BS EN ISO 10439-4:2015

BSI Standards Publication

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

Part 4: Expander-compressors

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National foreword

This British Standard is the UK implementation of EN ISO 10439-4:2015. Together with BS EN ISO 10439-1:2015, BS EN ISO 10439-2:2015 and BS EN ISO 10439-3:2015, it supersedes BS EN ISO 10439:2002, which will be withdrawn upon publication of all parts of the series.

The UK participation in its preparation was entrusted to Technical Committee MCE/8/-/1, Compressors - Safety.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Foreword

This document (EN ISO 10439-4:2015) has been prepared by Technical Committee ISO/TC 118 "Compressors and pneumatic tools, machines and equipment" in collaboration with Technical Committee CEN/TC 12 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2015, and conflicting national standards shall be withdrawn at the latest by August 2015.

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Foreword

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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).

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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 10439-3, cancels and 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*

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Introduction

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

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.

An 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 is indicated on data sheets or stated in the enquiry or purchase order (see examples in Annex A, ISO 10439-2:2015, Annex A, ISO 10439-3:2015, 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;

— Annex E: Inspector's checklist;

— Annex F: Nozzle forces and moments;

— Annex G: Lubrication and sealing requirements.

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

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

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INTERNATIONAL STANDARD ISO 10439-4:2015(E)

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

Part 4: Expander-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 requirements for expander-compressors, in addition to the general requirements specified in ISO 10439-1:2015.

This scope covers only expanders and compressors on a common shaft (expander-compressor). This scope does not apply to expanders with separate output shafts (e.g. generator drives). Hot gas expanders over 300 °C (570 °F) are not covered in this part of ISO 10439.

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 10438 (all parts), *Petroleum, petrochemical and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries*

ISO 10439-1:2015, *Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors — Part 1: General requirements*

API 670, *Machinery protection systems*

3 Terms, abbreviated terms, and definitions

For the purposes of this document, the terms, abbreviated terms, and definitions given in ISO 10439-1:2015 apply.

4 General

NOTE A cross-section showing nomenclature of an expander-compressor can be found in Annex C.

4.1 Dimensions and units

The dimensional and unit requirements shall be in accordance with ISO 10439-1:2015, 4.1.

4.2 Statutory requirements

The statutory requirements shall be in accordance with ISO 10439-1:2015, 4.2.

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4.3 Unit responsibility

The unit responsibilities shall be in accordance with ISO 10439-1:2015, 4.3.

4.4 Basic design

4.4.1 The expander shall meet at least 98 % of the predicted efficiency at the certified point (see 6.3.5.1.1). The compressor shall deliver at least 98 % of the normal head at the normal capacity. The compressor power at the normal condition shall not be more than 106 % of that available from the expander, nor shall it be less than 96 % of that available from the expander.

NOTE Compressor-loaded expanders achieve a power balance that determines the speed of the machine. There is generally no speed control governor to control the speed the way other turbine-driven compressors are controlled. If the expander power is more than expected, then the speed of the machine will be higher than predicted. If the compressor power is more than expected, then the speed of the machine will be lower than predicted. The above tolerances are needed to set limits beyond which hardware changes will be required to achieve a reasonable normal speed.

4.4.2 The compressor head-capacity characteristic curve at the rated speed shall rise continuously from the rated point to surge. The compressor shall be suitable for continuous operation at any capacity on the predicted performance curve(s) at least 10 % greater than the predicted surge capacity shown in the proposal.

NOTE It is common for flow to be bypassed around the compressor during normal operation.

4.5 Materials

4.5.1 Materials shall be in accordance with ISO 10439-1:2015, 4.5. Refer to Annex D for a table of typical materials.

4.5.2 If traces of mercury have been specified, aluminium impellers shall be treated by anodizing or other approved methods.

4.6 Casings

Casings shall be in accordance with ISO 10439-1:2015, 4.6 and 4.6.1 to 4.6.7.7.

4.6.1 Pressure-containing casings

4.6.1.1 * The maximum allowable working pressure of the casing(s) shall be at least equal to the relief valve set pressure(s) specified by the purchaser.

