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ISO 13631

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Petroleum and natural gas industries — Packaged reciprocating gas compressors

*Industries du pétrole et du gaz naturel — Unités de compresseurs
alternatifs à gaz*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13631 was prepared by Technical Committee ISO/TC 118, *Compressors, pneumatic tools and pneumatic machines*.

Annex B forms a normative part of this International Standard. Annexes A, C, D and E are for information only.

Introduction

This International Standard is based on API specification 11P second edition, November 1989.

Users of this International Standard should be aware that further or differing requirements may be needed for individual applications. This International 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 International Standard and provide details.

A bullet (•) at the beginning of a subclause or paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the data sheets (see annex A).

Document ID: 13631-2002

Petroleum and natural gas industries — Packaged reciprocating gas compressors

1 Scope

This International Standard gives requirements and recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of packaged skid-mounted, reciprocating, separable or integral compressors with lubricated cylinders and their prime movers, for use in the petroleum and natural gas industries for the compression of hydrocarbon gas.

It is also applicable to all necessary auxiliary equipment, such as water and gas coolers, silencers, emission control equipment, filters, separators, control panel, piping, etc., required to install an operable unit in compliance with the purchase specifications and with the intent of minimizing field construction and field-purchased equipment.

This International Standard is not applicable to the following:

- reciprocating compressors for petroleum and natural gas industries covered by ISO 13707;
- column-mounted compressors;
- non-lubricated compressors;
- compressors having trunk-type (automotive-type) pistons that also serve as crossheads;
- utility or instrument air compressors with a discharge gauge pressure of 0,9 MPa (9 bar) or less;
- compressors driven by diesel engine, gas turbine and steam turbine prime movers.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

ISO 68-2:1998, *ISO general-purpose screw threads — Basic profile — Part 2: Inch screw threads*

ISO 185, *Grey cast iron — Classification*

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*

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ISO 263:1973, *ISO inch screw threads — General plan and selection for screws, bolts and nuts — Diameter range 0.06 to 6 in*

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

ISO 1813, *Belt drives — V-ribbed belts, joined V-belts and V-belts including wide section belts and hexagonal belts — Electrical conductivity of antistatic belts: Characteristics and methods of test*

ISO 4126-1:1991, *Safety valves — Part 1: General requirements*

ISO 4986:1992, *Steel castings — Magnetic particle inspection*

ISO 5864:1993, *ISO inch screw threads — Allowances and tolerances*

ISO 7005-1, *Metallic flanges — Part 1: Steel flanges*

ISO 7005-2, *Metallic flanges — Part 2: Cast iron flanges*

ISO 8504-2, *Preparation of steel substrates before application of paints and related products — Surface preparation methods — Part 2: Abrasive blast-cleaning*

ISO 9934-2, *Non-destructive testing — Magnetic particle testing — Part 2 Detection media*

ISO 10441, *Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — Special purpose applications*

ISO 13707, *Petroleum and natural gas industries — Reciprocating compressors*

ISO 14691, *Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — General purpose applications*

ISO 15649, *Petroleum and natural gas industries — Piping*

IEC 60034, *Rotating electrical machines*

IEC 60079, *Electrical apparatus for explosive gas atmospheres*

IEC 60364-5, *Electrical installation of buildings — Part 5: Selection and erection of electrical equipment — Common rules*

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

IEC 60848, *Preparation of function charts for control systems*

API Std 1B¹⁾, *Specification for oil-field V-belt*

API RP 520 Part I, *Sizing, selection and installation of pressure relieving devices in refineries. Part I — Sizing and selection*

API RP 520 Part II, *Sizing, selection and installation of pressure relieving devices in refineries. Part II — Installation*

1) American Petroleum Institute, 1220 L Street, N.W., Washington, DC 20005-4070, USA.

ASME²⁾ B 1.1 *Unified inch screw threads (UN and UNR thread form)*

ASME B 1.20.1, *Pipe threads, general purpose (inch)*

ASME VIII, ASME Boiler and pressure vessel code: 1998, Section VIII, *Rules for construction of pressure vessels*

ASTM A 320/A 320M, *Standard specification for alloy/steel bolting materials for low-temperature service*

ASTM A 503, *Standard specification for ultrasonic examination of forged crankshafts*

ASTM A 536, *Standard specification for ductile iron castings*

ASTM A 668/A 668M, *Standard specification for steel forgings, carbon and alloy, for general industrial use*

ASTM A 781/A 781M, *Standard specification for castings, steel and alloy, common requirements, for general industrial use*

EN 1561:1997 *Founding — Grey cast irons*

EN 1563:1997 *Founding — Spheroidal graphite cast irons*

EN 10213-1:1995, *Technical delivery conditions for steel castings for pressure purposes — Part 1: General*

EN 10213-2:1995, *Technical delivery conditions for steel castings for pressure purposes — Part 2: Steel grades for use at room temperature and elevated temperatures*

EN 10213-3:1995, *Technical delivery conditions for steel castings for pressure purposes — Part 3: Steel grades for use at low temperatures*

EN 10213-4:1995, *Technical delivery conditions for steel castings for pressure purposes — Part 4: Austenitic and austenitic-ferritic steel grades*

EN 10269, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties*

NACE MR 0175³⁾, *Standard material requirements, Sulfide stress cracking resistant metallic materials for oilfield equipment*

NEMA Standards Publication 250-1997, *Enclosures for Electrical Equipment (10 000 Volts Maximum)*

3 Terms and definitions

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

3.1

capacity

quantity of gas taken into the compressor at the specified inlet conditions, compressed and delivered at the specified discharge pressure

NOTE 1 It is expressed in units of mass flow or standard volume flow.

