INTERNATIONAL STANDARD

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Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors —

Part 3: Integrally geared centrifugal compressors

Industries du pétrole, de la pétrochimie et du gaz naturel — Compresseurs axiaux et centrifuges et compresseurs-détenteurs —

Partie 3: Compresseurs centrifuges et axiaux à multiplicateur intégré

Reference number
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Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 1, *Process compressors*.

This first edition, together with ISO 10439-1, ISO 10439-2, and ISO 10439-4, replaces ISO 10439:2002.

ISO 10439 consists of the following parts, under the general title *Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors*:

— *Part 1: General requirements*

— *Part 2: Non-integrally geared centrifugal and axial compressors*

— *Part 3: Integrally geared centrifugal compressors*

— *Part 4: Expander-compressors*

Introduction

This International Standard is based on the 7th edition of the American Petroleum Institute standard API 617.

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

A asterisk (*) at the beginning of the paragraph of a clause or subclause indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on data sheets or stated in the enquiry or purchase order (see examples in Annex A, ISO 10439-2:2015, Annex A, and ISO 10439-4:2015, Annex A).

This International Standard includes the following annexes:

— Annex A: Datasheets

— Annex B: Vendor (Supplier) data and drawing requirements (VDDR)

— Annex C: Nomenclature

— Annex D: Typical materials for integrally geared compressors

— Annex E: Inspector's checklist

— Annex F: External forces and moments

— Annex G: Rating formulae for integral gearing

Annex A and Annex G form a normative part of this part of ISO 10439. Annexes B to F are for information only.

In this International Standard, where practical, US customary units are included in parentheses for information.

Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors —

Part 3: Integrally geared centrifugal compressors

1 Scope

This part of ISO 10439 specifies minimum requirements and gives recommendations for axial compressors, single-shaft and integrally geared process centrifugal compressors, and expander-compressors for special purpose applications that handle gas or process air in the petroleum, petrochemical, and natural gas industries. This part of ISO 10439 specifies integrally geared centrifugal compressors in conjunction with ISO 10439-1.

NOTE 1 See API 672 for packaged plant instrument air compressors.

NOTE 2 Expander stages are sometimes provided on these machines.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5389, *Turbocompressors — Performance test code*

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

ISO 10439-1, *Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors — Part 1: General requirements*

API 670, *Machinery protection systems*

AGMA 2015-1-A01, *Accuracy classification system — Tangential measurements for cylindrical gears*

AGMA 2101-D04, *Fundamental rating factors and calculation methods for involute spur and helical gear teeth*

ASME PTC 10-1997, *Performance test code on compressors and exhausters*

3 Terms, abbreviated terms, and definitions

For the purposes of this document, the terms, abbreviated terms, and definitions given in ISO 10439-1 apply.

NOTE A cross-section showing nomenclature of an integrally geared centrifugal compressor is included in Annex C.

4 General

4.1 Dimensions and units

The dimensional and unit requirements shall be in accordance with ISO 10439-1.

4.2 Statutory requirements

The statutory requirements shall be in accordance with ISO 10439-1.

4.3 Unit responsibility

The unit responsibilities shall be in accordance with ISO 10439-1.

4.4 Basic design

4.4.1 Performance

4.4.1.1 The sectional head-capacity characteristic curve of each compressor section shall rise continuously from the rated point to predicted surge. The compressor, without the use of a bypass, shall be suitable for continuous operation at any capacity at least 10 % greater than the predicted surge capacity shown in the proposal.

4.4.1.2 Unless otherwise specified, the design lubricant shall be hydrocarbon oil of viscosity Grade 32 with an FZG load stage of 5, in accordance with ISO 8068. Viscosity Grade 46 with an FZG load stage of 5 can be used as a design lubricant, with the purchaser's approval. Oils with extreme pressure (EP) additives shall not be used.

NOTE Typical oil used in refineries and chemical plants has an FZG of 5 or higher. Requiring a higher FZG by design can require the need for special oil for this equipment.

4.5 Materials

Materials shall be in accordance with ISO 10439-1:2015, 4.5.

NOTE Refer to Annex D for typical materials.

4.6 Casings

Casings shall be in accordance with ISO 10439-1:2015, 4.6 and 4.6.1 to 4.6.6.

4.6.1 Pressure-containing casings

4.6.1.1 * The maximum allowable working pressure of each pressure casing shall be at least equal to the specified relief valve set pressure for that casing. The purchaser will specify the relief valve set pressure(s) for final discharge pressure and intermediate casing pressures, if applicable.

