INTERNATIONAL STANDARD

ISO 10439-1

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

Part 1: General requirements

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

Partie 1: Exigences générales

Reference number
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Foreword

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

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

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

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

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

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

This first edition, together with ISO 10439-2, ISO 10439-3, and ISO 10439-4, 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*

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 °C (–20 °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 (Nm^3/h)
	normal cubic meters per min (Nm^3/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. m^3/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_{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 × peak amplitude, r/min
N_2	final (greater) speed at 0,707 × 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 × S_{a1}/N_{ma}
STD	standard
U_a	input unbalance for the rotordynamic response analysis, g-mm (oz-in), = 2 × 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 course 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 H_2S 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/mm^2 (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 l, 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 l, 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 l, 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 l 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 l 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 l 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).

$$MASI = CSI \times (P_{ch}/150) \quad (1)$$

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 l 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:

$$R = \frac{25,4}{4}\sqrt{\frac{12000}{N}} \tag{2}$$

In US customary units:

$$R = \frac{1}{4}\sqrt{\frac{12000}{N}} \tag{3}$$

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:

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

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

In US customary units:

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

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

where

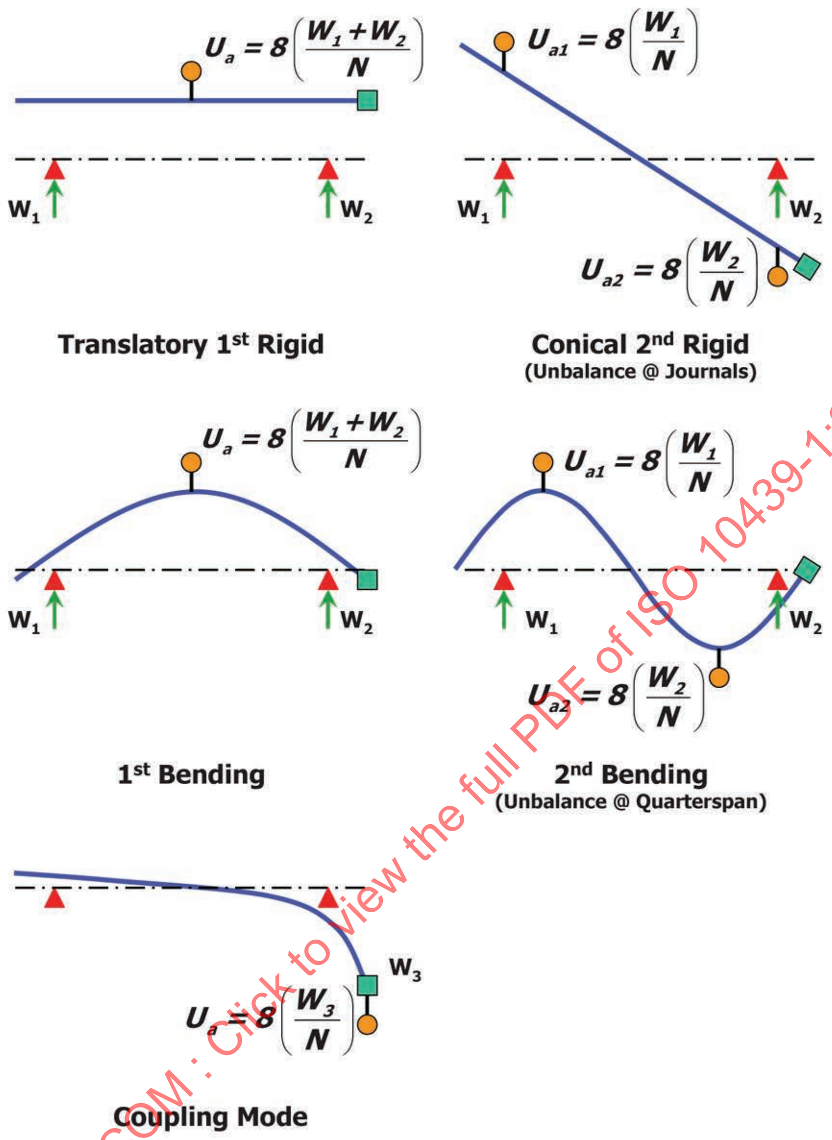
$U_a = 2 \times U_r$ is the input unbalance for the unbalance response analysis, expressed in g-mm (oz-in);

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.



$U_a = 8\left(\frac{W_1 + W_2}{N}\right)$
W1
W2
Translatory 1st Rigid
$U_{a1} = 8\left(\frac{W_1}{N}\right)$
W1
W2
$U_{a2} = 8\left(\frac{W_2}{N}\right)$
Conical 2nd Rigid
(Unbalance @ Journals)
$U_a = 8\left(\frac{W_1 + W_2}{N}\right)$
W1
W2
1st Bending
$U_{a1} = 8\left(\frac{W_1}{N}\right)$
W1
W2
$U_{a2} = 8\left(\frac{W_2}{N}\right)$
2nd Bending
(Unbalance @ Quarterspan)
W3
$U_a = 8\left(\frac{W_3}{N}\right)$
Coupling Mode

