

BS EN ISO 10439-1:2015



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

Part 1: General requirements

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National foreword

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ISO 10439-2:2015, BS EN ISO 10439-3:2015 and BS EN ISO 10439-4:2015, it supersedes BS EN ISO 10439:2002, which will be withdrawn upon publication of all parts of the series.

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Erdöl-, petrochemische und Erdgasindustrie - Axial- und Radialkompressoren und Expanderkompressoren für Sonderanwendungen zur Handhabung von Gas oder Prozessluft - Teil 1: Allgemeine Anforderungen (ISO 10439-1:2015)

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Foreword

This document (EN ISO 10439-1:2015) 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of an identical text or by endorsement, at the latest by August 2015, and conflicting national standards shall be withdrawn at the latest by August 2015.

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This document supersedes EN ISO 10439:2002.

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Endorsement notice

The text of ISO 10439-1:2015 has been approved by CEN as EN ISO 10439-1:2015 without any modification.

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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 may 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 may 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 should be indicated on data sheets or stated in the enquiry or purchase order (see examples in ISO 10439-2:2015, Annex A, ISO 10439-3:2015, Annex A, and ISO 10439-4:2015, Annex A).

This International Standard includes the following annexes:

- [Annex A](#): Procedure for the determination of residual unbalance;
- [Annex B](#): Typical shaft end seals;
- [Annex C](#): Requirements for lateral analysis reports;
- [Annex D](#): Requirements for torsional analysis reports;
- [Annex E](#): Magnetic bearings;
- [Annex F](#): Dry gas seal testing at manufacturer's shop;
- [Annex G](#): Guidelines for anti-surge systems;
- [Annex H](#): Typical bid tab template.

[Annex A](#), [Annex C](#), [Annex D](#), [Annex E](#), and [Annex F](#) form a normative part of this part of ISO 10439. [Annex B](#), [Annex G](#), and [Annex H](#) 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 1: General requirements

1 Scope

This International Standard specifies minimum requirements and gives recommendations for axial compressors, single-shaft, and integrally geared process centrifugal compressors, and expander-compressors for special purpose applications that handle gas or process air in the petroleum, petrochemical, and natural gas industries. This part of ISO 10439 specifies general requirements applicable to all such machines.

This International Standard does not apply to fans (these are covered by API 673) or blowers that develop less than 34 kPa (5 psi) pressure rise above atmospheric pressure. This International Standard also does not apply to packaged, integrally geared centrifugal plant, and instrument air compressors, which are covered by API 672. Hot gas expanders over 300 °C (570 °F) are not covered by this International Standard.

This part of ISO 10439 contains information pertinent to all equipment covered by the other parts of ISO 10439. It shall be used in conjunction with the following parts of ISO 10439, as applicable to the specific equipment covered:

- ISO 10439-2;
- ISO 10439-3;
- ISO 10439-4.

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.

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

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

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

ISO 7005-1, *Pipe flanges — Part 1: Steel flanges for industrial and general service piping systems*

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

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

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

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

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

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

ISO 15156-3, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

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

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

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

API 613, *Special purpose gear units for petroleum, chemical, and gas industry services*

ASME B1.1, *Unified inch screw threads (UN and UNR thread form)*

ASME B16.1, *Grey iron pipe flanges and flanged fittings (Classes 25, 125, and 250)*

ASME B16.11, *Forged fittings, socket-welding and threaded*

ASME B16.42, *Ductile iron pipe flanges and flanged fittings (Classes 150 and 300)*

ASME B16.47, *Large diameter steel flanges NPS 26 through NPS 60 metric/inch standard*

ASME B16.5, *Pipe flanges and flanged fittings NPS ½ through NPS 24 metric/inch standard*

ASME B1.20.1, *Pipe threads, General purpose (Inch)*

ASTM A247, *Standard test method for evaluating the microstructure of graphite in iron castings*

ASTM A395, *Standard specification for ferritic ductile iron pressure-retaining castings for use at elevated temperatures*

ASTM E125, *Standard reference photographs for magnetic particle indications on ferrous castings*

ASTM E165, *Standard practice for liquid penetrant examination for general industry*

ASTM E709, *Standard guide for magnetic particle testing*

AWS D1.1, *Structural welding code*

NACE MR0103, *Standard material requirements — Material resistant to sulfide stress cracking in corrosive petroleum refining environments*

NACE SP0472, *Methods and controls to prevent in-service environmental cracking of carbon steel weldments in corrosive petroleum refining environments*

NFPA 70, *National electrical code*

SAE J518, *Hydraulic flanged tube, pipe, and hose connections, four-bolt split flange type*

3 Terms, abbreviated terms and definitions

3.1 Terms and definitions

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

3.1.1

anchor bolts

bolts used to attach the mounting plates to the support structure (concrete foundation or steel structure)
cf. *hold-down bolts* ([3.1.11](#))

3.1.2

axially split joint

joint split with the principal face parallel to the shaft centreline

3.1.3

cartridge bundle assembly

<centrifugal> assembly consisting of the complete compressor assembly minus the casing

Note 1 to entry: It includes the inner barrel assembly, end heads, seals, bearing housings, and bearings. It also includes the rotor assembly. It is designed to be shop assembled, ready for insertion into the casing to minimize installation work in the field.

3.1.4

certified point

point to which the performance tolerances shall be applied

Note 1 to entry: This is usually the normal operating point and suppliers will normally require that this point is within their preferred selection range.

3.1.5

complex stiffness

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

3.1.6

compliant seal

seal design that allows rotor or rotor sleeve contact and possible stator element penetration without excessive loss of sealing performance

3.1.7

compressor rated point

intersection on the 100 % speed curve corresponding to the highest capacity of any specified operating point

3.1.8

compressor section

series of one or more impellers with defined external process conditions (i.e. side streams, bypassing, or injection)

Note 1 to entry: This is generally a derived point rather than an actual operating point (see Figure 1 in ISO 10439-2:2015 for a graphical representation).

3.1.9

critical speed

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

3.1.10

design

manufacturers' calculated parameter

Note 1 to entry: This is a term used by the equipment manufacturer to describe various parameters such as design power, design pressure, design temperature, or design speed. It is not intended for the purchaser to use this term.

3.1.11

bull gear gear wheel

lowest speed rotor in a gearbox cf. *pinion(s)* ([3.1.34](#))

3.1.12

gearing

pinion(s) and gear wheel combination(s)

Note 1 to entry: A gear mesh is a pinion and gear wheel that operates together. A gear wheel may mesh with more than one pinion and, therefore, be part of more than one gear mesh.

3.1.13

hold-down bolts

bolts holding the equipment to the mounting plate cf. *anchor bolts* ([3.1.1](#))

3.1.14

hydrodynamic bearings

bearings that use the principles of hydrodynamic lubrication

Note 1 to entry: The bearing surfaces are oriented so that relative motion forms an oil wedge, or wedges, to support the load without shaft-to-bearing contact.

3.1.15

hysteresis damping

<internal friction> causes a phase difference between the stress and strain in any material under cyclic loading; this phase difference produces the characteristic hysteric loop on a stress-strain diagram and, thus, a potentially destabilizing damping force

3.1.16

inlet volumetric flow

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

Note 1 to entry: Inlet volumetric flow is a specific example of actual volumetric flow. Actual volumetric flow is the volume flow at any particular location such as interstage impeller inlet or discharge or machine inlet or discharge. Actual volumetric flow should not be used interchangeably therefore with inlet volumetric flow.

3.1.17

inner barrel assembly

<centrigugal> assembly consisting of the internal stationary parts that make up the removable portion of the flowpath, including the inner barrel, the diaphragms, the impeller eye labyrinths, and the diaphragm labyrinths

3.1.18

low temperature service

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

3.1.19

maximum allowable temperature

maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred)

Note 1 to entry: The maximum allowable temperature is usually set by material considerations.

3.1.20

maximum allowable working pressure

maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred)

Note 1 to entry: Normally expected operating conditions can be based on settling-out pressure, maximum suction pressure plus the maximum developed differential pressure at the maximum speed (trip speed) or may be limited by relief valve set pressure or other means.

3.1.21

maximum continuous speed

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

3.1.22

maximum inlet pressure

highest specified inlet pressure the equipment shall be subject to

3.1.23

maximum sealing pressure

highest pressure the seals are required to seal during any specified static or operating conditions and during start-up and shutdown

3.1.24

minimum allowable speed

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

3.1.25

minimum design metal temperature:

lowest mean metal temperature (through the thickness) expected, including operation upsets, auto refrigeration, and temperature of the surrounding environment

3.1.26

modular rotor

rotor which is built up using stub shafts or similar devices and held together by one or more through bolts

3.1.27

moment simulator

auxiliary device intended to simulate the moment of the mass of a half coupling

Note 1 to entry: A moment simulator can also be designated to serve as an idling adapter (solo plate).

