6.14.6.5** If specified, the purchaser shall be given notice of repairs to other major components, such as distance pieces, and crankcase.

6.14.6.6 Pressure-containing castings shall not be repaired by peening, or burning-in, or impregnating. Pressure-containing castings and forgings shall not be repaired by welding, plating, or plugging except as specified in 6.14.6.7 through 6.14.6.8.

6.14.6.7 Weldable grades of steel castings and forgings may be repaired by welding using a qualified welding procedure (see 6.14.7.3). After major weld repairs but before hydrostatic testing, the complete casting or forging shall be given a post-weld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metals.

6.14.6.8 Gray cast iron or ductile iron may be repaired by plugging within the limits specified in the applicable material standard such as ASTM A278 or ASTM A395, but shall not be repaired by welding.

Plugs shall not be used in the gas-pressure-containing wall sections of cylinders, in particular in the bore under the liner, unless approved by the purchaser.

When plugs are allowed, the holes drilled for plugs shall be carefully examined, using liquid penetrant, to ensure that all defective material has been removed.

6.14.6.9 Damaged threaded holes in castings may be mechanically repaired by use of threaded inserts or bushings when approved by the purchaser.

6.14.7 Welding

6.14.7.1 Welding of piping, pressure-containing parts, rotating parts and other highly stressed parts, weld repairs, and any dissimilar-metal welds shall be performed and inspected by procedures and operators qualified in accordance with the specified pressure design code or internationally recognized standards such as ASME *BPVC* Section VIII, Division 1, and ASME *BPVC* Section IX.

6.14.7.2 Welding of non-pressure-containing components such as cylinder supports, pulsations suppression device supports, baseplates, nonpressure ducting, lagging, and control panels shall be performed by welders qualified in accordance with an appropriate recognized standard such as AWS D1.1 or ASME *BPVC* Section IX or other purchaser-approved welding standard.

6.14.7.3 The vendor shall ensure that repair welds are properly heat treated and nondestructively examined.

Repairs shall be nondestructively tested by the same method used to detect the original flaw. The minimum level of inspection after the repair shall be by the magnetic particle method in accordance with 8.2.2.4 for magnetic material and by the liquid penetrant method in accordance with 8.2.2.5 for nonmagnetic material.

6.14.7.4 Connections welded to pressure-containing parts shall be installed as specified in 6.14.7.5 through 6.14.7.9.

- **6.14.7.5** If specified, in addition to the requirements of 6.14.7.1, specific welds shall be subjected to 100 % radiography or magnetic particle inspection or liquid penetrant inspection of welds.
- **6.14.7.6** If specified, proposed connection designs shall be submitted to the purchaser for acceptance before the start of fabrication. The drawings shall show weld designs, size, materials, and preweld and post-weld heat treatments.

6.14.7.7 All welds shall be heat treated in accordance with the specified pressure vessel code or an internationally recognized standard such as the ASME *BPVC* Section VIII, Division 1, Sections UW-10 and UW-40. For steels in H₂S service, heat treatment shall also be in accordance with NACE MR0103.

6.14.7.8 If post-weld heat treatment is required, it shall be carried out after all welds, including piping welds, have been completed.

6.14.7.9 Auxiliary piping welded to alloy steel casings and cylinders shall be of a material with the same nominal properties as the casing or cylinder material or shall be of low-carbon austenitic stainless steel. Other materials compatible with the casing or cylinder material and intended service may be used with the purchaser's approval.

6.14.7.10 Flux-core welding may be used for equipment in hydrogen service, upon written agreement of the purchaser after submission of weld procedures.

6.14.8 Low-temperature Service

- **6.14.8.1** The purchaser shall specify the minimum design metal temperature and concurrent pressure used to establish impact test and other material requirements.

NOTE Normally, this will be the lower of the minimum surrounding ambient temperature or minimum inlet gas temperature. The purchaser may specify a minimum design metal temperature based on properties of the process gas, such as auto-refrigeration at reduced pressures.

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

NOTE Design practices for low temperature services include the selection of fabrication methods, welding procedures, and materials for steel pressure-retaining parts to ensure that the ductile-to-brittle transition temperature is suitable for the service. The published design-allowable stresses for many materials in internationally recognized standards are based on minimum tensile properties. Some standards do not differentiate between rimmed, semi-killed, fully-killed hot-rolled, and normalized material, nor do they take into account whether materials were produced under fine- or course-grain practices.

6.14.8.3 All carbon and low-alloy steel pressure-containing components, including nozzles, flanges, and weldments, shall be impact tested in accordance with the requirements of ASME *BPVC* Section VIII, Division 1, Sections UCS-65 through 68, or the specified pressure design code. High-alloy steels shall be tested in accordance with ASME *BPVC* Section VIII, Division 1, Section UHA-51, or the specified pressure design code. For materials and thicknesses not covered by ASME *BPVC* Section VIII, Division 1 or the specified pressure design code, testing requirements shall be as specified by the purchaser.

NOTE Impact testing of a material may be omitted depending on material selection; the minimum design metal temperature; thermal, mechanical, and cyclic loading; and the governing thickness. Refer to requirements of ASME *BPVC* Section VIII, Division I, Section UG-20F, for example.