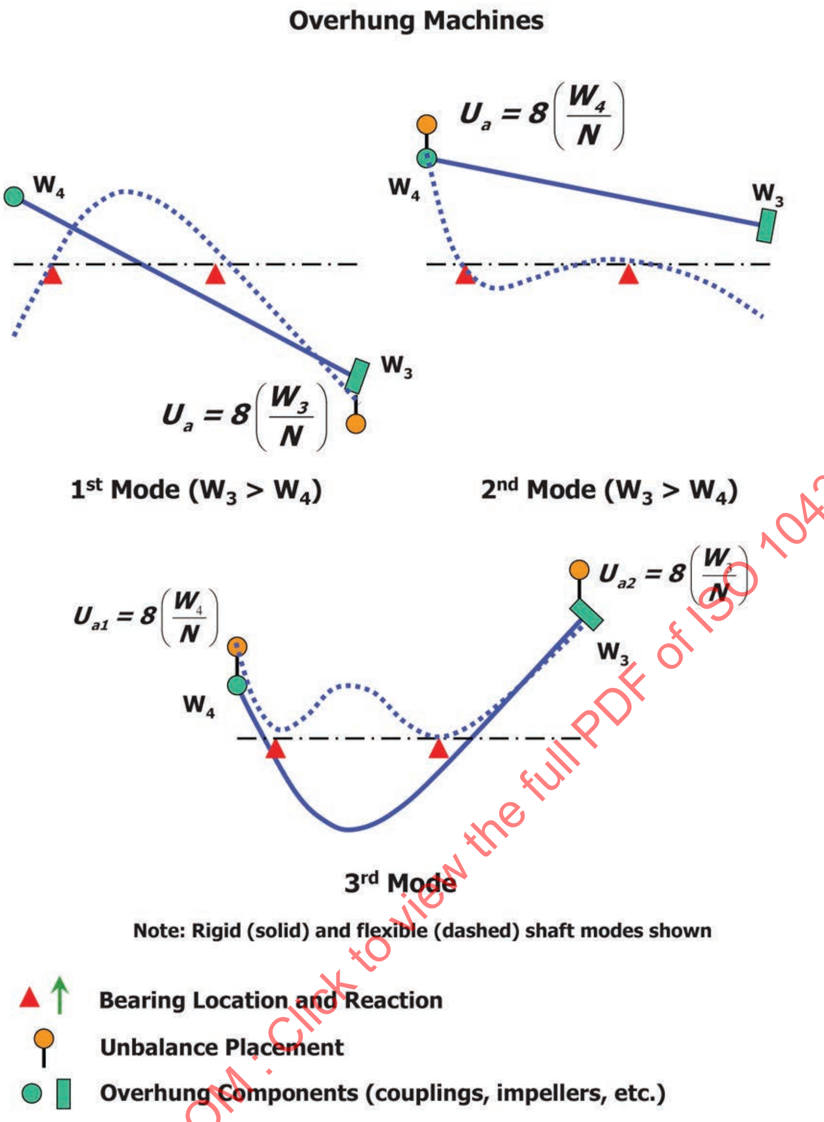


Figure 1 — Typical mode shapes and corresponding unbalance

4.8.2.8 As required by 4.8.3.1, additional analyses shall be made for use with the verification test specified in 4.8.3. The location of the unbalance shall be determined by the supplier. The unbalance shall not be less than 2 times or greater than 8 times the value from Formulae (4) and (5) or Formulae (6) and (7) or as specified in 4.8.2.8.1. Any test stand parameters which influence the results of the analysis shall be included.

4.8.2.8.1 For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall be greater or equal to 16 times the value of Formulae (4) and (5) or Formulae (6) and (7).

NOTE For most machines, there will only be one plane readily accessible for the placement of an unbalance, for example, the coupling flange on a single-ended drive machine, or the impeller hub or disk on an integrally geared machine, or expander-compressors. However, some compressor types (axial compressors, for example) may provide additional externally accessible balance planes. For these machines, when there exist the possibility of exciting other critical speeds, multiple runs will be required.

4.8.2.9 The damped unbalanced response analysis shall indicate that the machine meets the following requirement:

$$SM_a \geq SM_r \tag{8}$$

where

SM_r is the required separation margin, expressed in %;

SM_a is defined in Figure 2.

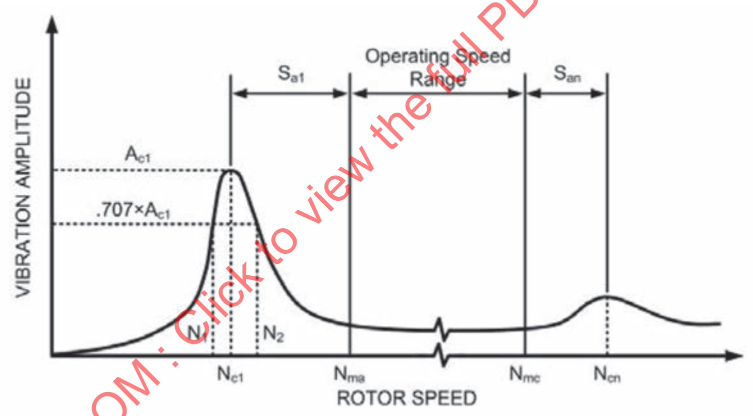
a) If the AF at a particular critical speed is less than 2,5, the response is considered critically damped and no separation margin is required ($SM_r = 0$).

b) If the AF at a particular critical speed is greater than or equal to 2,5 and that critical speed is below the minimum speed, the SM_r is given by Formula (9).

$$SM_r = 17\left(1 - \frac{1}{AF - 1,5}\right) \tag{9}$$

If the AF at a particular critical speed is greater than or equal to 2,5 and that critical speed is above the maximum continuous speed, the SM_r is given by Formula (10).

$$SM_r = 10 + 17\left(1 - \frac{1}{AF - 1,5}\right) \tag{10}$$



Key

N_{c1} rotor first critical speed
N_{cn} nth critical speed
N_{ma} minimum allowable speed
N_{mc} maximum continuous speed
A_{c1} amplitude at N_{c1}
N_1 initial (lesser) speed at $0.707 \times A_{c1}$
N_2 final (greater) speed at $0.707 \times A_{c1}$
AF_1 amplification factor of the first critical speed
$N_{c1} / (N_2 - N_1)$
S_{a1} actual separation between N_{c1} and the operating speed range
S_{an} actual separation between N_{cn} and the operating speed range
SM_{a1} actual separation margin of first critical speed (%)
$100 \times S_{a1} / N_{ma}$

SM_{an} actual separation margin of nth critical speed (%)
100 × S_{an} / N_{mc}

NOTE The shape of the curve is for illustration only and does not necessarily represent any actual rotor response plot.

Figure 2 — Typical rotor response plot

4.8.2.10 The calculated unbalanced peak-to-peak response at each vibration probe, for each unbalance amount and case as specified in 4.8.2.7, shall not exceed the mechanical test vibration limit, A_{vl}, of (25,4 µm (1,0 mil) or Formulae (11) and (12), whichever is less, over the range of N_{ma} to N_{mc} as shown in Figure 3.

In SI units:

$$A_{vl} = 25{,}4\sqrt{\frac{12000}{N_{mc}}} \qquad (11)$$

In US customary units:

$$A_{vl} = \sqrt{\frac{12000}{N_{mc}}} \qquad (12)$$

where

A_{vl} is the mechanical test vibration limit, expressed in µm (mil);

N_{mc} is the maximum continuous speed, expressed in r/min

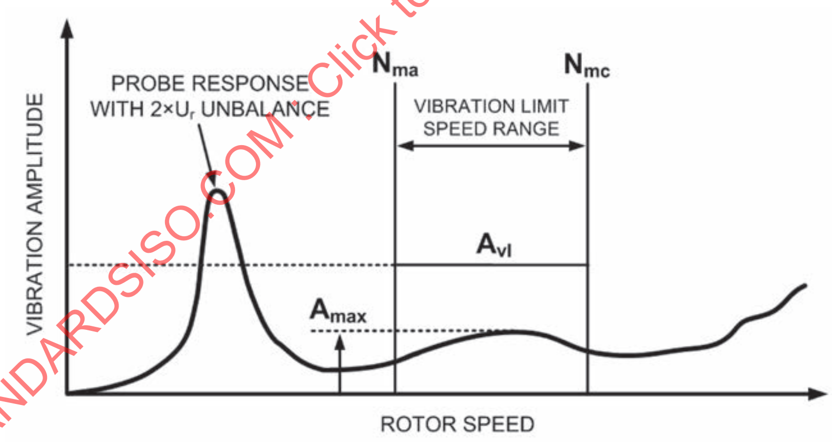


Figure 3 — Plot of applicable speed range of vibration limit

4.8.2.11 For each unbalance amount and case as specified in 4.8.2.7, the calculated major-axis, peak-to-peak response amplitudes at each close clearance location shall be multiplied by a scale factor defined by Formula (13).

$$S_{cc} = A_{vl} / A_{max} \text{ or 6, whichever is less} \tag{13}$$

where

S_{cc} is the scale factor for close clearance check;

A_{vl} is the mechanical test vibration limit defined in 4.8.2.10;

A_{max} is the 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.

NOTE To meet the requirements of 4.8.2.10, the scale factor will be greater than or equal to one.