3.1.28

mounting plate(s)

device used to attach equipment to concrete foundations; this is either baseplate(s) or soleplates

3.1.29

normal operating point

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

Note 1 to entry: This point is usually the point at which the supplier certifies that performance is within the tolerances stated in this part of ISO 10439.

3.1.30

normal speed

speed corresponding to the requirements of the normal operating condition

3.1.31

NPS

nominal pipe size

dimensionless value approximately equal to the diameter in inches

EXAMPLE NPS 3/4

Note 1 to entry: Adapted from ASME B 31.3–2002, 300.2.

Note 2 to entry: The number following the letters NPS does not represent a measurable value.

Note 3 to entry: NPS is a designation of pipe size only. The pipe end may be threaded or prepared for a welded fitting.

3.1.32

observed

<tests and inspections> inspection or test where the purchaser is notified of the timing of the inspection or test, and the inspection or test is performed as scheduled even if the purchaser or his representative is not present

3.1.33

overload

highest flow point at which the predicted curve terminates on a speed line

3.1.34

pinion(s)

high-speed rotor(s) in a gearbox cf. *bull gear* ([3.1.11](#))

3.1.35

PN

nominal pressure

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

EXAMPLE PN 100 [ISO 7268]

Note 1 to entry: The permissible working pressure associated with a PN designation depends upon the materials, design, and working temperature and has to be selected from the pressure/temperature rating tables in corresponding standards.

3.1.36

pressure casing

composite of all stationary pressure-containing parts of the unit, including all nozzles and other attached parts that isolates process gas from the atmosphere

3.1.37

purchaser

agency that issues the order and specification to the supplier

Note 1 to entry: The purchaser may be the owner of the plant in which equipment is to be installed or the owner's appointed agent.

3.1.38

radially split

split with the joint perpendicular to the shaft centreline

3.1.39

rated speed

100 % speed

highest rotational speed (revolutions per minute) required to meet any of the specified operating conditions

3.1.40

relief valve set pressure

pressure at which a relief valve starts to lift

Note 1 to entry: For information on relief valves, see API RP 520.

3.1.41

service factor

<gear> factor that is applied to the tooth pitting index and the bending stress number, depending upon the characteristics of the driver and the driven equipment, to account for differences in potential overload, shock load, and/or continuous oscillatory torque characteristics

3.1.42

settling-out pressure

highest pressure which the compressor experiences when the compressor is not running and equilibrium has been reached

Note 1 to entry: Determination of settling-out pressure requires consideration of the trapped volume of gas throughout the compressor and its associated piping system. This includes all gas trapped between the downstream valve and the upstream valve after a compressor is shut down.

3.1.43

shaft end seal

process gas seal on the shaft which restricts leakage of process gas to the atmosphere

3.1.44

slow roll

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

3.1.45

soleplate

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

3.1.46

special purpose application

application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no installed spare equipment

3.1.47

special tool

tool which is not a commercially available catalogue item

3.1.48

stability analysis

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

3.1.49

standard volume flow

flow rate expressed in volume flow units at standard conditions as follows:

ISO standard (normal) conditions

flow: normal cubic meters per hour (Nm³/h)
 normal cubic meters per min (Nm³/min)

pressure: 1,013 bar absolute

temperature: 0 °C

humidity: 0 %

US customary standard conditions

flow: standard cubic ft per min (scfm)
 million standard cubic ft per day (mmscfd)

pressure: 14,7 PSIA

temperature: 60 °F

humidity: 0 %

Note 1 to entry: There are no universally accepted conditions for normal or standard cubic meters; therefore, their reference pressure and temperature should always be spelled out, i.e. m³/h 0 °C, 1,013 bar absolute.

Note 2 to entry: Due to the lack of uniformity on standard conditions, standard volume flow is not a preferred unit and, if specified, should be given in conjunction with actual mass flow to avoid confusion.

3.1.50

structure stiffness and damping

bearing housing to ground equivalent complex stiffness

3.1.51

surge

instability which occurs in a centrifugal or axial compressor at low volumetric flow

3.1.52

synchronous tilt-pad coefficients

complex frequency dependent coefficient with the frequency equal to the rotational speed of the shaft

3.1.53

supplier

manufacturer or manufacturer's agent that supplies the equipment

3.1.54

support stiffness and damping

equivalent oil film to ground complex stiffness characteristics; pivot stiffness should be included in the oil film characteristics

3.1.55

tooth pitting index

surface durability rating factor that is determined by the tangential load, pitch diameter, face width, and gear ratio

3.1.56

TIR

total indicator reading

total indicator runout

difference between the maximum and minimum readings of a dial indicator or similar device, monitoring a face or cylindrical surface during one complete revolution of the monitored surface

Note 1 to entry: For a cylindrical surface, the indicated runout implies an eccentricity equal to half the reading. For a flat face, indicated runout implies an out-of-squareness equal to the reading. If the diameter in question is not cylindrical or flat, the interpretation of the meaning of TIR is more complex and may represent ovality or surface irregularities.

3.1.57

trip speed

<electric motor driver> speed corresponding to the synchronous speed of the motor at maximum supply frequency at the motor terminals

3.1.58

trip speed

<turbine, engine, expander, hydrostatic driver> speed at which the independent emergency overspeed device operates to shut down the driver

3.1.59

turndown

percentage of change in capacity (referred to rated capacity) between the rated capacity and the surge point capacity at the rated head when the unit is operating at rated suction temperature and gas composition

3.1.60

ultimate load rating

<hydrodynamic thrust bearing> load that shall produce the minimum acceptable oil film thickness without inducing failure during continuous service, or the load that shall not exceed the creep initiation or yield strength of the babbitt or bearing material at the location of maximum temperature on the pad, whichever load is less

3.1.61

unit responsibility

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

3.1.62

witnessed (tests and inspections)

<tests and inspections> inspection or test where the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or the purchaser's representative is in attendance

3.2 Abbreviated terms

A_{c1}	amplitude at N_{c1} , μm (mil)
A_{max}	maximum probe response amplitude (p-p) considering all vibration probes, over the range of N_{ma} to N_{mc} , for the unbalance amount/case being considered, μm (mil)
AF	amplification factor (refer to API RP 684 and Figure 2)
AF_1	amplification factor of the first critical speed, defined as: $AF_1 = N_{c1}/(N_2 - N_1)$
AMB	active magnetic bearing
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASME code	ASME boiler and pressure vessel code
ASTM	American Society for Testing and Materials
Avl	the mechanical test vibration limit defined in 4.8.2.10 , μm (mil)
AWS	American Welding Society
CCW	counter clockwise (rotation)
CSR	critical speed ratio, defined as: $CSR = N_{\text{mc}}/FCSR$
CW	clockwise (rotation)
cf	(Latin conferre) confer or compare — cross reference
DN	nominal diameter
δ	logarithmic decrement
δ_A	minimum log decrement at the anticipated cross coupling for either minimum or maximum component clearance
δ_b	basic log decrement of the rotor and support system only

δ_f	log decrement of the complete rotor support system from the Level II analysis
FCSR	first undamped critical speed on rigid supports, r/min
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MAWP	maximum allowable working pressure
MCS	maximum continuous speed
N	operating speed, r/min
N_{cn}	rotor n^{th} critical speed, r/min
N_{c1}	rotor first critical speed, r/min
N_{ma}	minimum allowable speed, r/min
N_{mc}	maximum continuous speed, r/min
N_1	initial (lesser) speed at $0,707 \times$ peak amplitude, r/min
N_2	final (greater) speed at $0,707 \times$ peak amplitude, r/min
NACE International	National Association of Corrosion Engineers
NFPA	National Fire Protection Association
PPM	proactive preventive maintenance
OEM	Original Equipment Manufacturer
Q_A	anticipated cross coupling for the rotor, kN/mm (klbf/in), defined as: $Q_A = \sum_{i=1}^S q_{Ai}$
Q_0	minimum cross coupling needed to achieve a log decrement equal to zero for either minimum or maximum component clearance, kN/mm (klbf/in)
q_a	cross coupling defined in Formula (7) or (8) for each stage or impeller, kN/mm (klbf/in)
R_{out}	combined mechanical and electrical runout, μm (mil)
ρ_{ave}	average gas density across the rotor, kg/m^3 (lb/ft ³)
S	number of stages or impellers
S_{an}	actual separation for n^{th} critical speed, r/min
S_{a1}	actual separation for 1st critical speed, r/min
SM	separation margin (see Figure 2)
SM_a	forced response analysis actual separation margin, %
SM_{an}	separation margin for n^{th} critical speed, %

SM_r	forced response analysis required separation margin, %
SM_1	separation margin for the 1st critical speed, %, $= 100 \times S_{a1}/N_{ma}$
STD	standard
U_a	input unbalance for the rotordynamic response analysis, g-mm (oz-in), $= 2 \times U_r$
U_r	maximum allowable residual unbalance, g-mm (oz-in)
VDDR	vendor (supplier) drawing and data requirements
VFD	variable frequency drive (variable speed motor drive)

4 General

4.1 Dimensions and units

Drawings and maintenance dimensions shall be in SI units or United States customary (USC) units. Use of an SI datasheet indicates that SI units shall be used. Use of an USC datasheet indicates that USC units shall be used.