NOTE If only one relief valve pressure is specified, its set pressure does not usually apply to the intermediate pressure.

4.6.1.1.1 When a relief valve set pressure is not specified, each pressure casing shall be rated for at least 125 % of the maximum specified discharge pressure (gauge) of that pressure casing as determined by the supplier. System protection shall be furnished by the purchaser.

4.6.1.2 Socket-head or spanner-type bolting shall not be used externally unless specifically approved by the purchaser. For limited space locations, integrally flanged fasteners might be required.

4.6.2 Casing repair

Casings repairs shall be in accordance with ISO 10439-1:2015, 4.6.2.

4.6.3 Material inspection of pressure-containing parts

Casing material inspection of pressure-containing parts shall be in accordance with ISO 10439-1:2015, 4.6.3.

4.6.4 Pressure casing connections

Pressure casing connections shall be in accordance with ISO 10439-1:2015, 4.6.4 and 4.6.4.1 and 4.6.4.2.

4.6.4.1 Main process connections

Main process connections shall be in accordance with ISO 10439-1:2015, 4.6.4.2.

4.6.4.2 Auxiliary connections

4.6.4.2.1 If flanged or machined and studded openings are impractical, threaded connections can be used where they do not come in contact with flammable or toxic gas, with the purchaser's approval as follows:

a) on non-weldable materials, such as cast iron;

b) where essential for maintenance (disassembly and assembly).

These threaded openings shall be as specified in ISO 10439-1:2015, 4.6.4.3.8.

4.6.4.2.2 Auxiliary connections shall be at least DN 20 (NPS 3/4-in). See 4.11.1.7 to 4.11.1.8 and Table 1 for auxiliary gearbox connections.

NOTE See ISO 10439-1:2015, 4.6.4.1.3 for allowable connection sizes.

4.6.4.2.3 Threaded connections for pipe sizes DN 20 (NPS 3/4-in) to DN 40 (NPS 1-1/2-in) size are permissible with the approval of the purchaser.

NOTE See ISO 10439-1:2015, 4.6.4.1.3 for allowable connection sizes.

4.6.5 Casing support structure

The mounting of the pressure casing (volute) to the gearbox shall be in accordance with ISO 10439-1:2015, 4.4.1.7. Bolting used to mount pressure casings shall be in accordance with ISO 10439-1:2015, 4.6.1.7.

4.6.6 External forces and moments

4.6.6.1 The supplier shall furnish the allowable forces and moments for each main process nozzle which has a customer connection in tabular form with the proposal. If nozzle loadings are not furnished, they shall be no less than NEMA SM23.

NOTE 1 Forces and moments allowed on integrally geared compressors are generally less than those allowed in ISO 10439-2 compressors (see Annex F).

NOTE 2 Piping system design needs to be rigorous in order to avoid piping expansion joints.

4.6.6.2 Pressure casing and supports shall be designed to have sufficient strength and rigidity to avoid adversely affecting impeller running clearances, gear contact pattern, seals, bearings, and coupling alignment.

4.6.7 Variable inlet and/or diffuser guide vanes

4.6.7.1 * Adjustable guide vanes shall be provided when specified or required by the supplier to meet specified operating conditions.

4.6.7.2 When provided, adjustable inlet guide vanes and operating mechanisms shall be suitable for all specified operating conditions, as well as start-up, shutdown, trip-out, settling-out, and momentary surge.

4.6.7.2.1 Guide vanes shall be mounted in replaceable bushings. Vanes can be positioned in the housing by replaceable permanently sealed rolling element bearings, if approved by the purchaser.

4.6.7.2.2 When adjustable guide vanes are used for toxic, flammable, or explosive process gas, then the linkage passing through the casing or enclosure shall be sealed to prevent leakage.

4.6.7.2.3 The inlet guide vanes shall be located sufficiently close to the eye of the impeller to be effective.

4.6.7.2.4 The vane foils shall have an aerodynamically smooth surface, especially where the shank enters the gas stream through the housing. A cantilevered design in lieu of a centre-supported vane design is preferred.

4.6.7.2.5 The vanes shall be designed such that the vanes will tend to open on loss of the control signal.

4.6.7.2.6 A vane control system consisting of a valve positioner with direct driven local position indicator shall be provided that will be visible during operation of the machine.

4.6.7.2.7 * Additional components to the vane control system in 4.6.7.2.6 shall be as specified.