4.8.2.11.1 For each close clearance location, the scaled response shall be less than 75 % of the minimum design diametral running clearance over the range of zero to trip speed.

4.8.2.11.2 For this evaluation, floating-ring, abradable and compliant seals are not considered close clearance locations. The response amplitude as compared to the running clearance at these locations shall be agreed.

Running clearances can be different than the assembled clearances with the machine shutdown. Consideration should be given to the following:

a) centrifugal/thermal growth;

b) bearing lift;

c) rotor sag;

d) non-concentricity (of stator to the bearings).

4.8.2.12 If the analysis indicates that if either of the following requirements cannot be met:

a) the required separation margins or

b) the requirements of 4.8.2.10 or 4.8.2.11

and the purchaser and supplier have agreed that all practical design efforts have been exhausted, then acceptable amplitudes, separation margins, and amplification factors shall be agreed by the purchaser and the supplier, subject to the requirements of 4.8.4.

4.8.3 Unbalanced rotor response verification test

4.8.3.1 * If specified or when the first critical speed is less than 127 % of N_{mc}, an unbalanced rotor response test shall be performed as part of the mechanical running test (see 6.3 of the applicable part), and the results shall be used to verify the analytical model. The actual response of the rotor on the test stand to the same arrangement of unbalance and bearing loads as was used in the analysis specified in 4.8.2.8 shall be used for determining the validity of the damped unbalanced response analysis. To accomplish this, the requirements of 4.8.3.1.1 to 4.8.3.1.6 shall be followed.

NOTE API RP 684 contains discussions related to verification testing performed in a balance bunker.

4.8.3.1.1 During the mechanical running test, the amplitudes and phase angle of the shaft vibration from trip to slow roll speed shall be recorded after the 4 h run. The recording instrumentation resolution shall be at least 1,25 µm (0,05 mil).

NOTE This set of readings is normally taken during a coastdown, with convenient increments of speed such as 50 r/min. Since at this point the rotor is balanced, any vibration amplitude and phase detected is the result of residual unbalance and mechanical and electrical runout.

4.8.3.1.2 The unbalance which was used in the analysis performed in 4.8.2.8 shall be added to the rotor in the location used in the analysis.

4.8.3.1.3 The machine shall then be brought up to trip speed after being held at maximum continuous speed for at least 15 min and the indicated vibration amplitudes and phase shall be recorded during the coast down using the same procedure as 4.8.3.1.1.

4.8.3.1.4 The location of critical speeds below the trip speed shall be established. If a clearly defined response peak is not observed during the test, then the critical speeds shall be identified as those in the lateral damped analysis report.

NOTE Slow roll runout is normally vectorially subtracted from the 1X Bode plots to accurately define the location of the critical speeds.

4.8.3.1.5 The corresponding indicated vibration data taken in accordance with 4.8.3.1.1 and 4.8.3.1.4 shall be vectorially subtracted.

NOTE Check slow roll runout prior to subtraction. The data are expected to be nearly identical for both runs.

4.8.3.1.6 The results of the mechanical run including the unbalance response verification test shall be compared with those from the analytical model specified at 4.8.2.8.

NOTE It is necessary for probe orientation to be the same for the analysis and the machine for the comparison to be valid.

4.8.3.2 Using the unbalance response test results, the supplier shall correct the model if it fails to meet either of the following criteria:

a) the actual critical speed(s) determined on test shall not deviate from the corresponding critical speed ranges predicted by analysis by more than ±5 %;

b) the maximum probe responses from the results of 4.8.3.1.5 shall not exceed the predicted ranges.

4.8.3.3 The supplier shall determine whether the comparison made is for absolute or relative motion.

NOTE For absolute motion, bearing housing vibration is vectorially added to relative probe readings. This is typically required for machinery with soft supports.

4.8.3.4 Unless otherwise specified, the verification test of the rotor unbalance shall be performed only on the first rotor tested, if multiple identical rotors are purchased.

4.8.3.5 After correcting the model, if required, the response amplitudes shall be checked against the limits specified in 4.8.2.10 and 4.8.2.11.

4.8.4 Additional testing

4.8.4.1 Additional testing is required if from the shop verification test data (see 4.8.3) or from the damped, corrected unbalanced response analysis (see 4.8.3.2), if either of the following conditions exists:

a) any critical speed which fails to meet the SM_r requirements (see 4.8.2.9);

b) the requirements of 4.8.2.10 and 4.8.2.11 have not been met.

NOTE When the analysis or test data does not meet the requirements of the standard, additional more stringent testing is required. The purpose of this additional testing is to determine on the test stand that the machine will operate successfully.

4.8.4.2 Unbalance weights shall be placed as described in 4.8.2.7; this may require disassembly of the machine. Unbalance magnitudes shall be achieved by adjusting the indicated unbalance that exists in the rotor from the initial run to raise the displacement of the rotor at the probe locations to the vibration limit defined in 4.8.2.10 at the maximum continuous speed; however, the unbalance used shall be no less than twice nor greater than 8 times the unbalance limit specified in 4.8.2.7, Formulae (4) and (5) or Formulae (6) and (7). The measurements from this test, taken in accordance with 4.8.3.1.1 to 4.8.3.1.3, shall meet the following criteria:

a) from zero to trip speed, the shaft deflections shall not exceed 90 % of the minimum design running clearances;

b) within the operating speed range, including the SM_r, the shaft deflections shall not exceed 55 % of the minimum design running clearances or 150 % of the allowable vibration limit at the probes (see 4.8.2.10);

c) for this evaluation, floating-ring, abradable, and compliant seals are not considered close clearance locations. The response amplitude to the running clearance at these locations shall be agreed.

4.8.4.3 The internal deflection limits specified in 4.8.4.2 items a thru c shall be based on the calculated displacement ratios between the probe locations and the areas of concern identified in 4.8.2.11 based on a corrected model, if required. Acceptance shall be based on these calculated displacements or inspection of the seals if the machine is opened.

NOTE Internal displacements for these tests are calculated by multiplying these ratios by the peak readings from the probes.

4.8.4.4 Damage to any portion of the machine as a result of this testing shall constitute failure of the test. Internal seal rubs that do not cause changes outside the supplier's assembly clearance range do not constitute damage.

4.8.5 Level 1 stability analysis

4.8.5.1 A stability analysis shall be performed on all centrifugal, axial compressors, or radial flow rotors that meet the following:

a) those rotors whose maximum continuous speed is greater than the first undamped critical speed on rigid supports, FCSR, in accordance with 4.8.2.3;

b) those rotors with fixed geometry bearings or oil film ring seals.

The stability analysis shall be calculated at the API defined maximum continuous speed.

NOTE Level I analysis was developed to fulfil two purposes: first, it provides an initial screening to identify rotors that do not require a more detailed study. The approach as developed is conservative and not intended as an indication of an unstable rotor. Second, the Level I analysis specifies a standardized procedure applied to all manufacturers similar to that found in 4.8.2. (Refer to API RP 684 for a detailed explanation.)

4.8.5.2 The model used in the Level I analysis shall include the items listed in 4.8.2.4.

4.8.5.3 When tilt-pad journal bearings are used, the analysis shall be performed with synchronous tilt-pad coefficients.

4.8.5.4 For rotors that have quantifiable external radial loading (e.g. integrally geared compressors), the stability analysis shall also include the external loads associated with the operating conditions defined in 4.8.5.5. For some rotors, the unloaded (or minimal load condition) may represent the worst stability case and shall be considered.