4.6.1.1.1 If a relief valve set pressure is not specified, the maximum allowable working pressure of an expander casing shall be at least 1,1 times the maximum specified inlet pressure (gauge). System pressure protection shall be furnished by the purchaser.

4.6.1.1.2 If a relief valve set pressure is not specified, the maximum allowable working pressure of the compressor casing of an expander-compressor shall be at least 1,25 times the maximum specified discharge pressure (gauge). System pressure protection shall be furnished by the purchaser.

4.6.1.1.3 When the purchaser has not supplied a relief valve setting, he shall be responsible for insuring that furnished relief valves are compatible with casing ratings as set by 4.6.1.1.1 and 4.6.1.1.2.

4.6.1.2 O-rings, gaskets, or other sealing devices which can be used on radially spilt casings shall be confined in machined grooves and shall be made of materials suitable for all specified service conditions.

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4.6.1.3 Provisions for lifting the casings and removing the centre section shall be provided.

4.6.1.4 The expander-compressor casing shall be designed with sufficient strength to contain parts which might separate in the event of uncontrolled overspeed.

4.6.2 Casing repairs

Casing repairs shall be in accordance with ISO 10439-1.

4.6.3 Material inspection of pressure containing parts

Material inspection of pressure containing parts shall be in accordance with ISO 10439-1.

4.6.4 Pressure casing connections

Pressure casing connections shall be in accordance with ISO 10439-1 and 4.6.4.

4.6.4.1 Main process connections shall be in accordance with ISO 10439-1.

4.6.4.2 Auxiliary connections shall be at least DN 15 (NPS 1/2) and in accordance with ISO 10439-1.

4.6.5 Casing support structures

NOTE 1 Expander-compressors have no coupling, therefore, there are no special requirements for casing support structures.

NOTE 2 Expander-compressor units do not require highly finished mounting surfaces.

4.6.6 External forces and moments

4.6.6.1 Expander-compressor packages shall be designed to withstand external forces and moments on each nozzle calculated in accordance with Formulae (F.1) and (F.2).

NOTE Expander-compressor shaft alignment is not affected by piping forces since they do not have a coupling.

4.6.6.2 The supplier shall furnish the allowable forces and moments for each nozzle in tabular form.

4.6.7 Variable nozzles and heat shields

4.6.7.1 Each expander shall be equipped with variable nozzles (variable inlet guide vanes).

NOTE Variable nozzles permit the efficient conversion of head into velocity throughout the design range of the unit.

4.6.7.2 Variable nozzles shall be sized, capable of flowing at least 110 % of the mass flow at any specified operating condition.

4.6.7.3 Actuating devices shall be capable of operation at all specified operating conditions, including maximum inlet pressure, maximum flow, and minimum discharge pressure.

NOTE Variable nozzles are used for flow and pressure control. Precise control of the nozzles is necessary for smooth process operation.

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4.6.7.4 Variable nozzles and actuators shall be capable of closing with maximum inlet pressure at all flow conditions.

Actuators shall be equipped with an agreed force limiting device to ensure no over-forcing in closing or opening the inlet guide vanes.

NOTE Adjustable nozzles are often required to control expander discharge pressure under conditions of restricted flow on the discharge. It is necessary for nozzles to close rapidly with minimal leakage; however, variable nozzles are not tight shutoff devices.

4.6.7.5 Variable nozzles shall be designed to minimize friction.

4.6.7.6 If variable nozzles are used for toxic, flammable, or explosive process gas, the linkage passing through the casing or enclosure shall be sealed.

4.6.7.7 If required, an insulating heat shield shall be provided between the cold expander process fluids and the bearing cavity. Heat shields shall be constructed of materials with good insulation properties.

NOTE See Annex D for typical heat shield materials.

4.7 Rotating elements

4.7.1 General

4.7.1.1 Rotating elements shall be in accordance with ISO 10439-1:2015, 4.7 and 4.7.

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

4.7.2 Shaft sleeve

Unless other shaft protection is approved by the purchaser, replaceable components shall be furnished at labyrinth shaft seal locations. Sleeves, spacers, or bushings shall be made of materials that are corrosion-resistant in the specified service.

4.7.3 Shafts

4.7.3.1 Shafts shall be of one piece or permanently joined multiple piece construction, and can be hollow.

NOTE 1 Expanders can have multi-piece construction hollow shafts that are joined by methods such as friction welding per ANSI/AWS—C6.1 Recommended practices for friction welding.