NOTE Datasheets for SI and USC units are provided in ISO 10439-2:2015, Annex A, ISO 10439-3:2015, Annex A, and ISO 10439-4:2015, Annex A.

4.2 Statutory requirements

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

4.3 Unit responsibility

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

4.4 Basic design

4.4.1 General

4.4.1.1 General requirements relating to performance are given in [4.4.1.1.1](#) to [4.4.1.1.5](#).

4.4.1.1.1 The equipment shall be capable of operating within the entire performance map, at all specified operating conditions, as well as accommodating other conditions such as momentary surge, settling-out, trip, and start-up.

4.4.1.1.2 * The purchaser shall specify all operating conditions for the equipment. Normal operating point shall be indicated.

NOTE Special operating conditions such as air dry out, field commissioning test run, catalyst regeneration, etc. can all be specified in order to ensure that operation can satisfactorily be met.

4.4.1.1.3 The compressor shall be designed to deliver normal head at the normal inlet volumetric flow. Performance tolerances given in the testing sections shall apply.

NOTE 1 The purchaser can furnish mass flow which is then converted to volumetric flow by the supplier.

NOTE 2 If a factory test is not performed, additional measuring tolerances can be considered for field measurements.

NOTE 3 See [6.3](#) of the applicable part for performance tolerances.

4.4.1.1.4 The overload condition shall be indicated on performance curves. Unless otherwise agreed, the sectional overload condition shall be at least 115 % of the rated condition.

NOTE See [3.1.33](#) for the definition of overload.

4.4.1.1.5 The purchaser shall supply a gas analysis. Gas properties used shall be agreed.

4.4.1.2 Any planned maintenance or inspection that may be required during the 5-year uninterrupted operation period shall be able to be performed without shutting down the equipment.

NOTE 1 It is recognized that this is a design criterion.

NOTE 2 It is realized that there are some services where this objective is easily attainable and others where it is difficult.

NOTE 3 Auxiliary system design and the design of the process in which this system is installed are very important in meeting this objective.

4.4.1.3 Unless otherwise specified, cooling water systems including those on process coolers shall be in accordance with ISO 10438.

NOTE API 614 5th edition is identical to ISO 10438 (all parts):2007.

4.4.1.4 * The purchaser shall advise the supplier in the inquiry of any specific requirements for liquid injection.

4.4.1.5 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the supplier at or before the coordination meeting. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance.

4.4.1.6 * The applicable electrical codes and area classification shall be specified.

NOTE Electrical codes vary widely depending upon the installed location. In the US, one of the governing codes is the National Electrical Code document number NFPA 70:2008, Articles 500, 501, 502, 504, and 505. In the European Union, the ATEX (from the French Atmosphere Explosible) directives, which are statutory law, govern. Other countries generally accept approval by an independent third party which states the equipment conforms to the governing standards. One of the third parties in the US is Underwriter Lab (UL) and in Canada it is the Canadian Standards Association (CSA).

4.4.1.7 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as casing components and bearing housings shall be designed and manufactured to ensure accurate alignment on reassembly.

NOTE This can be accomplished by the use of shouldering, cylindrical dowels or keys.

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

4.4.1.9 * The equipment including all auxiliaries shall be suitable for operation under the environmental conditions specified by the purchaser. These conditions shall include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, humidity, dusty or corrosive conditions, wind loads, and seismic zone.

4.4.1.10 * Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the supplier having unit responsibility. The equipment furnished by the supplier shall conform to the maximum allowable sound pressure level specified. The supplier shall provide expected values for maximum sound pressure level per octave band for the equipment.

NOTE The installed SPL depends on the installation

4.4.1.11 * If specified, sound power levels based on calculation methods shall be supplied in addition to sound pressure level based on a free field analysis.

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

4.4.1.12 Unless otherwise specified, the design lubricant shall be hydrocarbon oil of viscosity Grade 32 in accordance with ISO 8068 Type AR.

4.4.2 Speed requirements

4.4.2.1 The equipment's maximum continuous speed shall not be less than 105 % of the rated speed for variable speed machines (including VFD-controlled electric motors) and shall be equal to the synchronous speed for constant speed motor drives.

4.4.2.2 The equipment's trip speed shall not be less than the limiting speed of the emergency overspeed device furnished with the driver. [Table 1](#) provides typical values for various drivers. Purchaser and supplier shall agree whether turbine trip speed based on loss of inertial load applies to the compressor.

Table 1 — Driver trip speeds

Driver type	Trip speed (% of maximum continuous speed)
Steam Turbine	
NEMA Class Aa	115 %
NEMA Class B, C, Da	110 %
Gas turbine	105 %
Variable speed motor	100 %
Variable speed gear	102 %
Constant speed motor	100 %
Reciprocating engine	110 %

4.4.2.3 Equipment shall be designed to operate simultaneously at the MAWP and trip speed without damage, regardless of driver power.

4.4.2.4 Equipment driven by induction motors shall be rated at the actual motor speed for the rated load condition.

4.4.3 The equipment (machine, driver, and ancillary equipment) shall perform on the test stand and on their permanent foundation within the specified acceptance criteria. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the supplier who has unit responsibility.

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

To minimize the influence of these factors, the supplier shall, when requested, review and comment on the purchaser's piping and foundation drawings. If specified, the supplier's representative shall witness

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

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

4.4.5 * Motors, generators, instrumentation, electrical components, and electrical installations shall be suitable for the area classification (class, group, and division or zone) specified by the purchaser and shall meet the requirements of IEC 60079-10-1 or NFPA 70:2008, Articles 500 to 505 as applicable, as well as local codes specified and furnished by the purchaser.

NOTE See [4.4.1.6](#).

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

4.4.7 * If specified, the machine or machines shall be suitable for field run on air. Performance parameters, including any required precautions, shall be agreed.

4.5 Materials

4.5.1 General

4.5.1.1 Materials of construction shall be the manufacturer's standard for the specified operating and site environmental conditions, except as required or prohibited by the data sheets or by this standard. ISO 10439-2:2015, Annex D, ISO 10439-3:2015, Annex D, and ISO 10439-4:2015, Annex D list material specifications that, when used with appropriate heat treatment or impact testing requirements or both, are generally considered acceptable for major component parts. The metallurgy of all major components shall be clearly stated in the supplier's proposal. See [5.6](#) for requirements for auxiliary piping materials.

4.5.1.2 The materials of construction of all major components shall be clearly stated in the supplier's proposal. Materials shall be identified by reference to applicable international standards, including the material grade. When no such designation is available, the supplier's material specification, giving physical properties, chemical composition, and test requirements, shall be included in the proposal.

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

4.5.1.3 * The purchaser shall specify any corrosive agents (including trace quantities) present in the motive and process fluids in the site environment, including constituents that may cause corrosion.

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

NOTE 2 Selection of materials is a joint effort between manufacturer and supplier. Conditions including non-running conditions need to be considered.

4.5.1.4 The supplier shall specify the optional tests and inspection procedures that may be necessary to ensure that materials are satisfactory for the service. Such tests and inspections shall be listed in the proposal.

NOTE The purchaser can specify additional optional tests and inspections, especially for materials used for critical components or in critical services.

4.5.1.5 Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or lower temperatures. Therefore, only fully killed, normalized steels made to fine-grain practice are acceptable for pressure-containing machine components. The use of steel made to a coarse austenitic grain size practice (e.g. ASTM A515) shall not be used.

4.5.1.6 Unless otherwise specified, if hydrogen sulfide has been identified in the gas composition, materials exposed to that gas shall be selected in accordance with the requirements of NACE MR0103 and where applicable the referenced NACE SP0472.

NOTE 1 NACE MR0103 requires restrictive hardness limits, more restrictive weld qualification procedures, and limits to the carbon equivalent levels of materials versus NACE MR0175 (See [4.5.1.7](#)).

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

4.5.1.7 * If specified, ISO 15156-3 shall be used in place of NACE MR0103.

NOTE 1 ISO 15156-3 applies to material potentially subject to sulfide and chloride stress-corrosion cracking in oil and gas production facilities. These are upstream facilities; however, ISO 15156-3 (NACE MR0175 earlier editions) have been applied to compressors in downstream facilities since the fifth edition of API 617 (1988) prior to the introduction of NACE MR0103-2007.