4.8.5.5 The anticipated cross coupling, Q_A, present in the rotor is defined by the following procedures:

— For centrifugal compressors:

The parameters in Formula (14) shall be determined based on the machine conditions at normal operating point unless the supplier and purchaser agree upon another operating point.

$$q_a = \frac{(HP)B_c C}{D_c H_c N_r}\left(\frac{\rho_d}{\rho_s}\right) \tag{14}$$

where

B_c is 3;

C is 9,55 (63);

ρ_d is the discharge gas density per impeller, expressed in kg/m^3 (lbm/ft^3);

ρ_s is the suction gas density per impeller, expressed in kg/m^3 (lbm/ft^3);

D_c is the impeller diameter, expressed in mm (in);

H_c is the minimum of diffuser or impeller discharge width per impeller, expressed in mm (in);

N_r is the normal operating speed for calculation of aerodynamic excitation, expressed in r/min.

Formula (14) is calculated for each impeller of the rotor. Q_A is equal to the sum of q_a for all impellers.

— For axial flow rotors:

$$q_a = \frac{(HP)B_t C}{D_t H_t N_r} \tag{15}$$

where

B_t is 1,5;

D_t is the blade pitch diameter, expressed in mm (in);

H_t is the effective blade height, expressed in mm (in).

Formula (15) is calculated for each stage of the rotor. Q_A is equal to the sum of q_a for all stages.

4.8.5.6 An analysis shall be performed with a varying amount of cross coupling introduced at the rotor mid-span for between bearing rotors or at the centre of gravity of the stage or impeller for single overhung rotors. For double overhung rotors, the cross coupling shall be placed at each stage or impeller concurrently and shall reflect the ratio of the anticipated cross coupling, (q_a, calculated for each impeller or stage).

4.8.5.7 The applied cross coupling shall extend from zero to the minimum of

a) a level equal to 10 times the anticipated cross coupling, Q_A and

b) the amount of the applied cross coupling required to produce a zero log decrement, Q_0. This value can be reached by extrapolation or linear interpolation between two adjacent points on the curve shown in Figure C.2 in Annex C.

4.8.5.8 Level I screening criteria:

— For centrifugal compressors:

If any of the following criteria apply, a Level II stability analysis shall be performed:

i) $Q_0 / Q_A < 2,0$;

ii) $\delta_A < 0{,}1$;

iii) $Q_0 / Q_A < 10$ and the point defined by CSR and the average density at the normal operating point are located in Region B of Figure 4.

Otherwise, the stability is acceptable and no further analyses are required.

— For axial flow rotors:

If $\delta_A < 0{,}1$, a Level II stability analysis shall be performed. Otherwise, the stability is acceptable and no further analyses are required.

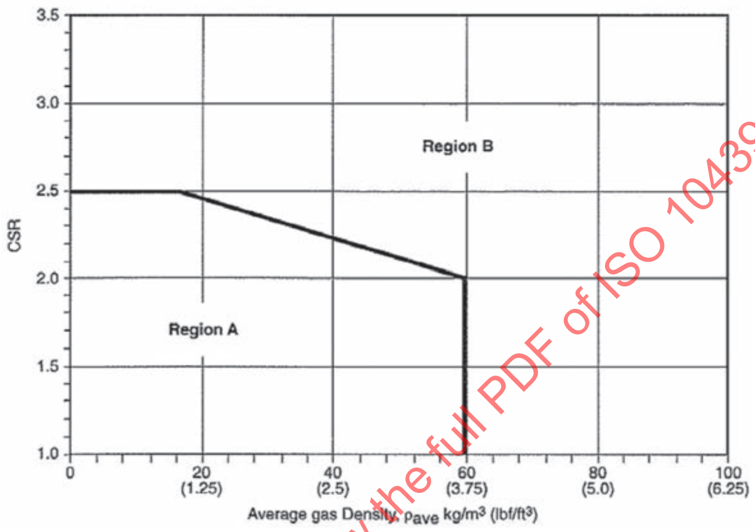


Figure 4 — Stability experience plot

4.8.6 Level II stability analysis

4.8.6.1 A Level II analysis, which reflects the actual dynamic forces (both stabilizing and destabilizing) of the rotor, shall be performed as required by 4.8.5.8.

4.8.6.2 The Level II analysis shall include the dynamic effects from all sources that contribute to the overall stability of the rotating assembly. These dynamic effects shall replace the anticipated cross coupling, Q_A. The following sources shall be considered:

a) labyrinth seals;

b) damper seals;

c) impeller/blade flow aerodynamic effects;

d) internal friction.

4.8.6.2.1 The supplier shall state how the sources are handled in the analysis.

NOTE It is recognized that methods are not available at present to accurately model the destabilizing effects from all sources listed in 4.8.6.2.

4.8.6.3 The Level II analysis shall be calculated at N_{mc}.

4.8.6.4 The operating conditions defined for the normal operating point shall be extrapolated to N_{mc}.

NOTE Extrapolated conditions are expected to fall within the operating limits of the equipment train (the defined operating map).

4.8.6.5 The modelling requirements of Level I shall also apply.

4.8.6.6 The dynamic coefficients of the labyrinth seals shall be calculated at minimum seal running clearance.

4.8.6.7 When calculating the dynamic coefficients of damper seals, the running clearance profile range, which is determined by drawing dimensions, manufacturing tolerances, and deformations in the seal, seal support, and rotor, shall be included.

4.8.6.8 The frequency and log decrement of the first forward damped mode shall be calculated progressively for the following configurations (except for double overhung machines where the first two forward modes shall be considered):

a) rotor and support system only (basic log decrement, δ_b);

b) each source from 4.8.6.2 utilized in the analysis;

c) for damper seals, the dependence due to parameters defined in 4.8.6.7;

d) complete model including all sources (final log decrement, δ_f).

4.8.6.9 Acceptance criteria

The Level II stability analysis shall indicate that the machine, as calculated in 4.8.6.1 to 4.8.6.8, shall have a final log decrement, δ_f, greater than 0,1.

4.8.6.10 If after all practical design efforts have been exhausted to achieve the requirements of 4.8.6.9, acceptable levels of the log decrement, δ_f, shall be agreed.

NOTE It is recognized that other analysis methods and continuously updated acceptance criteria have been used successfully since the mid-1970s to evaluate stability. The historical data accumulated by machinery manufacturers for successfully operated machines can conflict with the acceptance criteria of this International Standard. If such a conflict exists and the suppliers can demonstrate that their stability analysis methods and acceptance criteria predict a stable rotor, then the suppliers' criteria can be the guiding principle in the determination of acceptability.

4.8.7 Torsional analysis

4.8.7.1 For trains including motors, generators, positive displacement units, or gears, the supplier having unit responsibility shall ensure that a torsional vibration analysis of the complete coupled train is carried out and shall be responsible for directing any modifications necessary to meet the requirements of 4.8.7.3 to 4.8.7.7.

4.8.7.2 * If specified, for direct driven turbine trains, the supplier shall perform a torsional vibration analysis of the complete coupled train and shall be responsible for directing any modifications necessary to meet the requirements of 4.8.7.3 to 4.8.7.7.