NOTE 2 Because these parts are permanently joined, trapped process gas is not a problem.

4.7.3.2 All welds on the shaft shall be inspected by ultrasonic or radiographic examination. After finish machining, the welds shall be inspected by magnetic particle or liquid penetrant examination. Refer to ISO 10439-1:2015, 6.2.2 for material inspection methods and ISO 10439-1:2015, 6.2.2.1.1 for acceptance criteria.

4.7.3.3 For precipitation-hardened stainless steel shafts with maximum journal velocities (trip speed) above 95 m/s (315 ft/s), the supplier shall provide a coating or overlay on the journals to prevent wire wooling.

NOTE Chrome plating, weld overlay, High Velocity Oxygen Fuel (HVOF), High Velocity Liquid Fuel (HVLF), and graphite impregnation are some of the methods which have been used successfully to prevent wire wooling.

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4.7.4 Impellers

4.7.4.1 General

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

4.7.4.2 Thrust balancing

4.7.4.2.1 A balance cavity, line and porting shall be provided if required to limit axial loads on the thrust bearings.

4.7.4.2.2 When an automatic or fixed thrust equalizing valve is provided as per 4.9.3.4, this valve shall be flanged and sized to handle balance drum gas leakage at twice the initial design labyrinth clearance without exceeding the load rating of the thrust bearings. If the balance line involves a purchaser's connection to his piping, then the connection sizes shall be indicated on the data sheets.

4.7.4.2.3 An automatic thrust equalizing valve shall be provided. This valve shall react to changes in thrust load as measured by thrust pressure (magnetic bearing current, etc.) to actively maintain a low thrust load on the thrust bearings by injecting to or venting from balancing chambers inside the machine. See Figure 1 for typical automatic thrust equalizing valve schematic.

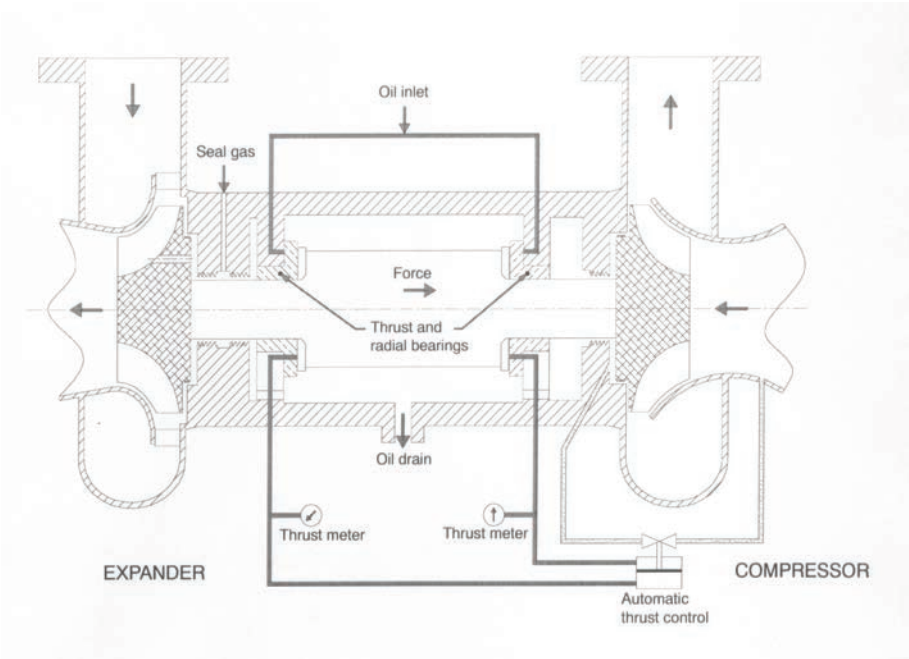

Figure 1 — Automatic thrust balancing system

4.8 Dynamics

Dynamics shall be in accordance with of ISO 10439-1:2015, 4.8.

4.8.1 Vibration balancing

4.8.1.1 The balancing method described in 4.8.1.2 to 4.8.1.5 shall apply only to single-shaft expander-compressors which require rotor disassembly and re-assembly to install. All other expander-compressors shall comply with ISO 10439-1:2015, 4.8.8.