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

NOTE 3 NACE MR0175-2008 is identical to ISO 15156-3.

4.5.1.8 Ferrous materials not covered by NACE MR0103 or ISO 15156-3 shall have a maximum yield strength of 620 N/mm² (90 000 psi) and a maximum Rockwell hardness of HRC 22. Components fabricated by welding shall be postweld heat treated, if required, so that both the weld and the heat-affected zones meet the yield strength and hardness requirements.

NOTE NACE MR0175-2008 is identical to ISO 15156-3.

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

NOTE Overlays or hard surfaces that contain more than 0,10 % carbon can sensitize both low-carbon and stabilized grades of austenitic stainless steel, unless a buffer layer that is not sensitive to intergranular corrosion is applied.

4.5.1.10 Austenitic steels shall not be used in services where stress-corrosion cracking is a possibility.

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

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

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

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

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

4.5.1.15 O-ring materials shall be compatible with all specified services. Special consideration shall be given to the selection of O-rings for high-pressure services to ensure that they are not damaged upon rapid depressurization (explosive decompression). For vertically split case designs, the supplier shall state the maximum allowable depressurizing rate of the compressor casing required to prevent explosive decompression of the O-ring material supplied.

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

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

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

4.5.1.17 * Coatings

If specified, mutually acceptable coatings shall be applied to the rotating and/or stationary components in the gas path. When coatings are applied to rotating components, the acceptance balance shall be made after coatings have been applied. The sequence of procedures for balancing and coating of rotating components shall be agreed.

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

NOTE 2 API RP 687:2009, Chapter 1 Appendix L is an informative tutorial on coatings.

4.5.1.18 Positive material identification (PMI)

4.5.1.18.1 * The extent of PMI testing shall be specified for materials, welds, fabrications, and piping. This shall be fully defined, including any sampling requirements.

4.5.1.18.2 When PMI is specified, techniques providing quantitative results shall be used.

4.5.1.18.3 Mill test reports, material composite certificates, visual stamps, or markings shall not be considered as substitutes for PMI testing.

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

4.5.1.19 Low-temperature service

NOTE See [3.1.18](#).

4.5.1.19.1 Pressure casings and rotating elements shall be designed with materials that comply with the paragraphs included in this section.

4.5.1.19.2 * If specified, other components of the machinery train shall also be evaluated for the prevention of brittle fracture due to materials exhibiting change from ductile to brittle fracture as temperatures are reduced.

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

NOTE Normally, this is the lower of the minimum surrounding ambient temperature or minimum fluid pumping temperature; however, the purchaser can specify a minimum design metal temperature based on properties of the pumped fluid, such as autorefrigeration at reduced pressures.

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

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

4.5.1.19.5 All carbon and low-alloy steel pressure-containing components for low-temperature service including nozzles, flanges, and weldments shall be impact tested in accordance with the requirements of Section VIII, Division 1, Sections UCS-65 to 68, of the ASME Code or equivalent standard. High-alloy steels shall be tested in accordance with Section VIII, Division 1, Section UHA-51, of the ASME Code or equivalent standard.

NOTE 1 In some situations, impact testing of a material is not necessary depending on the minimum design metal temperature, thermal, mechanical, and cyclic loading, and the governing thickness. Refer to requirements of Section VIII, Division 1, Section UG-20F of the ASME Code, for example.

NOTE 2 Design codes other than ASME can require additional certification and material testing.

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

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

The results of the impact testing shall meet the minimum impact energy requirements of Section VIII, Division 1, Section UG-84, of the ASME Code or equivalent standard.

4.5.1.19.7 For materials and thicknesses not covered by Section VIII, Division 1 of the ASME Code or equivalent standards, the purchaser shall specify the requirements.

4.5.2 Castings

4.5.2.1 Castings shall comply with material specification requirements regarding porosity, hot tears, shrink holes, blow holes, cracks, scale, blisters, and similar injurious defects. Surfaces of castings shall be cleaned by sandblasting, shotblasting, chemical cleaning, or other standard methods. Mould-parting fins and the remains of gates and risers shall be chipped, filed, or ground flush.

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

4.5.2.3 Pressure-containing ferrous castings shall only be repaired as specified in [4.5.2.3.1](#) to [4.5.2.3.3](#).

4.5.2.3.1 Weldable grades of steel castings shall be repaired, using a qualified welding procedure based on the requirements of the appropriate pressure vessel code such as Section VIII, Division 1 and Section IX of the ASME Code. After major weld repairs and before hydrotest, the complete repaired casting shall be given a postweld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal and dimensional stability during subsequent machining operations.

4.5.2.3.2 Cast grey iron may be repaired by plugging within the limits specified in ASTM A278, ASTM A395, or ASTM A536. The holes drilled for plugs shall be carefully examined, using liquid penetrant, to ensure that all defective material has been removed.

4.5.2.3.3 All repairs that are not covered by ASTM specifications shall be subject to the purchaser's approval.

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

4.5.2.5 All ductile (Nodular) iron castings shall be produced in accordance with ASTM A395 or other equivalent internationally recognized standard as approved. The production of the castings shall conform to the conditions specified in [4.5.2.5.1](#) to [4.5.2.5.4](#).

4.5.2.5.1 The keel or Y block cast at the end of the pour shall have a thickness not less than the thickness of critical sections of the main casting. This test block shall be tested for tensile strength and hardness and shall be microscopically examined. Classification of graphite nodules under microscopic examination shall be in accordance with ASTM A247. There shall be no intercellular flake graphite.

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

4.5.2.5.2 A minimum of one set (three samples) of Charpy V-notch impact specimens at one-third the thickness of the test block shall be made from the material adjacent to the tensile specimen on each keel or Y block. All three specimens shall have an impact value not less than 12 J (9 ft-lbf) and the mean of the three specimens shall not be less than 14 J (10 ft-lbf) at room temperature.

4.5.2.5.3 If approved, non-pressurized ductile (Nodular) iron castings may be produced in accordance with ASTM A536 or other equivalent internationally recognized standard.

4.5.2.5.4 An "as-cast" sample from each ladle shall be chemically analysed.

4.5.2.5.5 Brinell hardness tests shall be made on the actual casting at feasible critical sections such as section changes, flanges, and other accessible locations. Sufficient surface material shall be removed before hardness tests are made to eliminate any skin effect. Tests shall also be made at the extremities of the casting at locations that represent the sections poured first and last. These shall be made in addition to hardness test on keel or Y blocks in accordance with [4.5.2.5.1](#).

4.5.3 Forgings

4.5.3.1 The forging material should be selected from those listed in ISO 10439-2:2015, Annex D, ISO 10439-3:2015, Annex D, and ISO 10439-4:2015, Annex D as applicable.

4.5.3.2 Pressure-containing ferrous forgings shall not be repaired except as specified in [4.5.3.2.1](#) and [4.5.3.2.2](#).

4.5.3.2.1 Weldable grades of steel forgings shall be repaired by welding. Using a qualified welding procedure based on the requirements of the appropriate pressure vessel code such as Section VIII, Division I and Section IX of the ASME Code or the equivalent specified standard. After major weld repairs and before hydrotest, the complete forging shall be given a postweld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal.

4.5.3.2.2 All repairs that are not covered by ASTM specifications shall be subject to the purchaser's approval.

4.5.4 Welding

4.5.4.1 Unless otherwise specified, non-pressurized component welding, such as welding on baseplates, non-pressure ducting, lagging, and control panels, shall be performed and inspected by operators and procedures qualified in accordance with AWS D 1.1 or ASME Section IX or other purchaser-approved standard.

4.5.4.2 Welding of piping, pressure-containing parts, rotating parts, and other highly stressed parts, weld repairs, and any dissimilar-metal welds shall be performed and inspected by operators and procedures qualified in accordance with Section VIII, Division I and Section IX of the ASME Code or purchaser approved standard such as EN 287 and EN 288 for weld qualifications or procedures or other purchaser-approved standards.

4.6 Casings

4.6.1 Pressure-containing casings

4.6.1.1 The pressure casing shall be designed in accordance with [4.6.1.1.1](#) or [4.6.1.1.2](#). The casing joint bolting shall be in accordance with [4.6.1.1.4](#).

4.6.1.1.1 The allowable tensile stress used in the design of the pressure casing (excluding bolting) for any material shall not exceed 0,25 times the minimum ultimate tensile strength for that material at the maximum specified operating temperature. For cast materials, the allowable tensile stress shall be multiplied by the appropriate casting factor as shown in [Table 2](#).