4.8.7.3 For trains in 4.8.7.2, a simplified torsional model (lumped rotor inertia and stiffness) is sufficient.

NOTE The intent of the simplified analysis is to calculate the primary (coupling) modes of the system. Primary modes are those influenced primarily by the coupling torsional stiffness.

4.8.7.4 Excitation of torsional natural frequencies may come from many sources and should be considered in the analysis. These sources shall include but are not limited to the following:

a) gear characteristics such as unbalance, pitch line runout, and cumulative pitch error;

b) torsional pulsations due to gear radial vibrations;

c) cyclic process impulses;

d) torsional excitation resulting from electric motors and engines;

e) one and two times electrical line frequency;

f) one and two times operating speed(s).

4.8.7.5 Primary (coupling) modes shall be at least 10 % above or 10 % below any 1X excitation frequency (mechanical or electrical) within the specified operating speed range.

4.8.7.6 All other torsional natural frequencies shall preferably be at least 10 % above or 10 % below any possible excitation frequency within the specified operating speed range (from minimum to maximum continuous speed).

4.8.7.6.1 Any interference resulting from 4.8.7.6 shall be shown to have no adverse effect using 4.8.7.7.

4.8.7.7 When torsional resonances are calculated to fall within the margin specified in 4.8.7.6 (and the purchaser and the supplier have agreed that all efforts to remove the critical from within the limiting frequency range have been exhausted), a steady-state stress analysis shall be performed to demonstrate that the resonances have no adverse effect on the complete train.

4.8.7.7.1 The analysis shall show that all shaft sections, couplings, and gear mesh have infinite life using an agreed criteria.

4.8.7.8 In addition to the torsional analyses required in 4.8.7.3 to 4.8.7.7, the supplier shall perform a transient torsional vibration analysis for synchronous motor driven units, using a time-transient analysis. The requirements of 4.8.7.8.1 to 4.8.7.8.4 shall be followed.

4.8.7.8.1 In addition to the parameters used to perform the torsional analysis specified in 4.8.7.4, the following shall be included:

a) motor average torque, as well as pulsating torque (direct and quadrature axis) versus speed characteristics;

b) load torque versus speed characteristics;

c) electrical system characteristics affecting the motor terminal voltage or the assumptions made concerning the terminal voltage including the method of starting, such as across the line or some method of reduced voltage starting.

4.8.7.8.2 The analysis shall generate the maximum torque, as well as a torque versus time history for each of the shafts in the compressor train.

NOTE The maximum torques is used to evaluate the peak torque capability of coupling components, gearing, and interference fits of components such as coupling hubs. The torque versus time history is used to develop a cumulative damage fatigue analysis of shafting, keys, and coupling components.

4.8.7.8.3 Appropriate fatigue properties and stress concentrations shall be used.

4.8.7.8.4 An appropriate cumulative fatigue algorithm shall be used to develop a value for the safe number of starts. The safe number of starts shall be as agreed by the purchaser and supplier.

4.8.7.9 For VFD driven equipment trains, the supplier shall extend the analysis defined in 4.8.7.3 to 4.8.7.7 to include the following 4.8.7.9.1 to 4.8.7.9.4.

4.8.7.9.1 In addition to the excitations of 4.8.7.4, the following shall also be considered but is not limited to:

a) integer orders of the drive output frequency;

b) sidebands of the pulse width modulation.

NOTE VFD-produced broad band noise floor and feedback generated excitations can cause harmful torsional pulsations. Transient and/or mechanical/electrical coupled analyses can be required to understand the effects of these excitations.

4.8.7.9.2 A steady-state response analysis shall be performed from 0 to MCS to quantify the effects of the VFD excitation of 4.8.7.9.1.

4.8.7.9.3 For interferences occurring below the minimum operating speed, agreed criteria shall be used to establish acceptability of the train.

4.8.7.9.4 For interferences occurring within the operating speed range, the criteria set forth in 4.8.7.7.1 shall be used.

4.8.7.10 * If specified, for motor-driven equipment and trains including an electrical generator, a transient short circuit fault analysis shall be performed in accordance with 4.8.7.10.1 to 4.8.7.10.2.

4.8.7.10.1 The following faults shall be considered but is not limited to:

a) short circuits

   1) line-to-line;

   2) two phase;

   3) three phase;

   4) line-to-ground;

   5) line-to-line-to-ground;

b) synchronization (generators)

   1) single phase;

   2) three phase.

4.8.7.10.2 For these fault conditions, generated stresses in the shafting and couplings shall not exceed the low cycle fatigue limit.

NOTE The analysis for these fault conditions assumes a one-time event. It is possible that some components identified by the analysis will need to be replaced following the fault event.

4.8.7.11 * If specified, alternating torques produced by breaker reclosure shall be shown to have no negative impact on the intended operating life of the equipment train.

4.8.8 Vibration and balancing

4.8.8.1 Major parts of the rotating element, such as the shaft, balancing drum, and impellers, shall be individually dynamically balanced before assembly, to ISO 1940 Grade G0.67 or better. When a bare shaft with a single keyway is dynamically balanced, the keyway shall be filled with a fully crowned half key, in accordance with ISO 21940-32. Keyways 180 degrees apart, but not in the same transverse plane, shall also be filled. The initial balance correction to the bare shaft shall be recorded. The components mounted on the shaft (impellers, balance drum, etc.), shall also be balanced in accordance with the "half-key-convention", as described in ISO 21940-32.

4.8.8.2 Unless otherwise specified, the rotating element shall be sequentially multiplane dynamically balanced during assembly. This shall be accomplished after the addition of no more than two major components. Balancing correction shall only be applied to the elements added. Minor correction of other components may be required during the final trim balancing of the completely assembled element. In the sequential balancing process, any half keys used in the balancing of the bare shaft (see 4.8.8.1) shall continue to be used until they are replaced with the final key and mating element. On rotors with single keyways, the keyway shall be filled with a fully crowned half-key. The weight of all half-keys used during final balancing of the assembled element shall be recorded on the residual unbalance worksheet (see Annex A). The maximum allowable residual unbalance per plane (journal) shall be calculated as follows per Formulae (4) and (5) or Formulae (6) and (7) as applicable.

4.8.8.2.1 When the suppliers' standard assembly procedures require the rotating element disassembled after final balance to allow compressor assembly (i.e. stacked rotors with solid diaphragms and compressor/ expanders), the supplier shall, as a minimum, perform the following operations:

a) To ensure the rotor has been assembled concentrically, the supplier shall take axial and/or radial runout readings on the tip of each element (impeller or disc) and at the shaft adjacent to each element when possible. The runout on any element shall not exceed a value agreed between the purchaser and the supplier.

b) The supplier shall balance the rotor to the limits of 4.8.8.2, Formulae (4) and (5) or Formulae (6) and (7).

c) The supplier shall provide historic unbalance data readings of the change in balance due to disassembly and reassembly. This change in unbalance shall not exceed 4 times the sensitivity of the balance machine. For this purpose, balance machine sensitivity is 0,254 µm (10 µin) maximum.

d) The supplier shall conduct an analysis in accordance with 4.8.2, to predict the vibration level during testing, using an unbalance equal to that in item b), plus 2 times the average change in balance due to disassembly and reassembly as defined in item c). The results of this analysis shall show that the predicted vibration at design speed on test shall be no greater than 2 times the requirements of 4.8.8.8.