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NOTE Expander-compressors in cryogenic service are typically single-shaft rotors which require disassembly and re-assembly of the rotor to install in the machine casing. By requiring index balancing, either the compressor or expander component can be replaced individually without requiring the complete rotor to be rebalanced.

4.8.1.2 The expander wheel, compressor wheel, and the shaft shall be balanced using an index balancing procedure. All machining of components shall be completed before balancing. The wheels shall be supported by a concentric arbor during the balancing procedure. Two-plane balancing is preferred, but single-plane balancing can be used for components with a length to diameter (L/d) ratio of 0,2 or less. Each component shall be balanced so that the level of residual unbalance for each balance plane does not exceed the greatest value determined by Formulae (3) or (4) as applicable in ISO 10439-1:2015.

NOTE For information on the index balance procedure, refer to API 684.

4.8.1.3 Prior to starting the index balancing procedure for the compressor and expander wheels, the following steps shall be performed to check the integrity of the fits between the wheels and arbor.

a) Mount the wheel at an arbitrary 0 degree location on the arbor. Record the unbalance reading of the assembly.

b) Dismount and remount the wheel on the arbor in the original 0 degree position. Record the unbalance.

c) The vector reading from item b) shall be within 20 % of the vector reading from item a). If not, the arbor fit shall be checked for poor contact, dirt, or other items affecting the fit integrity.

4.8.1.4 Index balance both wheels, using an arbor, to the tolerance specified in 4.8.1.2. After this step, the wheels should be in balance and no further corrections should be required.

4.8.1.5 The shaft index balance procedure shall be performed using both wheels mounted in the following manner:

a) Mount the expander and compressor wheels on the shaft. Both wheels should be marked to an arbitrary 0 degree location on the shaft.

b) Identify appropriate balance planes on the shaft. Perform index balancing of the shaft using the wheels to the tolerance specified in 4.8.1.2.

c) Both wheels shall be treated as one part and turned together during the index balancing procedure.

4.8.1.6 * If specified, rotors shall be assembled and the balance verified. The residual unbalance for the randomly assembled components shall not exceed 10 times the maximum allowable residual unbalance as determined by Formulae (3) or (4) as applicable in ISO 10439-1:2015.

Assembled rotors that fail to meet these criteria shall be balance corrected by repeating the component index balance, not by trim balancing the assembly.

4.8.1.7 * If specified, a residual unbalance check shall be performed on assembled rotors. The residual unbalance check shall be performed after assembly balancing or assembly check-balancing is complete and before the assembled rotor is removed from the balancing machine.

NOTE Refer to ISO 10439-1:2015, Annex A for a description of the procedure for residual unbalance determination.

4.9 Bearings and bearing housings

4.9.1 General

4.9.1.1 Unless otherwise specified, hydrodynamic radial and thrust bearings shall be provided.

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NOTE The typical expander-compressor has both the radial and thrust bearing built into a single assembly.

4.9.1.2 * If specified, magnetic bearings shall be supplied in accordance with ISO 10439-1:2015, Annex E.

4.9.1.3 Bearing material selection criteria shall include compatibility with the process gas.

NOTE Bearings are generally in contact with the process gas.

4.9.2 Hydrodynamic radial bearings

4.9.2.1 Sleeve or pad type bearings shall be used. The bearings shall be precision machined. Materials used shall be steel, brass, bronze, aluminium, copper alloy, or other suitable material.

4.9.2.2 Unless otherwise specified, hydrodynamic radial bearings shall be fitted with bearing metal temperature sensors, installed in accordance with API 670.

4.9.3 Hydrodynamic thrust bearings

Hydrodynamic thrust bearings shall be in accordance with ISO 10439-1:2015, 4.9.3 and 4.9.3.1 to 4.9.3.4.

4.9.3.1 Hydrodynamic thrust bearings shall be precision machined, continuous or segmented face design. Continuous face designs shall have grooving, such as spiral grooving, to allow oil distribution. Segmented face designs can be either fixed or tilting pad configuration. Materials used shall be steel, bronze, aluminium, copper alloy, or other materials suitable for the application. Hydrodynamic thrust bearings shall be arranged for continuous pressurized lubrication to each side.