4.6.7.3 * If specified, the actuation shaft seal shall be buffered using a barrier gas.

4.7 Rotating elements

4.7.1 Each impeller and shaft shall be clearly marked with a unique identification number. This number shall be on an accessible area that is not prone to maintenance damage.

4.7.2 Unless other shaft protection is approved by the purchaser, renewable components shall be furnished at close clearance points. Sleeves, spacers, or bushings shall be made of materials that are corrosion-resistant in the specified service (see ISO 10439-1:2015, 4.5.1.6 for limitations).

4.7.2.1 Shaft sleeves shall be provided under shaft end seals. Sleeves shall be treated to resist wear and sealed to prevent gas leakage between the shaft and sleeve.

4.7.3 Thrust loads from impellers and gears shall be absorbed by individual thrust bearings on pinions or transmitted to the bull gear thrust bearing by means of thrust rider rings fixed to the pinions and bull gear. All specified operating conditions and start-up conditions shall be evaluated for residual thrust loads.

NOTE Balance pistons are normally not used. Thrust balancing can be achieved by helix thrust force direction of the gearing and offsetting impeller aerodynamic thrust forces.

4.7.4 Impeller requirements shall be in accordance with ISO 10439-1:2015, 4.7.10.

4.8 Dynamics

Dynamics requirements shall be in accordance with ISO 10439-1.

4.8.1 For equipment covered in this part of ISO 14039, a lateral analysis shall be carried out for each shaft. For the bull gear, this shall consist only of an undamped critical speed map.

4.9 Bearings and bearing housings

Bearings and bearing housings shall be in accordance with 4.9.1 to 4.9.4 and ISO 10439-1:2015, 4.9.

4.9.1 General

4.9.1.1 Unless otherwise specified, radial and thrust bearings shall be of the hydrodynamic fluid film type.

4.9.1.2 Unless otherwise specified, thrust bearings and radial bearings shall be fitted with bearing-metal temperature sensors installed in accordance with API 670.

4.9.1.2.1 As design criteria, bearing metal temperatures shall not exceed 100 °C (212 °F) at specified operating conditions with a maximum oil inlet temperature of 50 °C (120 °F).

4.9.1.2.2 In the event the design criteria in 4.9.1.2.1 cannot be met, the purchaser and the supplier shall agree on acceptable bearing metal temperatures.

4.9.2 Hydrodynamic radial bearings

4.9.2.1 Sleeve or pad radial bearings shall be used and shall be split for ease of assembly. The use of non-split designs requires the purchaser's approval. The bearings shall be precision bored with steel, copper, cupro-nickel, or bronze-backed babbitted liners, pads, or shells. The bearings shall be equipped with anti-rotation pins and shall be positively secured in the axial direction.

4.9.2.2 * If specified, tilting pad bearing pads shall be copper-alloy backed.

4.9.2.3 * Unless otherwise specified, the liners, pads, or shells shall be in axially split housings. The bearing design shall not require removal of the coupling hub to permit replacement of the bearing liners, pads, or shells unless approved by the purchaser.

4.9.3 Hydrodynamic thrust bearings

4.9.3.1 Thrust bearings can be fixed-geometry (e.g. tapered-land) or tilting-pad type, steel-backed and babbitted, arranged for continuous pressurized lubrication to each side.

NOTE See 4.7.3 for thrust rider rings.

4.9.3.2 If specified, bearings shall be tilting pad on one or both sides.

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

a) the shaft speed;

b) the temperature of the bearing babbitt;

c) the deflection of the bearing pad;

d) the minimum oil film thickness;

e) the feed rate, viscosity, and supply conditions of the oil over the specified allowable oil supply condition range;

f) the design configuration of the bearing;

g) the babbitt or other bearing surface material alloy and pad material;

h) the turbulence of the oil film;

i) load changes due to process changes over the specified operating range.

NOTE See ISO 10439-1:2015, 3.1.60 for a definition of ultimate load rating for hydrodynamic thrust bearings.

4.9.3.4 Thrust bearings shall be sized for continuous operation under the most adverse specified operating conditions. Calculations of the thrust forces shall include, but shall not be limited to, the following factors:

a) seal maximum design internal clearances and twice the maximum design internal clearances;

b) pressurized rotor diameter step changes;

c) stage maximum differential pressures;

d) specified extreme variations in inlet, interstage, and discharge pressures;

e) the maximum thrust force that can be transmitted to the compressor thrust bearing by other equipment in the train (i.e. couplings, gears, or a motor without a thrust bearing);

f) the maximum thrust force from the sleeve bearing type drive if the motor or generator is directly connected.