NOTE 2 The capacity of a compressor does not include any gas that leaks out of the compressor during the compression process, nor any air that leaks into a compressor used as a vacuum pump.

2) American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, USA.

3) National Association of Corrosion Engineers, P.O. Box 218340, Houston, TX 77218-8340, USA.

3.2

combined rod load

algebraic sum of gas load and inertia force on the crosshead pin

3.2.1

gas load

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

3.2.2

inertia force

force resulting from the acceleration of reciprocating mass

NOTE 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 accelerations.

3.3

manufacturer's rated capacity

capacity of the compressor used by the manufacturer to assign its size

3.4

maximum allowable continuous combined rod load

highest combined rod load at which none of the forces in the running gear and the compressor frame exceeds the values that the compressor manufacturer's design permits for any component for continuous operation

NOTE Running gear includes the piston, piston rod, crosshead assembly, connecting rod, crankshaft, bearings, etc.

3.5

maximum allowable speed

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

3.6

maximum allowable temperature

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

3.7

maximum allowable working pressure

MAWP

maximum continuous gauge pressure for which the compressor manufacturer has designed the equipment (or relevant part thereof) when handling the specified fluid at the specified temperature

3.8

minimum allowable speed

lowest speed at which the manufacturer's design permits continuous operation

3.9

normal operating point

point at which usual operation is expected and optimum efficiency is desired

NOTE This is usually that point at which the manufacturer certifies that performance is within the tolerances stated in this International Standard.

3.10

rated discharge pressure

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

3.11**rated power**

⟨of the compressor⟩ maximum power required of the compressor plus any shaft-driven appurtenances for any of the specified operating conditions

NOTE The rated power includes the effect of equipment such as pulsation suppression devices, process piping, intercoolers and separators. Driver and transmission losses are not included in the rated power of the compressor. Losses incurred in outboard bearings (e.g. as used to support large flywheels) are included.

3.12**rated speed**

highest speed required to meet any of the specified operating conditions

3.13**required capacity**

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

3.14**rod reversal**

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

3.15**standard flow**

flowrate at an absolute pressure of 0,101 3 MPa (1,013 bar) and a temperature of 0 °C

NOTE It is expressed in units of volume flow.

4 Statutory requirements

The purchaser shall specify any applicable regulations. The purchaser and the vendor shall mutually determine the measures to be taken to comply with those regulations that are applicable to the equipment.

Use of the word “design” in the purchaser’s specifications should be avoided.

5 General package requirements**5.1 Compressor package performance curves**

- If specified, the compressor package performance curves shall cover the range of operating conditions indicated by the purchaser. Any limitations such as rod load, available driver power, additional clearance required to meet the range of operating conditions, etc., shall be marked on the performance curves.

5.2 Package arrangement

The arrangement of the package components shall be developed by the vendor to provide reasonable access for operation and maintenance.

5.3 Drawings

- The vendor shall furnish plan and elevation drawings. Pre-fabrication approval or additional drawings may be specified by the purchaser.

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5.4 Sound pressure level

- Control of the sound pressure level of all equipment furnished shall be the joint effort of the purchaser and the vendor. If specified, the equipment furnished by the vendor shall not exceed the maximum sound pressure level required by the purchaser.

5.5 Electrical area classification

- Motors, electrical components and electrical installations shall be suitable for the area classification (zone) specified by the purchaser, shall meet the requirements of IEC 60079 and other standards specified by the purchaser and shall comply with all applicable local codes and regulations.

5.6 Package installation

- The purchaser shall specify the site conditions (altitude, ambient temperature, etc.), and whether the installation is indoors (heated or unheated) or outdoors (with or without a roof) and the weather or environmental conditions in which the equipment must operate (including maximum and minimum temperatures, unusual humidity or dust problems). The unit and its auxiliaries shall be suitable for operation in these specified conditions. The purchaser shall specify dimensional limitations, if any.

5.7 Torsional analysis

- The vendor shall provide a torsionally sound system and perform an analysis to demonstrate this. When specified, a torsional analysis report shall be provided, and the vendor shall be responsible to coordinate with the compressor and prime-mover manufacturers to produce such a report.

6 Compressor

6.1 General

6.1.1 Manufacturer's rated capacity

The compressor shall be sized to handle not less than the required capacity with the gas composition, suction pressures, suction temperatures, discharge pressures and site conditions specified by the purchaser. The number of stages of compression shall accommodate pressure limitations and gas additions or withdrawals as specified. The package design shall also allow for all pressure drops through the separators, pulsation suppression devices (if any), coolers and piping from the inlet flange to the outlet flange of the package.