Table 2 — Casting factors

Type of NDE	Casting factor
Visual, magnetic particle and/or liquid penetrant	0,8
Spot radiography	0,9
Ultrasonic	0,9
Full radiography	1,0

4.6.1.1.2 Pressure-containing components may be designed with the aid of finite element analysis provided that the design limits comply with Section VIII, Division 2 of the ASME Code stress intensity as modified by Formula (1).

$$\text{MASI} = \text{CSI} \times (\text{P}_{\text{ch}}/150) \quad (1)$$

where

MASI is the maximum allowable stress intensity expressed in kPa (psi);

CSI is the code stress intensity expressed in kPa (psi);

P_{ch} is the code hydrotest pressure, expressed in per cent of MAWP.

The manufacturer shall state the source of the material properties, such as ASTM, as well as the casting factors applied in his proposal.

NOTE Refer to ASME Code Section VIII, Div 2 Part AD-140(a) for definition of stress intensity.

4.6.1.1.3 A corrosion allowance of at least 3 mm (0.12 in) shall be added to the casing thickness used in [4.6.1.1.1](#) or [4.6.1.1.2](#).

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

4.6.1.1.4 For casing joint bolting, the allowable tensile stress (as determined in [4.6.1.1.1](#)) shall be used to determine the total bolting area based on hydrostatic load and gasket preload as applicable. The preload stress shall not exceed 75 % of the bolting material minimum yield. During hydrotest, the bolting preload stress shall not exceed 90 % of the bolting material minimum yield and a positive method for measuring bolting elongation shall be used. Preload during the assembled gas leakage test shall not exceed 75 % of the bolting material minimum yield strength.

Thread stress in the nut or case can be the limiting factor and should be evaluated.

NOTE Torque wrenches are not an acceptable way to determine bolt elongation due to variations in friction factor.

4.6.1.2 For flammable or toxic gases, compressor casings shall be steel or purchaser-approved alloy. Expander casings shall be made of material in ISO 10439-4:2015, Annex D or approved alloy.

4.6.1.3 For air or non-flammable gases, casings may be steel, ductile iron, or cast iron materials depending on the following ratings:

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

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

4.6.1.4 Jackscrews, guide rods, cylindrical casing-alignment dowels, and/or special tools shall be provided to facilitate disassembly and reassembly. Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly. Lifting lugs or eyebolts shall be provided for lifting only the top half of the casing of axially split casings. When jackscrews are used as a means of parting contacting faces, one of the faces shall be relieved (counterbored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

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

4.6.1.5 The use of threaded holes in pressure parts of cast iron casings shall be minimized. To prevent leakage in pressure sections of casings, metal equal in thickness to at least 12 mm (1/2 in), in addition to the allowance for corrosion, shall be left around and below the bottom of drilled and threaded holes. The depth of the threaded holes shall be at least 1,5 times the diameter of the threaded insert (stud, plug, etc.).

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

4.6.1.7 Bolting shall be furnished as specified in [4.6.1.7.1](#) to [4.6.1.7.6](#).

4.6.1.7.1 The details of threading shall conform to ISO 261 or ASME B1.1.

NOTE 1 ISO 261 covers general metric screw threads and ASME B 1.1 covers general inch series screw threads.

NOTE 2 For the purposes of this provision, ASME B 1.13M is equivalent to ISO 261.

NOTE 3 Glossary of terms for screw threads can be found in ASME B 18.12.

4.6.1.7.2 Studs shall be supplied on the main joint of axially split casings and bolted end covers of radially split casings. Studs shall be used instead of cap screws, on all other external joints, except where hexagonal head cap screws are essential for assembly purposes and have been approved by the purchaser.

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

4.6.1.7.4 Supplier shall advise whether bolting that needs to be disassembled for maintenance is metric or imperial thread series.

4.6.1.7.5 * If specified, the main casing joint studs and nuts shall be designed for the use of hydraulic bolt tensioning. Procedures and extent of special tooling provided by the supplier shall be agreed.

4.6.1.7.6 The minimum quality bolting material for pressure joints shall be carbon steel (such as ASTM A307, Grade B) for cast iron casings and high-temperature alloy steel (such as ASTM A193, Grade B7) for steel casings. Carbon steel nuts (such as ASTM A194, Grade 2H) shall be used. Where space is limited, case-hardened carbon steel nuts (such as ASTM A563, Grade A) shall be used.

NOTE For low temperature requirements, see [4.5.1.19](#).

4.6.1.8 Materials, casting factors, and the quality of any welding shall be equal to those required by Section VIII, Division 1 of the ASME Code or other purchaser-approved standard. The manufacturer's data report forms, as specified in the code, are not required unless required by regulation.

NOTE For low temperature requirements, see [4.5.1.19](#).

4.6.1.9 Welding of piping, pressure-containing parts, weld repairs and any dissimilar-metal welds shall be performed and inspected by operators and procedures qualified in accordance with Section VIII Division I and Section IX of the ASME Code or other purchaser approved standard.

4.6.2 Casing repairs and inspections

4.6.2.1 The supplier shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat treated and non-destructively examined for soundness and compliance with the applicable qualified procedures (see [4.6.1.9](#)). Repairs shall be non-destructively tested by the same method used to detect the original flaw; however, the minimum level of inspection after the repair shall be by the magnetic particle method in accordance with [6.2.2.4](#) for magnetic material and by the liquid penetrant method in accordance with [6.2.2.5](#) for non-magnetic material.

Unless otherwise specified, procedures for major repairs shall be subject to review by the purchaser prior to any repair.

4.6.2.2 The purchaser shall be notified before making a major repair to a pressure-containing part. Major repair, for the purpose of purchaser notification only, is any defect that equals or exceeds any of the three criteria defined below:

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

4.6.2.3 Actual repairs shall be made as required by the following documents:

- a) the repair of plates, prior to fabrication, shall be performed in accordance with the ASTM standard to which the plate was purchased;
- b) the repair of castings or forgings shall be performed prior to final machining in accordance with the ASTM standard to which the casting or forging was purchased;
- c) the repair of a fabricated casing or the defect in either a weld or the base metal of a cast or fabricated casing, uncovered during preliminary or final machining, shall be performed in accordance with Section VIII of the ASME Code or other purchaser-approved standard.

4.6.2.4 Pressure-containing casings made of wrought materials or combinations of wrought and cast materials shall conform to the conditions specified in [4.6.2.4.1](#) to [4.6.2.4.6](#).

4.6.2.4.1 Plate edges shall be inspected by magnetic particle or liquid penetrant examination as required by Section VIII, Division 1, UG-93 (d) (3) of the ASME Code. Alternative standards may be applied when approved by the purchaser.

4.6.2.4.2 Accessible surfaces of welds shall be inspected by magnetic particle or liquid penetrant examination after back chipping or gouging and again after postweld heat treatment

4.6.2.4.3 * If specified, the quality control of welds that will be inaccessible on completion of the fabrication shall be agreed on by the purchaser and supplier prior to fabrication.

4.6.2.4.4 Pressure-containing welds, including welds of the case to horizontal or vertical joint flanges, shall be full penetration (complete joint) welds unless otherwise approved by the purchaser prior to any fabrication.

NOTE This does not apply to auxiliary connections as described in [4.6.4.3](#).

4.6.2.4.5 Casings and fabrications that require machining to precise dimensions and tolerances to ensure assembly shall be heat treated regardless of thickness.

NOTE The ASME code does not require all fabrications to be postweld heat treated.

4.6.2.4.6 All pressure-containing welds shall be examined as required by Section VIII, Division 1 of the ASME Code. Requirements for additional examination shall be agreed.

NOTE See [4.6.3](#) for required procedures and acceptance criteria.

4.6.3 Material inspection of pressure-containing parts

NOTE Refer to [6.2.2](#) for inspection of non-pressure-containing parts

4.6.3.1 Regardless of the generalized limits presented in this section, it shall be the supplier's responsibility to review the design limits of all materials and welds in the event that more stringent requirements are specified. Defects that exceed the limits imposed in [4.6.3](#) shall be removed to meet the

quality standards cited, as determined by additional magnetic particle or liquid penetrant inspection as applicable prior to repair welding.

4.6.3.2 * If radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds or materials is required or specified, the procedures and acceptance criteria in [Table 3](#) shall apply, except as noted (see [6.2.2](#)).