4.9.4 Bearing housings

4.9.4.1 The term bearing housing refers to all bearing enclosures including the gearbox.

4.9.4.2 Bearing housings for pressure-lubricated hydrodynamic bearings shall be arranged to minimize foaming. The drain system shall be adequate to maintain the oil and foam level below shaft seals.

4.9.4.3 Oil reservoirs and housings that enclose moving lubricated parts (such as bearings and 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.

4.9.4.4 Provision shall be made in the bearing housings for the probes specified in 5.5.7.1.

4.10 Shaft end seals

4.10.1 Process seals and seal systems shall be in accordance with ISO 10439-1:2015, 4.10.

NOTE 1 Typical cross sections of various seal systems are given in ISO 10439-1:2015, Annex B.

NOTE 2 Equipment covered in this part can be available with any of the shaft end seal types covered in ISO 10439-1 or additional hybrid types are available.

4.10.2 * The purchaser shall specify the type of shaft end seal(s) to be provided and all operating conditions including start-up, shutdown, and settling-out conditions.

4.11 Integral gearing

4.11.1 The supplier shall dowel or key the gearbox to the mounting plate to maintain alignment.

NOTE Integrally geared compressors are fixed to the mounting plate and are not to be moved for alignment (to avoid distortion of the gearbox).

4.11.1.1 To the maximum extent practical, gearboxes shall be designed with internal oil passages to minimize external piping. External piping connections shall conform to the requirements of ISO 10439-1:2015, 4.6.4.3.

4.11.1.2 The design of internal piping and tubing shall achieve proper support and protection to prevent damage from vibration or from shipment, operation, and maintenance. Cantilevered piping in excess of 10 pipe diameters shall include reinforcing gussets in two planes at all pipe-to-flange connections.

4.11.1.3 The gearbox shall be designed to permit rapid drainage of lube oil and to minimize oil foaming (which could lead to excessive heating of the oil). For gears with pitch line velocities of more than 125 m/s (25 000 ft/min), consideration should be given to design features such as windage baffles, false bottoms, adequate sump depth, and an additional full-size drain connection.

4.11.1.4 A removable and gasketed inspection cover or covers shall be provided in the gearbox to permit direct visual inspection of the full-face width of the pinion(s) and gear. The inspection opening or openings shall be at least one-half the width of the gear face.

4.11.1.5 Permanent coatings or paint shall not be applied to the interior of the casing, unless the purchaser approves in advance the material and method of application.

4.11.1.6 A single lube-oil supply connection is preferred.

4.11.1.7 A single lube-oil drain connection from the gear casing is preferred. The minimum drainpipe size shall be sized to be no more than half full and shall be based on the total inlet flow to the gear casing, as shown in Table 1.

Table 1 — Drain pipe sizes

Inlet flow rate		Minimum drain size[a]	
Litres per minute	US Gallons per minute	Millimetres	Inch
74	19	50	2
176	46	75	3
370	97	100	4
1 146	302	150	6

[a] Nominal pipe size.

4.11.1.8 Gearboxes shall be provided with a plugged or flanged-and-blinded purge gas connection.

4.11.2 Gearbox split lines shall use a metal-to-metal joint. Adequate sealing shall be provided with a suitable joint compound or groove-type seals. Gaskets (including string type) shall not be used on the gearbox split lines.

4.11.3 Gear rating

4.11.3.1 When a gearbox has a gear mesh with a ratio of 7:1 or greater, all of the gearing in that gearbox shall be rated in accordance with Annex G. All other gear sets shall be rated per API 613.

4.11.3.2 The rated power of the gearing shall not be less than the driver nameplate rating multiplied by the driver service factor. When there are multiple pinions, the power rating of the gear sets shall not be less than the following:

a) 110 % of the maximum power transmitted by the gear set.

b) The maximum power of the driver (including service factor) prorated between all the gear sets, based on normal power demands. If the maximum transmitted torque occurs at a continuous operating speed other than the maximum continuous speed, this torque and its corresponding speed shall be the basis for sizing the gear set.

4.11.3.3 The power rating based upon both pitting resistance and bending strength shall be calculated for each member of each gear set in the unit. The pinion and bull gear teeth can have different ratings due to differences in material properties, geometry factors, and number of cycles under load. The lowest of the four ratings (pinion bending, pinion pitting, bull gear bending, bull gear pitting) shall be used as the gear rating (see Annex G). Wherever possible, gear sets shall be designed such that failure will occur due to pitting rather than bending (i.e. wear out before breaking).