6.1.2 Performance calculations

The vendor shall use the specified values of mass flowrate, the specified gas composition and the gas conditions to calculate average molar mass, ratio of specific heats (c_p/c_v), compressibility factors (z) and inlet volume flowrate. The compressor vendor shall indicate his values on the data sheets with the proposal and use them to calculate performance data.

6.1.3 Compressor size

- If specified, the compressor shall be furnished with cylinders which, when operating at the specified operating condition(s), shall as far as practical, load the gas engine to the limit specified in 8.2.1 or electric motor to the limit specified in 8.3.2.

Compressors driven by induction motors shall be sized at the motor operating speed.

6.1.4 Forces and couples

The vendor shall furnish values for the unbalanced primary and secondary forces and couples in the horizontal and vertical planes for the package.

6.2 Allowable speeds

- The maximum acceptable average piston speed (in metres per second) and the maximum acceptable speed (in revolutions per minute) may be specified by the purchaser where experience indicates that specified limits should not be exceeded for a given service.

6.3 Allowable discharge temperature

- Unless otherwise specified and agreed, the maximum predicted discharge temperature shall not exceed 135 °C. This limit applies to all specified operating and load conditions. If specified, the vendor shall provide the purchaser with both the predicted and adiabatic discharge temperatures.

NOTE The actual discharge temperature will vary from the adiabatic depending on such factors as the power input to a cylinder, the ratio of compression, the size of the cylinder, the surface area of the cooling passages and the velocity of the coolant.

6.4 Rod loads

6.4.1 Allowable rod loads

6.4.1.1 The combined rod load shall not exceed the manufacturer's maximum allowable continuous combined rod load for the compressor running gear at any specified operating conditions and any load step. These combined rod loads shall be calculated on the basis of the set point pressure of the discharge relief valve of each stage and the lowest specified suction pressure corresponding to each load step.

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

6.4.2 Rod load reversal

For all specified operating load conditions, the axial component of the combined rod load shall reverse enough to ensure adequate lubrication between the crosshead pin and bushing during each complete turn of the crankshaft.

6.5 Compressor cylinders

6.5.1 General

6.5.1.1 The maximum allowable working pressure of the cylinder shall exceed the rated discharge pressure by at least 10 % or 0,17 MPa (1,7 bar), whichever is greater. The maximum allowable working pressure shall be at least equal to the specified relief valve set pressure including accumulation.

6.5.1.2 Horizontal cylinders shall have bottom discharge connections except where side or top discharge connections are accepted by the purchaser.

6.5.1.3 Cylinders shall be spaced and arranged to permit access and removal for normal maintenance of all components (including covers, packing, valves or unloaders mounted on the cylinder) without removing the cylinder, major piping or pulsation suppression devices.

6.5.2 Cylinder/crankcase appurtenances

6.5.2.1 The cylinder support shall be designed to avoid misalignment or excessive rod run-out during the warm-up period and at actual operating temperature. The cylinder support shall, where practical, not be attached to the outboard cylinder head. When impractical, then the crankcase through to cylinder assembly shall be capable of supporting the weight of the cylinder during maintenance. The pulsation suppression device, if furnished, shall not be used to support the compressor cylinder, unless approved by the purchaser.

Most cylinder supports are attached at the end of the distance piece. Some pulsation analyses require both a distance piece support and a cylinder end support. A cylinder end support should not be used unless required due to a pulsation requirement, as incorrect support types or their adjustment result in operation difficulties. Additionally a cylinder end support should not be used in place of the distance piece support.

6.5.2.2 Cylinders may be non-liquid-cooled (no provision for coolant jackets) or liquid-cooled (coolant jacket around the cylinder bore and cylinder head).

6.5.2.3 Bolting shall be furnished as specified in 6.5.2.3.1 through 6.5.2.3.4.

6.5.2.3.1 Details of threading shall conform to ASME B1.1 or ISO 68-2, ISO 261, ISO 262, ISO 263 and ISO 5864. The use of fine-pitch threads shall not be used in cast irons and in external fasteners subject to routine maintenance, including pressure-containing parts.

Fine-pitch threads should be avoided in all cases, as being subject to self-unfastening.

6.5.2.3.2 Studs are preferred to cap screws.

6.5.2.3.3 Stud material shall be in accordance with EN 10269 for steel and ductile iron cylinders. EN 10269 or ASTM A 307 Grade B may be used for cast iron cylinders. ASTM A 320 shall be used for temperatures of -20°C and below. Stud markings shall be located on the exposed end of the stud. With high-temperature studs, use nuts in accordance with EN 10269. Nuts in accordance with EN 10269 are acceptable for use with EN 10269 or ASTM A 307 studs.

NOTE For the purposes of this subclause, ASTM A 193 Grade B7 for studs and ASTM 194 Grade 4, Grade 7 or Grade 2H, as appropriate, for nuts, are equivalent to EN 10269.

6.5.2.3.4 Hexagonal head bolting is preferred. Adequate clearance shall be provided at bolting locations to permit the use of socket or box wrenches. If extended studs are provided for hydraulic tensioning, the exposed threads shall be protected by a cover.