Table 3 — ASME materials inspection standards

Type of inspection	Methods	Acceptance criteria	
		For fabrications	For castings
Radiography	Section V, Articles 2 and 22 of the ASME Code	Section VIII, Division 1, UW-51 (for 100 % radiography) and UW-52 (for spot radiography) of the ASME Code	Section VIII, Division 1, Appendix 7 of the ASME Code
Ultrasonic inspection	Section V, Articles 4, 5 and 23 of the ASME Code	Section VIII, Division 1, UW53 and Appendix 12 of the ASME Code	Section VIII, Division 1, Appendix 7 of the ASME Code
Magnetic particle inspection	Section V, Articles 7 and 25 of the ASME Code	Section VIII, Division 1, Appendix 6 of the ASME Code	See acceptance criteria in 6.4.16.6 and Table 2
Liquid penetrant inspection	Section V, Articles 6 and 24 of the ASME Code	Section VIII, Division 1, Appendix 8 of the ASME Code	Section VIII, Division 1, Appendix 7 of the ASME Code

4.6.3.2.1 Spot radiography shall consist of a minimum of one 150-mm (6-in) spot radiograph for each 7,6 m (25 ft) of weld on each casing. As a minimum, one spot radiograph is required for each welding procedure and welder used for pressure-containing welds.

4.6.3.2.2 For magnetic particle inspections, linear indications shall be considered relevant only if the major dimension exceeds 1,6 mm (1/16 in). Individual indications that are separated by less than 1,6 mm (1/16 in) shall be considered continuous.

4.6.3.3 Cast steel casing parts shall be examined by magnetic particle methods. Acceptability of defects shall be based on a comparison with the photographs in ASTM E125. For each type of defect, the degree of severity shall not exceed the limits specified in [Table 4](#).

Table 4 — Maximum severity of defects in castings

Type	Defect	Degree
I	Linear discontinuities	1
II	Shrinkage	2
III	Inclusions	2
IV	Chills and Chaplets	1
V	Porosity	1
VI	Welds	1

4.6.4 Pressure casing connections

4.6.4.1 General

4.6.4.1.1 All connections shall be flanged or machined and studded, except where threaded connections are permitted by [4.6.1.5](#) or [4.6.4.3](#). All process gas connections to the casing shall be suitable for the maximum allowable working pressure.

4.6.4.1.2 All of the purchaser's connections shall be accessible for disassembly without requiring the machine, or any major part of the machine, to be moved.

4.6.4.1.3 All openings or nozzles for piping connections on pressure casings shall be in accordance with ISO 6708 (ASME B1.20.1). Sizes DN 32, DN 65, DN 90, DN 125, DN 175, and DN 225 (NPS 1-1/4, NPS 2-1/2, NPS 3-1/2, NPS 5, NPS 7, and NPS 9) shall not be used.

NOTE NPS designates pipe per ASME B1.20.1.

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

4.6.4.1.5 All welding of connections shall be completed before the casing is hydrostatically tested (see [6.3.2](#)).

4.6.4.1.6 For axially split pressure casings, the supplier shall provide connections for complete drainage of all gas passages. For radially split pressure casings, the drains shall be located at the lowest point of each inlet section, the lowest point of the section between the inner and outer casings, and the lowest point of each discharge section. The number and size of drain connections shall be shown in the data sheet.

4.6.4.1.7 * If specified, individual stage drains, including a drain for the balance piston cavity, shall be provided (see [4.6.4.1.6](#)).

4.6.4.2 Main process connections

4.6.4.2.1 Main process connections shall be flanged or machined and studded and oriented as specified on the data sheets.

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

4.6.4.2.2 Flanges shall conform to ISO 7005-1:1992 Series 1, including [Annex D](#) and [Annex E](#), or ISO 7005-2:1998 Series 1 or ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 Series B, or other approved standard as applicable, except as specified in [4.6.4.2.3](#) to [4.6.4.2.4](#).

NOTE 1 ASME B16.47 includes both the former MSS SP 44 and API 605 flanges. Since these flange dimensions are not compatible, the MSS were designated as Series A and the API as Series B.

NOTE 2 ISO 7005-1 (steel flanges) PN 20, 50, 110, 150, 260, 420 are designed to be interchangeable with ASME B16.5 and MSS SP-44 flanges – ISO 7005-1 flanges are not identical to ASME B 16.5 and MSS SP 44 flanges but are deemed to comply with the dimensions specified in the ASME B 16.5 and MSS SP 44.

NOTE 3 ISO 7005-2 (cast iron) flanges PN 20, 50 are designed to be interchangeable with ASME B16.1 (grey cast iron) and ASME B 16.42 (ductile cast iron) but they are not identical. They are deemed to comply with dimensions specified in ASME B16.1 (grey cast iron) and ASME B 16.42 (ductile cast iron).

NOTE 4 ISO PN 2-5 and PN 6 do not have a corresponding ASME class and ASME class 75, 400, and 800 do not have a corresponding ISO PN designation. The use of these PN and class ratings are therefore not recommended.

4.6.4.2.3 If ISO 7005-1:1992 is used, materials shall be in accordance with ISO 1995-1:1992, Annex D (DIN) or [Annex D-2](#) (ASTM) as specified. The pressure temperature ratings in ISO 7005-1:1992, Annex E shall correspond to the materials specified.

4.6.4.2.4 * If specified, ASME B16.47 Series A flanges may be supplied.

4.6.4.2.5 Supplier shall state the particular flange standard and provide details of the flanges which are being provided.

4.6.4.2.6 Cast iron flanges shall be flat faced and conform to the dimensional requirements of ISO 7005-2 (ASME B16.1 or ASME B16.42). Class 125 flanges shall have a minimum thickness equal to Class 250 for sizes DN 200 (NPS 8) and smaller. PN 20 (Class 125) flanges shall have a minimum thickness equal to PN 50 (Class 250) for sizes DN 200 (NPS 8) and smaller.

NOTE NPS designates pipe per ASME B1.20.1.

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

4.6.4.2.8 Flanges in all materials that are thicker or have a larger outside diameter than required by ISO (ANSI/ASME) are acceptable. Non-standard (oversized) flanges shall be completely dimensioned on the arrangement drawing. If oversized flanges require studs or bolts of non-standard length, this requirement shall be identified on the arrangement drawing.

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

4.6.4.2.10 Connections and flanges not in accordance with ISO 7005-1 or ISO 7005-2 (ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 Series A or Series B) require the purchaser's approval.

4.6.4.2.11 The supplier shall supply mating flanges, studs, and nuts for non-standard connections.

4.6.4.2.12 The concentricity of the bolt circle and the bore of all casing flanges shall be such that the area of the machined gasket-seating surface is adequate to accommodate a complete standard gasket without protrusion of the gasket into the fluid flow.

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

4.6.4.2.14 Machined and studded connections shall conform to the facing and drilling requirements of ISO 7005-1 or ISO 7005-2 (ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47). Studs and nuts shall be furnished installed, the first 1,5 threads at both ends of each stud shall be removed.

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

4.6.4.2.15 To minimize nozzle loads and facilitate installation of piping, machine flanges shall be parallel to the plane shown on the arrangement drawing to within 0,5 degree. Studs or bolt holes shall straddle centrelines parallel to the main axis of the equipment.

4.6.4.3 Auxiliary connections

4.6.4.3.1 Auxiliary connections may include but are not limited to those for vents, liquid injection, drains (see [4.6.4.1.6](#)), water cooling, lube and seal oil, flushing, seal and buffer gas, and balance piston cavity.

4.6.4.3.2 Flanges shall conform to ISO 7005-1 or ISO 7005-2 (ASME B16.1, ASME B16.5, or ASME B16.42) or SAE J518 as applicable.

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

4.6.4.3.4 Auxiliary connections for lube oil, seal oil, or dry gas seal operation shall use weld-neck or slip-on flanges only.

NOTE Socket-weld is not allowed due to the possibility of a dirt trap.

4.6.4.3.5 Pipe nipples screwed or welded to the casing, preferably not more than 150 mm (6 in) long, shall be a minimum of Schedule 160 seamless for sizes DN 25 (NPS 1) and smaller and a minimum of Schedule 80 for DN 40 (NPS 1-1/2).

4.6.4.3.6 Each pipe nipple shall be provided with a welding-neck, socket-weld, or slip-on flange, except as indicated in [4.6.4.3.4](#).

4.6.4.3.7 For socket-welded construction, a gap of 1,5 mm (1/16 in), as measured prior to welding, shall be left between the pipe end and the bottom of the socket in the casing.

NOTE See [4.6.4.3.4](#) for connections where socket-weld is not allowed.

4.6.4.3.8 Requirements for threaded connections

4.6.4.3.8.1 * Threaded openings for tapered pipe threads shall conform to ISO 7-1 or ASME B 1.20.1 as specified. If ISO 7-1 has been specified, tapered or straight internal threads shall also be specified. Bosses for pipe threads shall conform to ASME B 16.5.

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

4.6.4.3.8.2 * Pipe threads shall be taper thread conforming to ISO 7-1 or ASME B1.20.1 as specified.

4.6.4.3.8.3 Threaded connections shall not be seal welded.

4.6.4.3.8.4 For threaded connections that are connected to pipe, a pipe nipple, preferably not more than 150 mm (6 in) long, Schedule 160 seamless minimum, shall be installed in the threaded opening. Each pipe nipple shall be provided with a welding-neck, socket-weld, or slip-on flange. The nipple and flange materials shall meet the requirements of [4.6.4.1.4](#).