NOTE Trim balancing in the compressor case can be done to achieve this level.

4.8.8.2.2 * If specified, the supplier shall record the balance readings after initial balance for the contract rotor. The rotor shall then be disassembled and reassembled. The rotor shall be check balanced after reassembly to determine the change in balance due to disassembly and reassembly. This change in balance shall not exceed that defined in 4.8.8.2.1 c).

4.8.8.3 The following options are available concerning operating speed balancing.

4.8.8.3.1 * If specified or with purchaser's approval, after low-speed sequential balancing, the rotor shall be operating speed balanced in accordance with 4.8.8.4.

4.8.8.3.2 * If specified or with purchaser's approval, completely assembled rotating elements shall be subject to operating speed balancing (in accordance with 4.8.8.4) in lieu of a sequential low-speed balancing.

4.8.8.4 Operating speed balancing procedure

4.8.8.4.1 The following information shall be provided, prior to operating speed balancing:

a) the contract rotor dynamics analysis;

b) final low-speed balance records when applicable;

c) mechanical radial and axial runout checks of the rotor;

d) job and balance stand bearing details.

4.8.8.4.2 The rotor shall be supported in bearings of the same type and with similar dynamic characteristics as those in which it shall be supported in service.

NOTE 1 Job bearings can be used when practical.

NOTE 2 Operating speed balance units run under a vacuum. Operation in a vacuum can require the need for temporary end seals.

4.8.8.4.3 The rotor shall be completely assembled including thrust collars with locking collars and any auxiliary equipment. Shaft end seals are not added.

4.8.8.4.4 The high-speed drive assembly shall be shown to have an effect less than 25 % of the balance tolerance.

NOTE In some cases, the facility drive coupling and adapter is adequate to simulate the job coupling half moment. In some cases, the job-coupling hub with moment simulator will be required, especially for the outboard ends of drive-through machines.

4.8.8.4.5 * If specified, two orthogonally mounted radial non-contacting vibration probes shall be mounted next to the bearings, at mid-shaft or at overhung locations as agreed by the purchaser and the supplier.

4.8.8.4.6 When non-contacting proximity vibration probes have been specified, structural resonance frequency of the probes and supports shall be determined after installation of the rotor and probe assemblies in the balance machine when non-standard mounting is used (i.e. cantilevered probe holders).

4.8.8.4.7 The smallest pedestal available rated for the rotor weight shall be used without pedestal stiffening engaged.

NOTE Light rotors used with larger pedestals could require a reduction of the rotor balance criteria.

4.8.8.4.8 Prior to operating speed balance, the complete rotor shall be low-speed balance checked in the operating speed facility. If the measured unbalance exceeds five times the maximum allowable residual unbalance for the rotor, then the cause of the unbalance shall be identified prior to operating speed balancing.

NOTE The purpose of identifying the unbalance is to increase the possibility of the rotor successfully traversing its critical speed(s) and to increase the likelihood of a successful balance.

4.8.8.4.9 Prior to balancing, the rotor residual unbalance shall be stabilized. This shall be accomplished by the following:

a) record low-speed residual unbalance (amount and phase) before running up in speed;

b) run rotor to trip speed plus 4 % of MCS, hold for 3 min;

c) reduce to maximum continuous operating speed and record unbalance readings for each pedestal;

d) reduce speed and record low-speed unbalance again;

e) repeat until readings taken in 4.8.8.4.9 c) and 4.8.8.4.9 d) are consistent.

4.8.8.4.10 Balance weights (if used) shall be compatible with disk material and suitable for the operating environment.

4.8.8.4.11 After the rotor is balanced within the tolerances of 4.8.8.5, repeat the final balance run with the pedestal stiffening engaged.

4.8.8.4.12 Upon completion of the balancing, Bode and polar plots for each pedestal velocity and proximity probe (when used) shall be provided for the initial run, stabilized rotor prior to balancing, and final balanced rotor with and without pedestal stiffening. Proximity probe data shall be compensated for slow roll mechanical and electrical runout.

4.8.8.5 The acceptance criteria shall be agreed between the purchaser and the supplier.

NOTE The criteria are typically based on the operating speed balance provider's experience and can be expressed in pedestal vibration, pedestal force, or residual unbalance.

4.8.8.5.1 When non-contacting vibration probes have been specified in 4.8.8.4.5, the acceptance criteria for the readings shall be agreed.

4.8.8.6 A rotor that has been operating speed balanced shall have the residual unbalance recorded in a low-speed balance machine. No corrections shall be made to the rotor. A permanent mark or part (such as a keyway) shall be used and recorded for the phase reference.

NOTE 1 This is for future reference if a low-speed balance check is performed on the rotor before installation.

NOTE 2 The operating speed balanced rotor does not generally meet the low-speed balance criteria.

4.8.8.7 For a rotor that has been low-speed balanced, a low-speed residual unbalance check shall be performed in a low-speed balance machine and recorded in accordance with the residual unbalance worksheet (see Annex A).

4.8.8.8 During the mechanical running test of the machine, assembled with the balanced rotor, operating at any speed within the specified operating speed range, the peak-to-peak amplitude of unfiltered vibration in any plane, measured on the shaft adjacent and relative to each radial bearing, shall not exceed the value from Formulae (16) and (17) or 25,4 µm (1 mil), whichever is less.

In SI units:

$$A_{vl} = 25,4\sqrt{\frac{12000}{N_{mc}}} \qquad (16)$$

In US customary units:

$$A_{vl} = \sqrt{\frac{12000}{N_{mc}}} \qquad (17)$$

where

A_{vl} is the mechanical test vibration limit, expressed in µm (mil);

N_{mc} is the maximum continuous speed, expressed in r/min.

4.8.8.8.1 At any speed greater than the maximum continuous speed, up to and including the trip speed of the driver, the vibration level shall not increase more than 12,7 µm (0,5 mil) above the value recorded at the maximum continuous speed prior to accelerating to trip for each probe.

NOTE These limits are not to be confused with the limits specified in 4.8.3 for shop verification of unbalanced response.

4.8.8.9 Electrical and mechanical runout shall be determined by rotating the rotor through the full 360 degrees supported in V blocks at the journal centres. The combined runout, measured with a non-contacting vibration probe, and the mechanical runout, measured with dial indicators at the centreline of each probe location, shall be continuously recorded during the rotation. Polytetrafluoroethylene (PTFE) shall not be used in the V blocks.

NOTE The rotor runout determined above is generally not reproduced when the rotor is installed in a machine with hydrodynamic bearings. This is due to pad orientation on tilt-pad bearings and effect of lubrication in all journal bearings.

4.8.8.10 Records of electrical and mechanical runout for the full 360 degrees at each probe location shall be included in the mechanical test report (mechanical test section).

4.8.8.11 If the supplier can demonstrate that electrical or mechanical runout is present, a maximum of the level from Formulae (18) and (19) or 6,35 µm (0,25 mil), whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory test. Where shaft treatment such as metalized aluminium bands have been applied to reduce electrical runout, surface variations (noise) may cause a high-frequency noise component which does not have an applicable vector. The nature of the noise is always additive. In this case, the noise shall be mathematically subtracted.