6.5.3 Cylinder connections

6.5.3.1 The main inlet and outlet gas connections and all other process gas connections shall be flanged or machined and studded, and shall be suitable for the working pressure of the cylinder as specified in 6.5.1.1. The facing and bolting of the main inlet and outlet flanges and auxiliary connections shall conform to the dimensional requirements of ISO 7005-1 or ISO 7005-2 as applicable. Alternative standards are acceptable by mutual agreement. The details of any special connections, such as a lens joint, shall be submitted to the purchaser for review.

- **6.5.3.2** If specified, each cylinder shall be provided with a DN 12 (1/2 in) indicator tap at each end.

6.6 Valves

6.6.1 Average valve gas velocity

The vendor shall state the average valve gas velocity for each specified operating condition. The average valve gas velocity shall be computed as follows:

$$v = \frac{F}{f} c_m$$

where

- v is the average gas velocity, in metres per second;
- F is the effective piston area of the cylinder end or ends concerned, in square centimetres;
- f is the product of the actual lift, the valve opening periphery and number of inlet or discharge valves, in square centimetres;
- c_m is the average piston speed, in metres per second.

The valve lift used in the above equation shall be shown on the data sheets. If the lift area is not the smallest area in the flow path of the valve, it shall be so noted on the data sheet and the velocity shall be computed on the basis of the smallest area.

NOTE Velocities calculated from this formula should be treated only as a general indication of valve performance and should not be confused with effective velocities based on crank angle, degree of valve lift, unsteady flow and other factors. The velocity computed from the above formula is not necessarily a representative index for valve power loss or disc/plate impact.

6.6.2 Valve design

6.6.2.1 The valve design, including that for double-decked valves, 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.

6.6.2.2 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.

6.6.2.3 Valve discs or plates shall be suitable for installation with either-side sealing.

6.6.2.4 Valves shall be suitable for operation with any specified gas.

6.7 Pistons, piston rods and piston rings

6.7.1 Piston attachment

Pistons that are removable from the rod shall be attached to the rod by a shoulder-and-nut design or by a multi-through-bolt design. All nuts shall be positively locked in place. Nuts attaching the piston rod to the piston and to the crosshead shall be tightened in accordance with the manufacturer's regulations. The rod shall be positively locked to the crosshead to prevent rotation. Hydraulic or thermal methods are preferred for tightening piston-rod nuts.

6.7.2 Hollow pistons

Hollow pistons (single or multi-piece), when used, shall be self-venting.

6.7.3 Piston wear bands

- Non-metallic wear bands, if required by the manufacturer or specified by the purchaser, shall not overrun the valve ports or counterbores by more than one-half the axial width of the wear band.

6.7.4 Piston rod hardness

A minimum surface hardness of HRC 50 is required on piston rods in the area that passes through the packing. For piston rods in corrosive gas service, see clause 20.

6.7.5 Piston rod threads

Piston rods shall be furnished with rolled threads.

6.7.6 Coated piston rods

The material and surface treatment of piston rods shall be proposed by the vendor for the purchaser's approval. Consideration should be given to the use of hard coatings to increase the wear resistance. If 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. Fusion techniques that require temperatures high enough to permanently affect the mechanical characteristics of the base material are unacceptable.

Piston-rod base material and coatings for use in corrosive environments shall be suitable for the service and operating conditions specified.

High-velocity and high-impact thermal coating processes are acceptable for coating of piston rods. Metal-spray techniques requiring roughening of the surface of the base material are not recommended because of the potentially destructive stress raisers left in the surface. Use of sub-coating under the main coating is not recommended.

6.8 Crankcases, crankshafts, connecting rods, bearings and crossheads

6.8.1 Crankshafts

Crankshafts shall be of the compressor manufacturer's standard material and design and shall be heat-treated and machined on all working surfaces and fits. They shall be free of sharp corners. Drilled holes or changes in section shall be finished with radii and shall be polished. Forced-lubrication passages in crankshafts shall be drilled.

6.8.2 Bearings

Main bearings shall be replaceable sleeve type or of the tapered or spherical roller type. Roller bearing selection shall be based on an L10 rating equivalent to 44 000 h or greater as defined in ISO 281 at rated compressor speed and maximum allowable continuous combined rod load. Cylindrical roller or ball-type bearings are unacceptable. Crank pin bearings shall be replaceable sleeve type.

6.8.3 Connecting rods

Connecting rods shall be of the compressor manufacturer's standard material with removable cap. They shall be free of any sharp corners. Forced-lubrication passages shall be drilled.

6.8.4 Crossheads

Crossheads shall be of the compressor manufacturer's standard material and design. Adequate openings for removal of crosshead shall be provided.

6.8.5 Crankcases

- If specified, the crankcase shall be provided with relief devices to protect against rapid pressure rises. These devices shall incorporate downward-directed apertures (away from the operator's face), a flame-arresting mechanism, and a rapid-closure device to minimize reverse flow.

The total throat area of these devices should be not less than 70 mm² for each cubic decimetre of crankcase free volume.

6.9 Distance pieces

6.9.1 Design

- **6.9.1.1** Distance pieces shall conform to Type 1, 2 or 3 as specified by the purchaser. Type 1 (short, close-coupled, without compartment) is used where it is desired to keep overall width of the compressor to a minimum. Type 2 (single compartment) is used when physical separation of the pressure and wiper packing is desired. Type 3 provides double compartments for varying degrees of purging when required.
- **6.9.1.2** If specified, slinger rings shall be provided to Type 2 or 3 distance pieces to prevent migration and mixing of oil between the crankcase and the compressor cylinders, in which case the respective compartment will be of the long type.