6.14.8.4 The 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) structural sections required for attachment or inclusion of mechanical features, such as jackets or seal chambers;
- c) one-fourth of the nominal flange thickness (recognizing that the predominant flange stress is not a membrane stress).

The results of the impact testing shall meet the minimum impact energy requirements of ASME *BPVC* Section VIII, Division I, Section UG-84, or the specified pressure design code.

6.15 Nameplates and Rotation Arrows

6.15.1 A nameplate shall be securely attached at a visible location on the compressor crankcase, on each compressor cylinder, and on any major piece of auxiliary equipment.

6.15.2 Rotation arrows shall be cast-in or attached to each major item of rotating equipment at a readily visible location.

6.15.3 Nameplates and rotation arrows (if attached) shall be of austenitic stainless steel or nickel-copper (UNS N04400 alloy). Attachment pins shall be of the same material. Nameplates shall not be attached by welding.

6.15.4 The following data shall be clearly stamped or engraved on the compressor crankcase nameplate:

- a) vendor's name;
- b) serial number;
- c) frame size and model;
- d) rated speed;
- e) stroke;
- f) purchaser item number or other reference.

6.15.5 Nameplates on compressor cylinders shall include the following data:

- a) vendor's name;
- b) serial number;
- c) bore, stroke, model number;
- d) MAWP;
- e) hydrostatic test pressure;
- f) maximum allowable working temperature;
- g) cold piston end-clearance setting for each end;
- h) minimum allowable temperature [required if the material is rated for a minimum allowable temperature below $-30\text{ }^{\circ}\text{C}$ ($-20\text{ }^{\circ}\text{F}$)].

7 Accessories

7.1 Drivers

7.1.1 General

- **7.1.1.1** Unless otherwise specified, the compressor vendor shall furnish the driver and power transmission equipment. The type of driver shall be as specified by the purchaser.

7.1.1.2 The driver shall be sized to meet the maximum specified operating conditions, including external power transmission losses, and shall be in accordance with applicable specifications as stated in the inquiry and order. The driver shall operate under the utility and site conditions specified in the proposal.

7.1.1.3 The driver shall be capable of driving the compressor with all stages at full flow, rated suction pressure, and discharging at the relief valve set pressure.

7.1.1.4 The driver shall be sized to accept any specified process variations such as changes in the pressure, temperature or properties of the fluids handled, and plant start-up conditions.

- **7.1.1.5** The purchaser shall specify anticipated process variations that can affect the sizing of the driver (such as changes in the pressure, temperature or properties of the fluid handled, and special plant start-up conditions).
- **7.1.1.6** The purchaser shall specify the starting conditions for the driven equipment. The starting procedure shall be agreed by the purchaser and the vendor. The driver's starting-torque capabilities shall exceed the starting-torque requirements of the driven equipment from zero to operating speed.

7.1.1.7 The inertial characteristics of the rotating parts of the compressor and of the drive train shall be such that rotational oscillations will be minimized. Undesirable oscillations include those that cause damage, undue wear of parts or interference with the governor or governing system of the driver and those that result in harmful torsional and/or electrical system disturbances. For initial design purposes and other than motor drivers, peak-to-peak speed oscillation of the rotating system shall be limited to 1.5 % of rated speed at full load and partial cylinder loads if step unloading is specified.

The compressor vendor shall inform the driver manufacturer of the nature of the application, including the torque variation characteristics, and shall obtain confirmation from the driver manufacturer that the driver is suitable for this service.

7.1.1.8 For purposes of sizing flywheels and couplings for gear drives, the peak-to-peak torque variation at the gear shall not exceed 25 % of the torque corresponding to the maximum compressor load and in no case shall there be any torque reversal in the gear mesh.

7.1.1.9 For belt-driven compressors the peak-to-peak speed variation shall not exceed 3 % of rated compressor speed at any operating condition (see 7.4).

7.1.1.10 The supporting feet of drivers with a mass greater than 225 kg (500 lb) shall be provided with vertical jackscrews.

7.1.2 Motor Drivers

7.1.2.1 Motor drives shall conform to API 541, API 547, or API 546 or other standards as approved by the purchaser. Motors that are below the power scope of API 541, API 547, or API 546 shall be in accordance with IEEE 841 or IEC 60034.

- **7.1.2.2** The type of motor supplied and its characteristics and accessories, including, but not limited to, the following, shall be as specified by the purchaser:

- a) type of motor (synchronous or induction);
- b) bearing and coupling arrangement;
- c) line voltage and frequency.

If belt drives are required, see 7.4.3.

7.1.2.3 For motor-driven units, the motor rating shall be not less than 110 % of the greatest power required (including power transmission losses) for any of the specified operating conditions. In addition, the motor rating shall be not less than 105 % of the power required (including power transmission losses) for the relieving operation specified in 7.1.1.3.