NOTE A typical expander-compressor thrust bearing can be made of brass or bronze, have a tapered land or spiral groove face design, and be unbabbited.

4.9.3.2 Unless otherwise specified, thrust bearings shall be designed for equal thrust capacity in both axial directions.

4.9.3.3 Loads on hydrodynamic thrust bearings shall be limited to no more than 50 % of the bearing manufacturer's ultimate load rating at specified operating conditions.

4.9.3.4 When calculated, loads on hydrodynamic thrust bearings exceed 50 % of the ultimate capacity of the bearings, expander-compressors shall be equipped with automatic or fixed position thrust equalizing valves to reduce the bearing loads for the specified conditions to a minimum, reducing expected loads to no more than 50 % of the ultimate capacity of the bearing (see Annex C).

Bearings shall also be capable of meeting start-up and upset conditions.

NOTE 1 This device can be a direct operated valve, using fluid pressures taken from the thrust bearing oil film for actuation.

NOTE 2 Loading of 50 % of the ultimate load can be exceeded during start-up or upset conditions.

4.9.4 Bearing housings

4.9.4.1 Bearing housings shall be in accordance with ISO 10439-1:2015, 4.9.4 and 4.9.4.2.

4.9.4.2 Rotor support system parts (bearings, bearing housings, bearing shells, and bearing brackets) shall be separable from the mating casings.

NOTE Expander bearing housings are pressurized.

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4.10 Expander-compressor shaft seals

4.10.1 Shaft seals shall comply with the requirement of ISO 10439-1:2015, 4.10 and 4.10.2 and 4.10.3.

NOTE Expander-compressors do not have shaft end seals, but the same types of seals are used for internal sealing between the process gas and the bearing housing.

4.10.2 Shaft seals shall be provided to restrict the leakage of process gas into the bearing housing over the range of specified operating conditions, including start-up and shutdown. Seals shall be suitable for specified variations in seal operating conditions that can prevail during start-up, shutdown, or settling out, and during any other special operation specified.

4.10.3 Shaft seals used in expanders can be either clearance seals or self-acting dry gas seals.

NOTE See ISO 10439-1:2015, 4.10 for information on shaft end seals.

4.11 Integral gearing

Integral gears are not applicable to expander-compressors.

4.12 Nameplates and rotation arrows

4.12.1 Nameplates and rotation arrows shall be in accordance with ISO 10439-1:2015, 4.12.

NOTE Rotation arrows are generally not provided for expander-compressors.

4.12.2 The following data shall be clearly stamped or engraved on the nameplate:

— supplier's name;

— serial number;

— size, type, and model number;

— design power;

— rated speed (rpm);

— trip speed (rpm);

— purchaser's item number or other reference;

— maximum allowable working pressure of each casing;

— maximum and minimum working temperature of each casing;

— hydrostatic test pressure of each casing;

— maximum continuous speed;

— lateral critical speeds up to and including the next critical above maximum continuous speed.

5 Accessories

5.1 Drivers

NOTE Expander-compressor units do not have separate drivers.

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5.2 Couplings and guards

NOTE Expander-compressors do not have couplings and guards.

5.3 Lubrication and sealing systems

When required, a pressurized oil system shall be furnished to supply oil at suitable pressure(s) to the machine. Such systems shall be in accordance with ISO 10438 (all parts) as modified by Annex G.

5.4 Mounting plates

Mounting plates shall be in accordance with ISO 10439-1:2015, 5.4 and 5.4.1. and 5.4.2.

NOTE Soleplates are not used with expanders.

5.4.1 Unless an externally connected piece of rotating equipment such as a generator is supplied, jackscrews and other levelling devices are not required.

5.4.2 The expander-compressor shall be furnished with a baseplate in accordance with ISO 10439-1:2015, 5.4.2.

NOTE Expander-compressor units do not have couplings; therefore, sections of ISO 10439-1 that invoke requirements for alignment shims, machined surfaces, etc. are not applicable to expanders.

5.5 Controls and instrumentation

Controls and instrumentation shall be in accordance with ISO 10439-1:2015, 5.5 and 5.5.1 to 5.5.5.