6.9.2 Openings

Openings of adequate size to permit servicing of the pressure packing case shall be provided and shall have bolted access covers, a bottom drain connection, and a top vent connection. See 11.17.1 for drain and vent specifications.

6.9.3 Pressure-relief devices

The vendor shall confirm that the vent connection or relief device is adequate to prevent overpressuring of the distance piece in the event of a packing case failure.

6.10 Packing cases and pressure packings

6.10.1 Type

All oil-wiper, intermediate-seal and gas-cylinder pressure packings shall be segmental rings with corrosion-resistant garter springs.

6.10.2 Construction

Packing case flanges shall be bolted to the cylinder head or to the cylinder with no less than four bolts. Packing cases shall be pressure-rated at least to the MAWP of the cylinder. Packing case assemblies shall have positive alignment features, such as cup-to-cup pilot fits and/ or sufficient body-fitted tie bolts.

6.10.3 Services

For flammable, hazardous, toxic or wet gas service, the pressure packing case shall be provided with a common vent and drain below the piston rod piped to the outside of the distance piece. See 11.17.1 for drain and vent specifications and clause 20 for corrosive gas applications.

6.10.4 Oil-wiper packing

Crosshead packing boxes shall employ an oil-wiper packing to effectively minimize oil leakage from the crankcase.

6.11 Compressor crankcase lubrication system

6.11.1 Crankcase lubrication

The crankcase lubrication system shall be pressurized and shall have sufficient capacity to provide adequate lubrication at all speeds required to meet the specified operating conditions. Splash systems may be used on horizontal compressors with rolling element bearings when the compressor's nominal frame rating is 150 kW or less.

NOTE Information on lubricants is provided in ISO 3448.

6.11.2 Level indication

The oil reservoir shall be equipped with an oil-level sight glass. The maximum and minimum operating levels shall be permanently indicated.

6.11.3 Lubrication oil pumps

6.11.3.1 The main oil pump shall be crankshaft-driven either directly, or through gears or a chain.

6.11.3.2 For each unit having a nominal rating of more than 225 kW, the vendor shall provide a separate, independently driven auxiliary oil pump.

6.11.4 Oil filtration

Full-flow filters with replaceable elements shall be supplied with filtration of 10 µm (nominal) or finer. For babbitt bearings, filtration may be 25 µm (nominal) or finer. The filters shall be located downstream of the cooler. Filters shall not be equipped with a relief valve or automatic by-pass. Filter cartridge materials shall be corrosion-resistant. Metal-mesh or sintered-metal filter elements shall not be used. The design of the filter-cartridge assembly shall assure that internal by-passing cannot occur due to filter-to-cartridge or cartridge-to-cartridge misalignment, inadequate end cover sealing design, or other sealing deficiencies. Additionally, the cartridge collapse differential pressure shall be at least 0,35 MPa (3,5 bar) and the clean differential pressure shall not exceed 0,03 MPa (0,3 bar) at design temperature and flow.

6.11.5 Materials

All parts in the crankcase and lubricating oil system shall be of materials suitable for the site environment. For corrosive gas services, see clause 20 for material requirements.

6.11.6 Oil level control

- If cylinder lubrication oil is taken from the crankcase, then a compressor crankcase oil-level control device shall be furnished (see 6.12.2). If specified by the purchaser, the vendor shall furnish a storage tank with level gauge and compressor crankcase oil-level control device.

6.11.7 Lubricating oil heater

- If specified by the purchaser, a lubricating oil heater shall be furnished by the vendor. When an internal heater is used, it shall be fully immersed even at minimum oil level and its surface heat flux shall not exceed 2 W/cm².

6.12 Compressor cylinder lubrication

6.12.1 Cylinder lubrication

Either block-distribution lubrication systems or pump-to-point lubrication systems shall be furnished for lubrication of compressor cylinder ring travel bore and piston rod packing. The force-feed lubricator shall be suited for variable flow and of weather-proof construction and shall be equipped with a reservoir level indicator. Unless otherwise specified, lubricators shall be crankcase-mounted and crankshaft-driven. Block-distribution lubrication systems shall be complete with no-flow shutdown, rupture relief discs, check valves and carbon steel or austenitic stainless steel tubing. Line filters, flow meter and fault indicators may be specified by the purchaser for block-distribution lubrication systems. For pump-to-point lubrication systems, a sight indicator for each point, check valves and carbon steel or austenitic stainless steel tubing shall be furnished.

6.12.2 Oil supply

- The force-feed lubrication system shall be complete with automatic oil replacement. The oil supply should be from a separate reservoir in preference to filtered oil from the compressor crankcase. A storage tank with level gauge shall be furnished if specified by the purchaser.

6.13 Materials

6.13.1 General

6.13.1.1 Materials of construction of the compressor and auxiliaries shall be the compressor manufacturer's standard for the specified operating conditions, unless otherwise required in the data sheets.