- **7.1.2.4** If specified, single bearing motors shall be provided with a temporary inboard support device to facilitate erection and alignment.
- **7.1.2.5** The motor starting-torque shall be sufficient to start the compressor without the need to depressurize any stage from the compressor suction pressure as long as all cylinder ends are unloaded or all stages are 100 % bypassed. Special agreement may be necessary in the following circumstances: high suction pressure; high settling-out gas pressure specified by the purchaser; high-pressure unloaded starts; or alternate gas unloaded starts.

7.1.2.6 The combined inertia of rotating parts of synchronous motor-compressor installations shall be sufficient to limit motor current variations to a value not exceeding 66 % of the full load current for all specified loading conditions, including unloaded operation with cylinders pressurized to their normal suction pressures. The electrical system data necessary for proper design shall be provided by the purchaser.

NOTE The power supply for some installations can require tighter control of current pulsation to protect other equipment in the electrical system. Standard motor performance data are based on steady-state load conditions and may not reflect actual performance under the variable-torque conditions encountered when driving reciprocating compressors. With induction-motor drivers, the effects of variable torque and resultant current pulsation are more pronounced and require closer evaluation (see 6.7.4 and 7.1.1.7).

For this reason, high-efficiency induction motors with their lower slip factors can experience higher current pulsation and consequently draw higher average current and higher power than standard efficiency motors when driving reciprocating compressors.

7.1.2.7 When the motor is supplied by the purchaser, the compressor vendor shall furnish the purchaser with the following:

- a) compressor data required by the motor manufacturer to calculate the inertia necessary to satisfy the current pulsation limits;
- b) starting-torque requirements;
- c) coupling details.

7.1.2.8 The rotor of a single bearing motor driver shall be mounted on a shaft extension with a keyed interference fit. The shaft extension shall be rigidly coupled to the crankshaft, with forged flanges integral with the shaft extension and crankshaft. Split or clamped hubs shall not be used. The interference fit shall carry the maximum transmitted torque by itself; the key shall not be relied on to carry any of the torque. Side clearance for the key shall be 0.025 mm (0.001 in.) at maximum. Top clearance for the key shall be adequate to prevent overstressing of the keyway. Keyless interference fits are acceptable only if accepted by the purchaser. Keys and keyways shall be machined with smooth, generous radii to minimize the effects of stress concentration. An outboard bearing shall be provided by the vendor to support the end of the shaft extension.

7.1.2.9 Unless otherwise specified, the necessary motor starting apparatus shall be supplied by the purchaser.

7.1.2.10 Cantilevered (overhung) motors shall not be supplied.

7.1.2.11 For single bearing motors, the motor manufacturer's drawing shall show the allowable tolerance for setting the air gap. All sections of the motor (and rotary exciter, if applicable) stator shall be doweled after internal alignment is completed to ensure maintenance of the proper air gap. The exciter housing (if applicable) shall be mounted with sufficient lateral and axial rigidity to prevent excessive motion of the stator relative to the rotor.

- **7.1.2.12** The bearing of motors rigidly coupled to a compressor shall be of the same generic type (hydrodynamic or rolling element) as the main bearings of the driven compressor. The use of a rolling element bearing in other cases shall be subject to the purchaser's approval. The design of direct coupled motors shall be such, that the bearing can be inspected, removed, and replaced in situ.

Hydrodynamic bearings shall be self-lubricated (e.g. oil-ring and sump) or, if specified, shall receive lubricating oil from the compressor frame lubrication system.

7.1.3 Steam Turbine Drivers

- **7.1.3.1** Steam turbine drivers shall conform to API 611 or API 612. The turbine power rating shall be not less than 110 % of the power required (including power transmission losses) for the relieving operation specified in 7.1.1.3 with the specified normal steam conditions. In addition, the turbine continuous power rating shall be no less than 120 % of the greatest power required (including any power transmission losses) when operating at any of the specified operating conditions, with the specified normal steam conditions.

NOTE 1 The 120 % factor includes an allowance for the cyclic torque load of reciprocating compressors.

NOTE 2 The 120 % is a design criterion. After testing, this margin might not be available due to performance tolerances of the driven equipment.

- **7.1.3.2** If specified, a separate special-purpose lube oil system in accordance with API 614 shall be furnished for a turbine drive train.

7.2 Couplings and Guards

7.2.1 Couplings

7.2.1.1 A flexible coupling shall be supplied, except where a single bearing motor is supplied as defined in 7.1.2.8. The coupling shall be supplied by the manufacturer of the driven equipment.

7.2.1.2 Unless otherwise specified, the coupling shall be of the all-steel, nonlubricated, flexible membrane, torsionally rigid, spacer-type. Couplings may be of the elastomeric type where necessary to avoid torsional resonance problems. The coupling type, manufacturer, model, and mounting arrangement shall be agreed.

NOTE For information on torsional damping couplings and resilient couplings see API 671, Annex A.

- **7.2.1.3** If specified, special-purpose couplings shall conform to and be mounted in accordance with API 671.

7.2.1.4 For compressors rated at 1500 kW (2000 hp) or more and driven by a double-reduction gear, the low-speed coupling can be a quill shaft. In such cases, the quill shaft shall be directly coupled to the compressor flywheel, shall pass through the hollow low-speed gear shaft, and shall couple with the low-speed shaft on the side opposite the compressor.