5.5.1 Vibration and position monitoring

5.5.1.1 Unless otherwise specified, vibration transducers shall be supplied, installed, and calibrated in accordance with API 670.

5.5.1.2 * If specified, axial position probes shall be provided in accordance with API 670.

NOTE Expander-compressors normally use pressure from active thrust compensation system rather than axial position probes for alarm/shutdown functions.

5.5.1.3 * If specified, vibration monitors shall be supplied and calibrated in accordance with API 670.

5.5.2 Hydrodynamic bearings

5.5.2.1 *Unless otherwise specified, hydrodynamic radial bearings shall be fitted with bearing-metal temperature sensors installed in accordance with API 670. The purchaser will specify the type of detector.

5.5.2.2 *If specified, hydrodynamic thrust bearings shall be fitted with bearing-metal temperature sensors installed in accordance with API 670. The purchaser will specify the type of detector required.

5.5.2.3 * If specified, a bearing temperature monitor shall be supplied and calibrated in accordance with API 670.

5.5.3 Magnetic bearings

If magnetic thrust and radial bearings have been specified, they shall be fitted with bearing temperature sensors, installed in accordance with ISO 10439-1:2015, Annex E.

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5.5.4 Overspeed shutdown system

5.5.4.1 General

5.5.4.1.1 Unless otherwise specified, an overspeed shutdown system based on a single circuit shall be provided.

The design of an expander-compressor provides an inherent degree of overspeed protection. Overspeed primarily results from an interruption of flow to the compressor or operation, primarily during start-up, with a very low compressor suction pressure. The design of the piping system, including all valves and associated controls, should ensure that compressor flow interruption or very low suction pressure does not occur. Since the system is unlikely to produce an overspeed condition, single circuit overspeed detection and trip systems are the standard.

5.5.4.1.2 * If specified, an overspeed shutdown system based on two-out-of-three voting logic shall be furnished.

5.5.4.1.3 The supplier shall design an overspeed shutdown system consisting of

a) electronic overspeed circuit [speed sensor(s) and logic device];

b) expander inlet trip valve;

c) electric solenoid valves.

NOTE Due to the wide variation in process services using expanders, it is not unusual for the expander inlet trip valve to be furnished by the purchaser.

5.5.4.2 Electronic overspeed detection circuit

5.5.4.2.1 Unless otherwise specified, an electronic overspeed detection circuit, consisting of a speed sensor(s) and logic device, shall be furnished. The design of the circuit shall include the following:

a) failure of either the sensor(s) or logic device shall initiate a shutdown;

b) all settings incorporated in the overspeed circuit shall be protected through control access;

c) it shall accept inputs from a frequency generator for verifying the trip speed setting;

d) it shall provide an output for a speed indicator.

5.5.4.2.2 Unless otherwise specified, magnetic pickups shall be supplied for speed sensing.

5.5.4.2.3 A hole or grooved surface integral with the shaft shall be provided for speed sensing. The hole or grooved surface can be used by both the overspeed system and the tachometer sensors.

5.5.4.3 Expander trip valve

5.5.4.3.1 Unless otherwise specified, the supplier will provide an expander inlet trip valve that will close when the supplier's shutdown system senses overspeed.

NOTE 1 Due to the wide variation in process services using expanders, it is not unusual for the expander inlet trip valve and solenoids to be furnished by the purchaser. The expander inlet trip valve is not the control mechanism for the expander. The trip valve is either full open or full closed (tripped). Capacity and speed control are provided by expander variable inlet nozzles, compressor minimum flow valve, or other means. The inclusion of a unit isolation valve upstream of the trip valve is typical of most installations, with provisions to depressurize the piping volume between the isolation and trip valves so that the trip valve does not have to be opened against full line pressure. The isolation valve is meant to close when the trip valve closes.