6.13.1.2 Steel compressor cylinders shall be equipped with steel heads.

6.13.1.3 Unless otherwise specified, materials for pressure-containing parts shall be used with the limitation of the MAWP indicated in Table 1.

Table 1 — Gauge MAWPs for cylinder materials

Material	MAWP MPa (bar)	
	Internal cylinder diameter	
	≤ 200 mm	> 200 mm
Grey cast iron	11,0 (110)	7,0 (70)
Nodular iron	17,0 (170)	10,0 (100)
Cast steel	18,0 (180)	18,0 (180)
Fabricated steel	10,0 (100)	8,5 (85)
Forged steel	No limitation	

6.13.1.4 ISO/TS 16528 should be used as a guideline for material and the quality of all welding of parts other than pressure vessels. The applicable standards shall be agreed between purchaser and vendor. For pressure vessels, see clause 10.

6.13.2 Castings and forgings

6.13.2.1 Castings shall be sound and free of shrink holes, blow holes, cracks, scale, blisters or other similar injurious defects. Surfaces of castings shall be cleaned by sandblasting, shotblasting, pickling or another standard method. All mould-parting fins and remains of gates and risers shall be chipped, filed or ground flush.

6.13.2.2 The use of chaplets in pressure castings shall be held to a minimum. The chaplets shall be clean and corrosion-free (plating permitted) and of a composition compatible with the casting.

6.13.2.3 Unless otherwise specified by the purchaser, grey iron castings shall be produced in accordance with ISO 185 for pressure-containing castings. Grade shall be specified by the compressor manufacturer.

6.13.2.4 Unless otherwise specified by the purchaser, nodular iron castings shall be produced in accordance with EN 1563 or ASTM A 536 for pressure-containing castings. Grade shall be specified by the compressor manufacturer.

NOTE For the purposes of this provision, ASTM A 395 is equivalent to EN 1563.

6.13.2.5 The minimum quality standard allowed for steel castings shall be the appropriate part of EN 10213 and ASTM A 781. Grade shall be specified by the compressor manufacturer.

NOTE For the purposes of this provision, ASTM A 216, ASTM A 487 and ASTM A 703 are equivalent to EN 10213.

6.13.2.6 Forgings for pressure-containing parts shall as a minimum meet quality in accordance with ASTM A 668. Grade shall be specified by the compressor manufacturer.

6.13.2.7 Chemical analysis of an as-cast sample from each ladle is not required, unless otherwise specified or for use in corrosive services as identified in clause 20.

6.13.3 Casting repair

6.13.3.1 Major repairs to pressure-containing-parts and all repairs to moving parts subject to load reversals and crankshafts shall not be undertaken without notifying the purchaser. Pressure-containing castings shall not be repaired by peening, burning-in or impregnating. Pressure-containing castings and forgings shall not be repaired except as specified in 6.13.3.2 and 6.13.3.3.

6.13.3.2 Weldable grades of steel castings and forgings may be repaired by welding using qualified welding procedures based on the requirements of applicable recognized standards. After major weld repairs and prior to hydrotest, 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.

6.13.3.3 Cast grey iron or nodular iron may be repaired by plugging. Repairs by plugging shall be within the limits specified in EN 1561 or EN 1563.

NOTE 1 For the purposes of this provision, ASTM A 278 is equivalent to EN 1561, and ASTM A 395 is equivalent to EN 1563.

Cast grey iron or nodular iron shall not be repaired by welding. However, unless otherwise agreed by the purchaser and the manufacturer, plugs shall not be used in the gas pressure-containing wall sections, including the bore under the liner. The holes drilled for plugs shall be carefully examined, using liquid penetrant, to ensure that all defective material has been removed.

NOTE 2 Some acceptable repair techniques are described in annex E.

6.14 Power transmission

6.14.1 Gears

Speed-increasing or -reducing gears shall not be used, unless otherwise specified by the purchaser.

6.14.2 Couplings

Flexible shaft couplings shall be non-lubricated, steel disc type, except when torsional analysis requires a torsionally soft coupling or for low-speed applications. Couplings shall be selected for the maximum continuous power rating of the prime mover plus the coupling manufacturer's standard service factor for reciprocating compressor applications. The material shall be suitable for the ambient conditions specified in 5.6. Flexible couplings shall comply with ISO 10441 or ISO 14691.

6.14.3 V-belt drives

V-belt drives for compressor applications shall be in accordance with ISO 1813 or API Std 1B.

6.14.4 Clutches

A clutch power take-off shall not be used unless specified by the purchaser.

6.14.5 Guards

Guards shall be provided for all moving parts which might be hazardous to personnel. Guards shall comply with specified applicable safety codes. Openings shall be provided in flywheel guards for barring-over the machine and

provide for access to indicator timing marks, wheel centre (if available) and to any other parts which may require attention.

Unless otherwise specified, guards shall be supplied by the vendor. They shall be easily removable, corrosion-resistant, of non-sparking construction, with continuous welding and sufficiently rigid to withstand deflection and prevent rubbing as a result of body contact. This also applies to auxiliary coupling guards.

Guards over belt drives shall be corrosion-resistant and properly ventilated to prevent excessive heat build-up.