NOTE Higher gear ratios require a large number of teeth; therefore, it might not be possible to provide tooth design (which will fail in pitting rather than bending) without compromising other aspects of the gear design (i.e. higher pitchline velocities).

4.11.3.4 Gearing shall be designed and manufactured to meet the requirements of AGMA 2015-1-A01, accuracy Grade 4.

NOTE For equivalent loading conditions, gearing produced to higher quality levels will always result in longer service life and reduced bearing loads.

4.11.3.5 The manufacturer shall provide documentation showing that the required quality levels in 4.11.3.4 have been met.

4.11.3.6 The pinion face width to working pitch diameter ratio (L/d ratio) shall be limited based on pinion tooth hardness, as follows:

4.11.3.6.1 For pinion hardness equal to or less than 38 Rc (BHN 354), L/d shall be limited to 2,0 maximum.

4.11.3.6.2 For pinion hardness equal to or greater than 58 Rc (BHN 615), L/d shall be limited to 1,6 maximum.

4.11.3.6.3 For pinion hardness between 38 and 58 Rc (BHN 354 and BHN 615), L/d shall be limited to $L/d = 2{,}76 - 0{,}02 \times H$ (see Figure 1), where H is the hardness in Rockwell C.

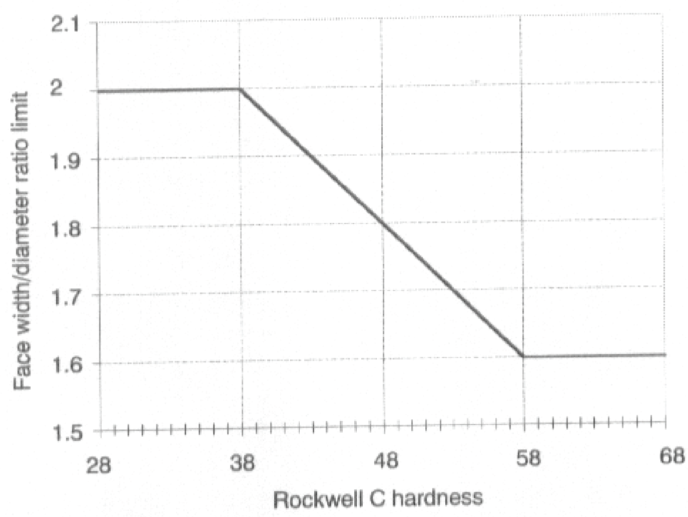

Figure 1 — Face width limit

4.11.3.7 The material used for gearing shall meet the specifications for AGMA 2101 Grade 2 material, as a minimum. If a superior grade of material is used, credit for the better material shall not be taken in the gear rating.

4.11.3.8 The tooth portion of pinions shall be integral with their shafts.

4.11.3.9 The bull gear can be integral with or separate from its shaft. Separate shafts shall be assembled into the bull gear with an interference fit suitable for all torque requirements including pulsations.

4.11.3.10 Shafts shall be made of one-piece, heat-treated steel that is suitably machined. Shafts that have a finished diameter larger than 200 mm (8 in) shall be forged steel. Shafts that have a finished diameter of 200 mm (8 in) or less shall be forged steel or hot rolled barstock, providing such barstock meets all quality and heat treatment criteria established for shaft forgings.

4.11.3.11 Gearboxes shall not require a break-in period.

4.11.3.12 The gearing shall be designed to withstand all internal and external loads inherent to geared, rotating machinery systems to the limit of the installed driver.

4.11.3.13 The unplated tooth surface on loaded faces of completed gears shall have a finish, as measured along the pitch line, of 0,8 µm (32 µin) Ra or better.

4.11.3.14 Hunting tooth combinations are preferred. To achieve this, it can be necessary for the manufacturer to adjust the exact gear ratio. If such adjustment is impractical, the purchaser and the supplier shall negotiate a solution. At least one mesh shall be hunting tooth.

NOTE A hunting tooth combination is preferred because the intent is for every tooth on a pinion to mesh with as many teeth as possible on the mating gear before the same teeth mesh again or repeat. However, with multiple pinion units, a hunting tooth combination is not as critical because the gear wheel meshes with multiple pinions and is, therefore, not as susceptible to the problems of non-hunting tooth designs.

4.11.3.15 Each gear and each pinion shall be supported between two bearings. Overhung designs are not permitted.