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NOTE 2 See 4.6.1.4

5.5.4.3.2 The design of expander inlet trip valves shall include, but not be limited to, the following:

a) the ability to close rapidly as possible within a time as agreed;

b) actuation from a fail-safe spring loaded actuator, a gas operated actuator, or an air-operated actuator (If the design of the gas or air supply system could permit loss of gas or air pressure, then connections to provide volume bottles with capacity for two full stroke closures of the trip valve);

   The torque capability of the actuator shall be sufficient to permit the valve to close with ice build-up on it. Consideration shall be given to additional sealing devices such as flexible pressure-assisted seal rings to overcome the friction of ice build-up.

c) an extended bonnet to maintain the stem packing at a non-cryogenic temperature;

d) special features to prevent ice, hydrates, and other solids from stopping valve closure.

5.5.4.3.3 If the expander inlet trip valve is furnished by the purchaser, the supplier shall review the selection and shall provide recommendations concerning the sizing, location, and closing time requirements.

5.5.4.3.4 An electric solenoid-operated valve shall be provided to initiate operation of the trip valve. Unless otherwise specified, the solenoid valve shall be de-energized to trip.

NOTE 1 Solenoids can draw significantly high currents.

NOTE 2 The purchaser can ensure that the electronic overspeed shutdown system is supplied from an uninterruptable power source.

5.5.4.3.5 When solenoids draw high currents that exceed the current rating of the relay in the overspeed shutdown system, interposing relays or other provisions shall be supplied.

5.5.5 Permanent strainer

5.5.5.1 * If specified, a permanent strainer located upstream of the trip valve in a removable spool piece, with an effective free flow area at least twice the cross-sectional area of the expander inlet trip valves shall be furnished by the supplier.

NOTE The spool piece is normally provided by the user. Differential pressure indication with a high pressure alarm switch can be provided for the strainer.

5.5.5.2 * If specified, the spool piece and differential pressure instrumentation for the permanent strainer shall be provided.

5.5.5.3 The supplier's design shall include provision for a local manual trip mechanism located near the expander inlet trip valve. Actuation of the manual trip mechanism shall close the trip valve and the variable inlet nozzles.

5.5.5.4 * If specified, the supplier shall furnish the local manual trip mechanism.

5.6 Piping and appurtenances

5.6.1 Piping and appurtenances furnished shall be in accordance with ISO 10439-1:2015, 5.6 and 5.6.2.

5.6.2 The supplier shall furnish all piping systems, including mounted appurtenances, located within the confines of the baseplate. The piping shall terminate with flanged connections at the edge of the

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baseplate. The purchaser will furnish only interconnection piping between equipment groupings and off-base facilities.

5.7 Special tools

Special tools shall be furnished in accordance with ISO 10439-1:2015, 5.7.

6 Inspection, testing, and preparation for shipment

6.1 General

6.1.1 Inspection, testing, and preparation for shipment shall be in accordance with ISO 10439-1:2015, Clause 6 and 6.1 to 6.4.

6.1.2 General requirements for 6.1 to 6.4 shall be in accordance with ISO 10439-1:2015, 6.1. Also refer to Annex E for the inspector's checklist.

6.2 Inspection

Requirements for inspection shall be in accordance with ISO 10439-1.

6.3 Testing

6.3.1 General

6.3.1.1 In addition to ISO 10439-1:2015, 6.3, the expander-compressor(s) shall be tested in accordance with 6.3.3 and 6.3.4. Other optional tests that might be specified are described in 6.3.5.

6.3.1.2 Immediately upon completion of each witnessed mechanical or performance test, copies of the log data recorded during the test shall be given to the witnesses.

6.3.2 Wheel shaker test

6.3.2.1 For any new design which has not been previously built and tested, a shaker test shall be performed. The purpose of this test is to verify that the fundamental natural frequency of the blades and disk are in agreement with the range of predicted values calculated during the design phase. The measured frequency shall be within ±5 % of the calculated frequency under wheel shaker test conditions.

6.3.2.2 If this test does not validate the calculated values, the actual natural frequency shall be assessed against the operating speed range and expected stresses and the need for corrective action mutually agreed between the supplier and the purchaser.

6.3.2.3 If it is necessary to modify the wheel to adjust this natural frequency, the modified wheel shall be retested to confirm that the modification was successful.

6.3.3 Mechanical running test

6.3.3.1 The requirements of 6.3.3.1.1 to 6.3.3.1.5 shall be met before the mechanical running test is performed.

6.3.3.1.1 Unless otherwise agreed, the contract shaft seals and bearings shall be used in the machine for the mechanical running test.

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