Where aluminium is not considered an acceptable non-sparking material, it shall be so specified by the purchaser.

7 Capacity control

7.1 General

- The compressor capacity may be controlled on the basis of the suction pressure, discharge pressure, flow rate, or some combination of these parameters. The required capacity variation shall be specified by the purchaser. The control system may be mechanical, pneumatic, hydraulic, electric or any combination thereof. The purchaser shall specify the parameter to be used for control. If the control signal is from a source furnished by the purchaser, then the purchaser shall specify the source, sensitivity and range of the control signal to be utilized by the vendor.

7.2 Method of capacity control

- Capacity control can be obtained by speed variation, clearance variation, bypass, single-acting or double-acting compressor cylinders, valve unloaders, or any combination thereof. Control operation shall be either automatic with manual over-ride or manual as specified by the purchaser on the data sheets. Some of these methods may require unit shutdown and depressurizing to effect a change. The purchaser shall specify if such unit shutdowns are acceptable. If any of these methods are implemented by other than the compressor manufacturer, then they shall be approved by the compressor manufacturer.

7.3 Speed variation

- If specified by the purchaser, capacity control can be achieved by prime-mover speed variation.

7.4 Clearance variation

7.4.1 Methods

Clearance variation may be achieved by one of the methods described in 7.4.2 through 7.4.6. These methods may be used alone or in combination. In all cases where clearance volume is added to a compressor cylinder end, the volumetric efficiency shall not be reduced to less than 15 %.

NOTE Volumetric efficiencies less than 15 % can cause excessive temperature rise, valve plate flutter, valve plate breakage and possible physical damage to the compressor cylinder.

7.4.2 Clearance pockets

- Clearance pockets may be specified by the purchaser and be either of the fixed type (pocket clearance is fixed and the pocket is either open or closed) or the variable type (pocket clearance is variable over the range from fully open to closed). Variable-volume clearance pockets shall have a non-restricted vent line provided to vent the back side of the variable pocket piston to the suction port of the compressor cylinder, to the suction piping or to the vent system.

7.4.3 Valve spacers

- Valve spacers (high-clearance assemblies or split-valve yokes) used to raise the valve a predetermined distance above the cylinder valve port may, if specified by the purchaser, be provided by the compressor manufacturer to meet an operating condition.

7.4.4 Clearance bottles

- If specified, clearance bottles for capacity control may be added to the compressor cylinder. They shall be designed for the maximum allowable working pressure of the compressor cylinder and according to the specified applicable pressure vessel code.

7.4.5 Cylinder head spacer(s)

Spacer(s) may be placed between the compressor cylinder body and cylinder head to add clearance volume.

7.4.6 Clearance plugs

The compressor cylinder head may be furnished with clearance plugs.

NOTE Clearance plugs usually have two clearance steps. When the plug is inserted into the head or cylinder bore, the clearance is minimum. When the plug is placed outside the head or cylinder bore, the clearance is maximum. Clearance steps between minimum and maximum can be achieved by different length plugs.

7.5 Bypass systems

7.5.1 General

Bypass systems can utilize either hot or cold gas and be either manual or automatic. Bypass systems shall be equipped for purging before start-up. A pressure-relief valve shall be installed to protect equipment which has a pressure rating lower than the pressure of the bypass gas.

7.5.2 Start-up bypass

- If specified by the purchaser, a manually operated hot-gas bypass (from the discharge of the final stage to the inlet side of the compressor with no cooling of the gas) shall be provided for start-up purposes. A hot-gas bypass shall not be used for capacity control.

7.5.3 Capacity control bypass

- When specified by the purchaser, a manual or automatic cold-gas bypass system (from downstream of the aftercooler or discharge separator, if furnished, back to the inlet separator) shall be furnished for capacity control.

A cold-gas bypass may be used for both start-up and capacity control purposes.

7.6 Valve removal or unloading

7.6.1 Valve removal

Removal of all the suction valves from the head-end side of a double-acting compressor cylinder is permitted to completely unload that end of the cylinder. Suction or discharge valves shall not be removed from the crank-end side of a compressor cylinder without specific approval of the compressor manufacturer.

7.6.2 Valve unloaders

Compressor cylinder capacity control can be accomplished with valve depressors or plug-type unloaders. Valve depressors, when used, shall be installed on all suction valves of the cylinder end involved.

If plug-type unloaders are used, the number of unloaders is determined by the area per plug opening, the total of which shall be equal to or greater than one-half of the total free lift area (or at least flow area) of all suction valves on that end.

If valve depressors are used only for start-up, and never for capacity control, the compressor manufacturer may approve a reduced number of unloaders. For start-up with plug unloaders, only one per cylinder end is needed.

7.6.3 Automatic valve unloading

- If specified, the vendor shall provide a system of properly sequenced unloader operation. Otherwise, a definition of acceptable operating configurations and sequences shall be supplied by the vendor. Pneumatically operated unloaders with no manual overrides shall be piped by the vendor in such a manner that inadvertent non-sequenced operation shall not occur.

7.6.4 Unloader operator

Pneumatically operated unloaders shall be suitable for operation with any specified gas. If air-operated, they shall be designed so that the air used for unloading cannot mix with the gas being compressed, even in the event of failure of the diaphragm or another part.