4.6.4.3.8.5 Threaded openings not required for piping connections shall be plugged with solid, round-head steel plugs in accordance with ASME B16.11. As a minimum, these plugs shall meet the material requirements of the pressure casing. Plugs that may later require removal shall be of a corrosion-resistant material. Plastic plugs are not permitted. A process-compatible thread lubricant of proper temperature specification shall be used on all threaded connections. Thread tape shall not be used.

4.6.5 Casing support structures

4.6.5.1 Machines requiring alignment shall meet the following criteria:

- a) mounting surfaces shall be machined to a finish of 6 µm (250 µin) arithmetic average roughness (Ra) or better;
- b) each mounting surface shall be machined within a flatness of 13 µm per 330 linear mm (0,000 5 in per linear ft) of mounting surface;

- c) different mounting planes shall be parallel to each other within 50 µm (0,002 in) over the distance between mounting surfaces;
- d) the upper machined or spot-faced surface shall be parallel to the mounting surface;
- e) hold-down bolt holes shall be drilled perpendicular to the mounting surfaces;
- f) the mounting hole in the equipment feet shall be 12 mm (1/2 in) larger in diameter than the hold-down bolt;
- g) mounting holes in equipment feet shall be machined or spot-faced to a diameter suitable for a washer positioned eccentrically around the bolt to allow for equipment alignment (holes shall not be slotted);
- h) the equipment feet shall be provided with vertical jack-screws and shall be drilled with pilot holes that are accessible for use in final doweling.

NOTE 1 Mounting requirements for equipment mounting feet are covered in ISO 10439-2, ISO 10439-3, and ISO 10439-4. Machinery requiring alignment (compressors, motors, gears, etc.) should have holes in the equipment feet larger than the diameter of the hold-down bolts in order to allow for movement for alignment.

NOTE 2 Expander-compressors as covered in ISO 10439-4 do not require alignment since driver and compressor are on the same shaft.

NOTE 3 Refer to [5.4.1.2.1](#) for horizontal jackscrew requirements.

4.6.6 External forces and moments

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

4.6.7 Guide vanes, stators, and stationary internals

Refer to subsequent parts for specific requirements.

4.7 Rotating elements

4.7.1 Shaft ends for couplings shall conform to the requirements of ISO 10441.

NOTE API 671:2010 is identical to ISO 10441:2007.

4.7.2 The rotor shaft sensing areas observed by radial-vibration probes shall be concentric with the bearing journals. All shaft sensing areas (both radial vibration and axial position) shall be free from stencil or scribe marks or any other surface discontinuity for a minimum of one probe tip diameter on each side of the probe. Only suppliers with proven experience or test data may metalize shafts to reduce electrical runout.

NOTE Shaft materials such as 17-4 PH frequently exhibit excessive electrical runout. Some suppliers have successfully reduced electrical runout to acceptable levels with treatments such as the application of 1 mm (0,04 in) radial thickness of metalized aluminium.

4.7.3 The final surface finish of sensing areas observed by radial vibration probes shall be a maximum of 0,8 µm (32 µin) Ra, preferably obtained by honing or burnishing. These areas shall be properly demagnetized to the levels specified in API 670, or otherwise treated so that the required combined total electrical and mechanical runout can be met. For areas observed by radial vibration probes, the combined

total electrical and mechanical runout shall not exceed the value from Formulae (2) and (3) or 6,35 µm (0,25 mil) whichever is greater.

In SI units:

$$R = \frac{25,4}{4} \sqrt{\frac{12000}{N}} \quad (2)$$

In US customary units:

$$R = \frac{1}{4} \sqrt{\frac{12000}{N}} \quad (3)$$

where

N is the maximum continuous operating speed, expressed in r/min;

R is allowable runout, expressed in µm (mil).

For areas observed by axial vibration probes, the combined total electrical and mechanical runout shall not exceed 12,7 µm (0,5 mil).

NOTE If all reasonable efforts fail to achieve the limits noted in 4.7.3, the supplier and the purchaser can agree on alternate acceptance criteria.

4.7.4 To prevent the build-up of potential voltages in the shaft, residual magnetism of the rotating element free air gauss level shall not exceed 0,000 5 Tesla (5 gauss) when measured with a calibrated indicator.

NOTE 1 The free air gauss level is measured while suspending the rotor from non-conductive straps with no influence from stray magnetic fields.

NOTE 2 A Hall effect probe is preferred.

4.7.5 The design of stressed parts shall include proper evaluation of the stress concentration factor (SCF) for the geometry. The design of stressed rotating parts shall include fillets that are limiting the SCF.

NOTE Areas of concern include the impeller vane-to-disk intersections, keyways, and shaft section changes.

4.7.6 Replaceable thrust collars shall be furnished only when they are required for removal of shaft end seals. When replaceable collars are furnished (for assembly and maintenance purposes), they shall be positively locked to the shaft to prevent fretting. When integral collars larger than 127 mm (5 in) diameter are furnished, they shall be provided with at least 3 mm (1/8 in) of additional stock to enable refinishing if the collar is damaged.

4.7.7 Both faces of thrust collars shall have a surface finish of not more than 500 µm (20 mil) Ra, and the axial total indicator runout (TIR) of either face shall not exceed 12,7 µm (0,5 mil).

4.7.8 Stationary labyrinth seals shall have replaceable shaft sleeves or be designed so that major rotating parts need not be replaced. Labyrinth-type seals with the teeth on the rotating element shall have replaceable non-rotating element of an abradable material.

4.7.9 The design of the shaft-sleeve-impeller assemblies shall not create temporary nor permanent distortions of the rotor assembly. The method of attaching the impeller shall adequately maintain concentricity and balance under all specified operating conditions, including overspeed to trip speed.

4.7.10 Impellers

4.7.10.1 Impellers may be closed, consisting of a hub, blades, and a cover or semi-open, consisting of a hub and blades. Impellers shall be of welded, brazed, milled, electro-eroded, or cast construction. Other manufacturing methods may be permitted if approved by the purchaser. Each impeller shall be marked with a unique identification number.

4.7.10.2 Impellers may consist of forged and cast components. Welds in the gas passageway shall be smooth and free of weld spatter. Impellers shall be heat treated and stress relieved after welding. Impeller blade entrance and exit tips shall not have knife edges.

4.7.10.3 All accessible weld surfaces on welded impellers and finish machined surfaces of electro-eroded impellers shall be inspected by visual and magnetic particle or liquid penetrant examination. Impeller fabrications resulting in joints that are not visually accessible, such as brazed joints, shall be subjected to ultrasonic examination to verify joint integrity. Refer to [6.2.2](#) for material inspection methods and [6.2.2.1.1](#) for acceptance criteria.

4.7.10.4 Cast impellers hubs and covers shall be inspected by radiographic or ultrasonic means prior to finish machining. Details of inspection techniques and acceptance criteria shall be agreed. Refer to [6.2.2](#) for material inspection methods and [6.2.2.1.1](#) for acceptance criteria.

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

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

4.7.10.7 After the overspeed test described in [6.3.3](#), each impeller shall be examined all over by means of magnetic particle or liquid penetrant methods. Refer to [6.2.2](#) for material inspection methods and [6.2.2.1.1](#) for acceptance criteria.

4.7.10.8 Metal plating of impeller bores is not permitted without the purchaser's approval.

4.8 Dynamics

4.8.1 General

NOTE Refer to API RP 684 for more information on rotordynamics.

4.8.1.1 In the design of rotor-bearing systems, consideration shall be given to all potential sources of excitation which shall include, but are not limited to, the following:

- a) unbalance in the rotor system;
- b) fluid destabilizing forces from bearings, seals, and aerodynamics;
- c) internal rubs;
- d) blade, vane, nozzle, and diffuser passing frequencies;
- e) gear-tooth meshing and side bands;
- f) coupling misalignment;
- g) loose rotor-system components;
- h) internal friction within the rotor assembly;

- i) synchronous excitation from complimentary geared elements;
- j) control loop dynamics such as those involving active magnetic bearings.

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

NOTE 2 When the frequency of a periodic forcing phenomenon (excitation) applied to a rotor-bearing support system coincides with a natural frequency of that system, the system is in a state of resonance. A rotor-bearing support system in resonance can have the magnitude of its normal vibration amplified. The magnitude of amplification and, in the case of critical speeds, the rate of change of the phase-angle with respect to speed is related to the amount of damping in the system.

4.8.1.2 Resonances of structural support systems that are within the supplier's scope of supply and that affect the rotor vibration amplitude shall not occur within the specified operating speed range or the required separation margins (SM) (see [4.8.2.9](#)). The dynamic characteristics of the structural support shall be considered in the analysis of the rotor-support system [see [4.8.2.4 d](#)].