In SI units:

$$R_{out} = \frac{25,4}{4}\sqrt{\frac{12000}{N_{mc}}} \tag{18}$$

In US customary units:

$$R_{out} = \frac{1}{4}\sqrt{\frac{12000}{N_{mc}}} \tag{19}$$

4.9 Bearings and bearing housings

4.9.1 General

Radial and thrust bearings shall be as specified in the subsequent parts of this international standard.

4.9.2 Hydrodynamic radial bearings

Hydrodynamic radial bearings shall be in accordance with the applicable parts of this international standard.

4.9.3 Hydrodynamic thrust bearings

4.9.3.1 For gear couplings, the external thrust force shall be calculated from Formulae (20) and (21).

In SI units:

$$F = \frac{(0,25)(9550)P_r}{N_r D} \tag{20}$$

In US customary units:

$$F = \frac{(0,25)(63300)P_r}{N_r D} \tag{21}$$

where

F is the external thrust force, expressed in kN (lb.);

P_r is the rated power, expressed in kW (HP);

N_r is the rated speed, expressed in r/min;

D is the shaft diameter at the coupling, expressed in mm (in).

4.9.3.2 Thrust forces for flexible-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

4.9.3.3 If the thrust forces from two or more rotors are carried by one thrust bearing (such as from a gear box or motor), the resultant of the forces shall be used, provided the directions of the forces make them numerically additive; otherwise, the largest of the forces shall be used.

4.9.3.4 The basis for the sizing of thrust bearings shall be provided.

4.9.4 Bearing housings

4.9.4.1 Bearing housings shall be equipped with replaceable labyrinth-type end seals and deflectors where the shaft passes through the housing. Lip-type seals shall not be used. The seals and deflectors shall be made of spark-resistant materials. Seals and deflectors shall be designed to retain oil in the housing and prevent entry of foreign material into the housing.

4.9.4.2 Bearing housings shall be arranged to minimize foaming. The drain system shall be adequate to maintain the oil and foam level below shaft seals.

4.9.4.3 Provisions for the installation of required instrumentation shall be provided.

4.9.4.4 Where practical, oil and instrument connections shall be in the lower half of the bearing housing to eliminate the need for their removal during bearing inspections. Instrument connections shall be above the oil level.

4.9.4.5 * If specified, provisions for locally disconnecting bearing temperature sensors' wiring within the bearing housing shall be provided.

4.9.4.6 Oil flow control orifices used within the housing shall be replaceable and shall be identified on contractual drawings.

4.10 Shaft and seals

4.10.1 General

4.10.1.1 Shaft seals and seal systems shall be provided to restrict or prevent process gas leaks to the atmosphere over the range of specified operating conditions, including start-up, shutdown, settling-out, or any other special conditions (air dry-out, etc.). The shaft seals and seal system shall be designed to permit safe machine pressurization with the seal system in operation prior to process start-up.

4.10.1.2 * The purchaser shall provide the settling-out pressure.

NOTE If a value is not provided, the manufacturer will estimate a value which needs to be checked later against suction relief valve set pressure.

4.10.1.3 The maximum sealing pressure shall be at least equal to the settling-out pressure.

4.10.1.4 Typical cross sections of various types of shaft end seals are given in Annex B.

4.10.1.5 * Shaft seals may be one or a combination of the types described in 4.10.2 to 4.10.4, as specified. The materials for component parts shall be suitable for the service.

4.10.1.6 Seal pressure equalizing lines and associated gas passages (including those for reference gas and axial thrust force balancing) shall be sized to maintain design shaft end seal performance at twice the maximum initial design clearances. The lines and passages shall also be sized to maintain minimal pressure drop through equalizing lines at all conditions.

Any reference pressure measurements for pressure control systems shall be drilled directly into the upper half of the cavity and should be taken from ports used only for that pressure measurement to eliminate exit and entrance losses. These ports should not be used for venting or supplying gas to the cavity.

NOTE This may not be practical on some smaller machines.

4.10.1.7 * The purchaser shall specify composition and conditions (pressure, temperature) of buffer, seal, and separation gas.

4.10.1.8 The method of control (flow control or pressure control) and system configuration shall be mutually determined.

4.10.1.9 When buffer gas or seal gas is specified by the purchaser or required by the supplier, the supplier shall state the gas requirements, including pressures, flowrates, and filtration.

NOTE 1 See ISO 10438-4:2007, Annex D for definitions of buffer and seal gas.

NOTE 2 API 614 5th edition is identical to ISO 10438 (all parts):2007

4.10.1.10 Unless otherwise specified, the supplier shall furnish the complete seal control system including schematic and bill of material. Seal systems shall be in accordance with ISO 10438 as applicable.

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

4.10.1.11 Unless otherwise specified, interconnecting piping (if required) shall be furnished by the purchaser.

4.10.1.12 Equipment supplier shall be responsible for the satisfactory function of the seal system and shall coordinate with the seal manufacturer and purchaser.

4.10.1.13 For compressors with sub-atmospheric pressure at the shaft end seals, provision shall be made to pressurize the seal(s) with gas at a pressure that is higher than the atmospheric pressure.

4.10.2 Clearance seals

4.10.2.1 The labyrinth seal (see Annex B) may include carbon rings, in addition to the labyrinths, if approved by the purchaser. Labyrinths may be stationary or rotating.

4.10.2.2 The restrictive-ring seal (a typical seal is shown in Figure B.3) shall include rings of carbon or other suitable material mounted in retainers or in spacers. The seal may be operated dry, or with a sealing liquid, or with a buffer gas.

4.10.2.3 Eductors or injection systems shall be furnished complete with piping, regulating and control valves, pressure gauges, and strainers. Each item shall be piped and valved to permit its removal during operation of the compressor. Where gas from the compressor discharge is used for the motivating power of the eductor, provisions shall be made for sealing during start-up and shutdown. Instrumentation and controls shall be provided to ensure proper eductor performance under all potential motive fluid and compressor discharge pressure conditions.

NOTE Eductor performance can be sensitive to the motive and discharge pressure of the eductor.

4.10.3 Oil seals

4.10.3.1 Shaft end oil seal(s) shall be provided with provision(s) to inject conditioned buffer gas between the seal and the process gas.

4.10.3.2 The leakage from each seal which contacts the process gas shall be piped to an independent drain pot.

4.10.3.3 Seal oil contaminated by the process gas that would damage components such as bearings, seal rings, O-rings, and couplings shall be piped away separately to allow disposal or reconditioning.

4.10.3.4 * If specified, and when separate lube and seal oil is required, the uncontaminated oil drain shall be separate from the bearing housing oil drain with an internal seal with buffer provision provided to prevent oil cross contamination.

4.10.3.5 Mechanical contact seals

4.10.3.5.1 The mechanical contact seal (a typical seal is shown in Figure B.2) shall be provided with labyrinths and slingers.

4.10.3.5.2 Oil or other suitable liquid furnished under pressure to the rotating seal faces may be supplied from the lube-oil system or from an independent seal system. Mechanical seals shall be designed to minimize gas leaks while the compressor is pressurized and being shut down and after it is stopped in the event of seal-oil failure.