7.7 Suction pressure limitation

- If specified by the purchaser, a suction pressure-reducing valve shall be used to limit the suction pressure to a set value in order to limit the load on the unit.

8 Prime mover

8.1 General

- The type of prime mover (gas engine or electric motor) shall be specified by the purchaser.

8.2 Spark-ignited gas engines

8.2.1 Engine rated power

Unless otherwise specified by the purchaser, the gas engine shall be sized for the compressor rated power plus transmission losses and plus engine accessories for the specific location, without exceeding the engine manufacturer's standard published rating criteria for continuous duty service. The engine manufacturer's continuous duty service is defined as the load and speed which can be applied without interruption after taking into consideration site conditions of altitude, temperature and fuel gas composition as listed on the data sheets.

NOTE A margin of 10 % on the engine rated power has been demonstrated to result in better operating reliability.

8.2.2 Operating speed

The vendor shall not apply an engine at an operating speed either greater or less than the engine manufacturer's recommended continuous duty speed range.

8.2.3 Starting systems

8.2.3.1 General

Electric, air or gas starting systems for the engine driver should be specified by the purchaser.

NOTE Engine shutdowns are addressed in clause 14.

8.2.3.2 Air or gas starting systems

Unless otherwise specified, air or gas starting systems shall include the items listed below:

- a) manual block valve to isolate the following system;
- b) if required, a regulator to provide proper starter pressure. The purchaser shall specify source and minimum/maximum pressure of air or gas available for the starting system;
- c) safety relief valve (see 11.18 for sizing, setting criteria and venting);
- d) spring-loaded (spring to close) quick-opening valve;
- e) air or gas starter with lubricator and strainer;
- f) The starter vent piping (sized for at least the same diameter as the starter exhaust connection) shall be piped to skid edge unless otherwise specified by the purchaser. The safe disposition of the starter vent gas shall be considered in the installation and is the responsibility of the purchaser.

8.2.3.3 Electric starting systems

Electric starting systems, when provided, shall be suitable for the electrical area classification (5.5) and shall include the following items:

- a) electric starting motor with starting control;
- b) if specified, a battery set with sufficient capacity to start the engine at the lowest specified ambient temperature;
- c) if specified, a charging alternator of sufficient capacity to charge the battery set furnished.

8.2.4 Air intake system

8.2.4.1 Air shall not be taken from inside enclosed buildings.

8.2.4.2 Unless otherwise specified, the engine manufacturer's standard dry-type air intake filter, suitable for outdoor service, shall be provided. If alternative filters are specified by the purchaser, their design shall conform to the following minimum criteria.

- a) The micrometre particle rating shall be that recommended by the engine manufacturer.
- b) Site environmental conditions (blowing sand, ice, snow, etc.) shall be taken into consideration.

NOTE For low temperature applications, the inlet air may need to be heated (with exhaust heat for example) to avoid frost build-up on the filter.

- c) The filter shall be oriented to allow in-service maintenance.

8.2.4.3 In addition to the above, the following features shall be considered for air filters that are mounted remote from the engine.

- a) Piping and supports shall be furnished by the purchaser, unless otherwise specified.
- b) Inlet piping to the engine shall have internal-surface corrosion protection.
- c) Air filters shall be placed so that ground dust or snow will not clog the filter.

8.2.4.4 All ducting, including air cleaner-to-manifold connections, shall be air-tight to avoid the intake of unfiltered air.

8.2.4.5 Restricted inlets, sharp or numerous bends, and undersized piping shall be avoided. Maximum pressure drop shall not exceed engine manufacturer's recommendation.

- **8.2.4.6** A pressure drop indicator shall be provided if specified by the purchaser.

8.2.5 Exhaust system

8.2.5.1 The exhaust system shall be properly anchored and supported, include all interconnecting piping, and direct the expansion of the piping involved away from the engine. If an expansion joint is required, it shall be stainless steel.

NOTE Bellow-type expansion joints are preferred to flanged ones.

8.2.5.2 The muffler/silencer shall be painted with high-temperature-resistant aluminium paint or equivalent protection.

8.2.5.3 Exhaust piping shall be designed such that the back-pressure limitations of the engine are not exceeded.

8.2.5.4 Provision shall be made to prevent rainwater from entering the system and to eliminate water from exhaust gases or condensation.

8.2.5.5 Unless otherwise specified, an industrial-type exhaust silencer shall be provided. If an alternative exhaust silencer is specified by the purchaser, its design shall conform to the minimum criteria as specified on the data sheets, such as

- sound attenuation,
- personnel protection,
- spark-arresting capability.

8.2.5.6 Insulation and/ or guarding of hot metal surfaces shall not be provided, unless otherwise specified by the purchaser. However, adequate clearance shall be provided for insulation and/ or guarding by others.

8.2.6 Engine ignition system

The engine ignition system shall be suitable for the electrical area classification specified by the purchaser. The engine shall be equipped with a complete ignition system of the manufacturer's standard design, unless otherwise specified by the purchaser.

- For outdoor installation or if specified by the purchaser, all components shall be of weather-protected design or fitted with weather covers to prevent rain from directly contacting or accumulating in system components.