4.8.1.3 * If specified, the supplier with unit responsibility shall communicate the existence of any undesirable running speeds in the range of zero to trip speed. This shall be illustrated by the use of Campbell Diagram, submitted to the purchaser for review and included in the instruction manual (see VDDR in [Annex B](#) of the applicable part).

NOTE 1 Examples of undesirable speeds are those associated with rotor lateral critical speeds with amplification factors greater than or equal to 2,5, train torsionals, and vane and blading modes.

NOTE 2 See [Annex D](#) for examples of Campbell diagrams.

4.8.1.4 Analysis requirements specified in [4.8.2](#), [4.8.5](#), and [4.8.6](#) shall be reported per [4.8.1.4.1](#) to [4.8.1.4.3](#) and [Annex C](#).

4.8.1.4.1 The basic rotordynamics report shall be provided.

4.8.1.4.2 * If specified, the reporting requirements identified as required for independent audit of the results shall be provided.

4.8.1.4.3 * If specified, provisions shall be made to provide the purchaser with access to drawings to develop independent models of the rotor, bearings, and seals. This data shall be made available in electronic format.

NOTE This should be requested at time of order as non-disclosure agreements may be required.

4.8.1.5 Torsional analysis requirements specified in [4.8.7](#) shall conform to [4.8.1.5.1](#), [4.8.1.5.2](#) and [Annex D](#).

4.8.1.5.1 Unless otherwise specified, the basic torsional report shall be provided for all covered machines.

4.8.1.5.2 * If specified, provisions shall be made to provide the purchaser with access to drawings to develop independent models of the rotors. This data shall be made available in electronic format.

NOTE This should be requested at time of order as non-disclosure agreements may be required.

4.8.2 Lateral analysis

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

4.8.2.2 If required, the location of all critical speeds below the trip speed shall be confirmed on the test stand during the mechanical running test (see [4.8.3.1](#)). The accuracy of the analytical model shall be demonstrated (see [4.8.3](#)).

4.8.2.3 The supplier shall conduct an undamped analysis to identify the undamped critical speeds and determine their mode shapes. The analysis shall identify the first four undamped critical speeds and cover, as a minimum, the stiffness range from 0,1 times to 10 times the expected support stiffness.

4.8.2.4 The rotordynamic analysis shall include but shall not be limited to the following:

NOTE The following is a list of items the analyst is to consider. It does not address the details and product of the analysis which is covered in [4.8.1.4](#), [4.8.2.7](#), and [4.8.2.8](#).

- a) Rotor stiffness, mass and polar and transverse moments of inertia, including coupling halves, and rotor stiffness changes due to shrunk on components.
- b) Bearing lubricant-film stiffness and damping values including changes due to speed, load, preload, range of oil inlet temperature, maximum to minimum clearances resulting from accumulated assembly tolerances, and the effect of asymmetrical loading which may be caused by gear forces (including the changes over range of maximum to minimum torque), side streams, eccentric clearances, volutes, etc.
- c) For tilt-pad bearings, the pad pivot stiffness.
- d) Structure stiffness, mass, and damping characteristics, including effects of excitation frequency over the required analysis range. For machines whose dynamic structural stiffness values are less than or equal to 3,5 times the bearing stiffness values in the range of 0 % to 150 % of N_{mc} , the structure characteristics shall be incorporated as an adequate dynamic system model, calculated frequency dependent structure stiffness and damping values (impedances), or structure stiffness and damping values (impedances) derived from modal or other testing. The supplier shall state the structure characteristic values used in the analysis and the basis for these values (for example, modal tests of similar rotor structure systems or calculated structure stiffness values).
- e) Rotational speed, including the various starting-speed detents, operating speed and load ranges (including agreed test conditions if different from those specified), trip speed, and coast-down conditions.
- f) The influence, over the operating range, of the casing shaft end oil seals. Minimum and maximum stiffness shall be considered taking into account the tolerance on the component clearance and the oil inlet temperature.
- g) The location and orientation of the radial vibration probes which shall be the same in the analysis as in the machine.
- h) Squeeze film damper mass, stiffness, and damping values considering the component clearance and centering tolerance, oil inlet temperature range, and operating eccentricity.
- i) For machines equipped with rolling element bearings, the supplier shall state the bearing stiffness and damping values used for the analysis. The basis for these values or the assumptions made in calculating the values shall be presented.
- j) Dry gas seals shall be assumed to have no stiffness or damping.

4.8.2.5 * If specified, the supplier with train responsibility shall provide a train lateral analysis.

4.8.2.6 The supplier with train responsibility shall provide a train lateral analysis for machinery trains with rigid couplings.

4.8.2.7 A separate damped unbalanced response analysis shall be conducted within the speed range of 0 % to 150 % of N_{mc} . Unbalance shall analytically be placed at the locations defined in [Figure 1](#). For

the translatory (symmetric) modes, the unbalance shall be based on the sum of the journal static loads. For conical (asymmetric) modes, these unbalances shall be 180 degrees out of phase and of a magnitude based on the static load on the adjacent bearing. For overhung modes, the unbalances shall be based on the overhung mass. [Figure 1](#) shows the typical mode shapes and indicates the location and definition of U_a for each of the shapes. The magnitude of the unbalances shall be 2 times the value of U_r as calculated by Formulae (4) and (5) or Formulae (6) and (7).

In SI units:

$$U_r = 6350 \frac{W}{N_{mc}} \quad (\text{for } N_{mc} < 25\,000 \text{ r/min}) \quad (4)$$

$$U_r = \frac{W}{3.937} \quad (\text{for } N_{mc} \geq 25\,000 \text{ r/min}) \quad (5)$$

In US customary units:

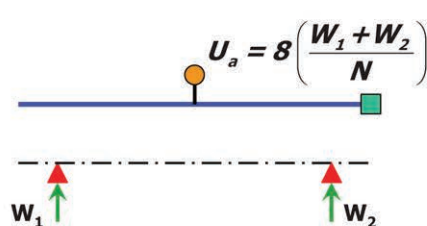
$$U_r = 4 \frac{W}{N_{mc}} \quad (\text{for } N_{mc} < 25\,000 \text{ r/min}) \quad (6)$$

$$U_r = \frac{W}{6250} \quad (\text{for } N_{mc} \geq 25\,000 \text{ r/min}) \quad (7)$$

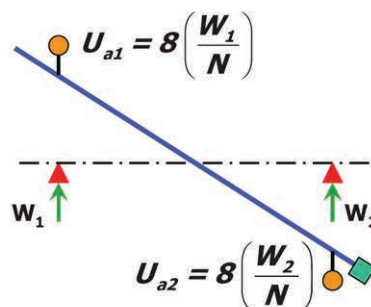
where

- $U_a = 2 \times U_r$ is the input unbalance for the unbalance response analysis, expressed in g-mm (oz-in);
- U_r is the maximum allowable residual unbalance, expressed in g-mm (oz-in);
- N_{mc} is the maximum continuous operating speed, expressed in r/min;
- W is the journal static load in kg (lbm), or for bending modes where the maximum deflection occurs at the shaft ends, the overhung mass (that is the mass of the rotor outboard of the bearing) in kg (lbm) (see [Figure 3](#)).

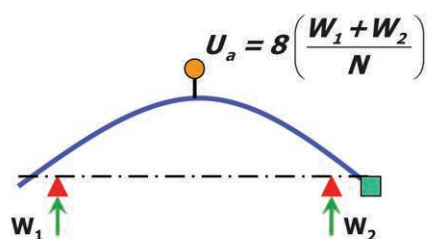
NOTE Above 25 000, the limit is based on 0,254 μm (10 μin) mass displacement, which is in general agreement with the capabilities of conventional balance machines and are necessary to invoke for small rotors running at high speeds.



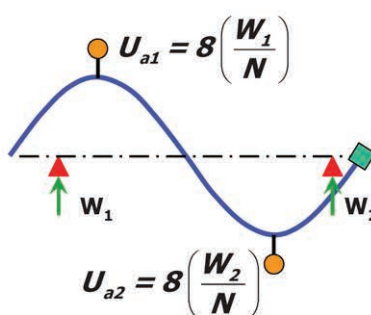
Translatory 1st Rigid



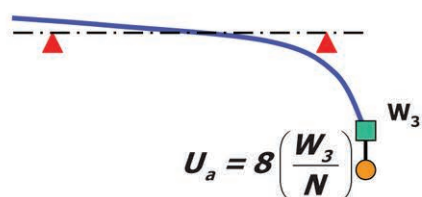
Conical 2nd Rigid
(Unbalance @ Journals)



1st Bending



2nd Bending
(Unbalance @ Quarterspan)



Coupling Mode