4.10.3.5.3 Unless otherwise specified, the seal shall be provided with a device to provide sealing while shutdown and when oil pressure is not applied.

4.10.3.6 Liquid film seal

4.10.3.6.1 The liquid-film seal (typical seals are shown in Figures B.4 and B.5) shall be provided with sealing rings or bushings and labyrinths. Liquid-film seals may be cylindrical-bushing seals as shown in Figure B.4 or pumping seals as shown in Figure B.5.

4.10.3.6.2 Unless otherwise specified, an elevated tank shall be provided with the required static head to overcome system pressure losses (such as friction losses in internal passages and seal-oil piping) to maintain positive sealing pressure. The supplier shall state the height of the tank reference mark above the compressor centreline. Other means to maintain this differential pressure and positive seal may be used with the purchaser's approval.

4.10.4 Self-acting dry gas seal

NOTE 1 Refer to ISO 10438-4:2007, Annex D for dry gas seal nomenclature.

NOTE 2 See ISO 10438-4:2007, Annex A for dry gas seal support system datasheets.

NOTE 3 API-614 Part 4 is equivalent to ISO 10438-4.

4.10.4.1 The self-acting dry gas seal may be a single, tandem, tandem with intermediate labyrinth or double configuration depending on the application. The self-acting dry gas seal requires external seal gas. Typical configurations are shown in Figures B.6, B.7, B.8, and B.9. The seal gas shall be dry, filtered, and free of any contaminants that form residues. The seal gas source shall be taken from the compressor discharge, or with purchaser's approval, an inter-stage point. An alternate seal gas source may be used and may be required during start-up or shutdown. The design of the gas seal support system is detailed in ISO 10438-4.

NOTE 1 Caution is to be exercised when air is used as a separation or buffer gas. This is to ensure that explosive mixtures are not created when air is mixed with the seal outer leakage consisting of process gas.

NOTE 2 API 614 5th edition is identical to ISO 10438 (all parts):2007.

4.10.4.2 Seal support systems for self-acting dry gas seals shall be in accordance with ISO 10438-4.

NOTE API 614 5th edition Part 4 is identical to ISO 10438-4:2007.

4.10.4.3 Each dry gas seal assembly, regardless of its arrangement, shall be cartridge mounted and positively located and attached to the compressor shaft. For unidirectional seals, cartridges shall be designed to prevent incorrect installation. The method and tolerances for locking the dry gas seal sleeve to the rotor shall be mutually determined between the seal and compressor manufactures. The seal mounting method shall be defined in the proposal.

4.10.4.4 Seal vents and drains shall conform to the following:

a) Seal cavities shall be designed to keep liquid from the dry gas seals. Drains shall be located in the bottom of all seal cavities to fully drain the cavity.

b) The compressor supplier shall define the sizing criteria (pressure drop and maximum flow) for primary and secondary vents.

c) Drain sizing shall be such to prevent blockage of the line.

NOTE There can be insufficient space for small compressors to have dedicated drain lines.

4.10.4.5 The supplier shall provide the following speed limits to prevent damage to the dry gas seals.

a) lift-off speed for slow roll and coastdown operation;

b) acceptable speed range for turning gear;

c) maximum operating speed (for possible overspeed conditions);

d) minimum speed for continuous operation.

4.10.4.6 Seal gas supply shall be checked under all operating/static cases and lowest ambient combinations to ensure adequate superheat.

4.10.4.7 Seal cartridge shall be equipped with anti-rotation and drive devices that shall be visible or installed after seal installation. Blind pins or blind keys shall not be used. Pins or keys shall be replaceable without compressor disassembly other than seal cartridge removal.

4.11 Integral gearing

For integral gears, see ISO 10439-3.

NOTE For separate gear units, see 5.1.7.

4.12 Nameplates and rotation arrows

NOTE Information regarding nameplates and rotational arrows can be found in ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable.

4.12.1 A nameplate shall be securely attached at a readily visible location on the equipment and on any major piece of auxiliary equipment.

4.12.2 Nameplates and rotation arrows (if attached) shall be of austenitic stainless steel or nickel-copper (UNS N04400) alloy. Attachment pins shall be of the same material. Welding to attach the nameplate to the casing is not permitted.

4.12.3 Where speed requires adjustment as a result of performance testing, the nameplate shall reflect these values.

NOTE Rated power on the nameplate can be the calculated value provided it is within allowable tolerances.

4.12.4 * SI or US customary units shall be specified for use on the nameplate.

4.12.5 Lateral critical speeds exhibited during the running tests shall be stamped on the nameplate followed by the word “test.” Lateral critical speeds predicted by calculation up to and including the critical speed above trip speed and not identifiable by test shall be stamped on the nameplate followed by the abbreviation “calc.”

5 Accessories

5.1 Drivers and gearing

5.1.1 The driver shall be of the type specified, sized to meet the maximum specified operating conditions, including external gear or coupling losses, and shall be in accordance with applicable specifications. The driver(s) shall operate under the utility and site conditions specified.

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

5.1.3 The driver shall be capable of starting under the process and utility conditions specified. The starting method and worst case starting torque requirements shall be agreed. The driver’s starting-torque capabilities shall exceed the speed-torque requirements of the machine train.

5.1.4 Steam turbine drivers shall conform to ISO 10437. Steam turbine drivers shall be sized to deliver continuously not less than 110 % of the maximum power required by the machine train, when operating at any of the specified operating conditions and specified normal steam conditions.

NOTE 1 For the purposes of this standard, API 612 is equivalent to ISO 10437.

NOTE 2 The 110 % applies to the design phase of the project. After testing, this margin may not be available due to performance tolerances of the driven equipment.

5.1.5 Motor drives shall conform to internationally recognized standards such as API 541 or API 546, as applicable. (Motors that are below the power scope of API 541 or API 546 shall be in accordance with IEEE 841.) Electric motor drivers shall be rated with a 1.0 S.F. The motor power shall be at least 110 % of the greatest power required (including gear and coupling losses) for any of the specified operating conditions. Consideration shall be given to the starting conditions of both the driver and driven equipment and the possibility that these conditions may be different from the normal operating conditions.

NOTE 1 The 110 % applies to the design phase of a project. After testing, this margin might not be available due to performance tolerances of the driven equipment.

NOTE 2 Refer to ISO 10439-2:2015, 6.3.3.1.5 and ISO 10439-3:2015, 6.3.3.1.3 for allowable tolerances for fixed speed applications. The purchaser can specify additional motor power or removal of excess head.

5.1.6 Gas turbine drivers shall conform to API 616 and shall be sized as agreed taking account of site conditions, particularly variations in ambient air temperature.

5.1.7 Separate gear units shall conform to API 613.

NOTE For integral gears in compressors, see ISO 10439-3.

5.2 Couplings and guards

5.2.1 Non-lubricated flexible couplings and guards between drivers and driven equipment shall be supplied by the manufacturer of the driven equipment.

5.2.2 Couplings, coupling to shaft junctures, and coupling guards shall conform to ISO 10441. The make, type, and mounting arrangement of the coupling shall be agreed by the purchaser and the supplier with unit responsibility of the driver and driven equipment.

NOTE 1 For the purposes of this standard, API 671 is equivalent to ISO 10441.

NOTE 2 See API 614/ISO 10438 for coupling requirements for auxiliary equipment.

5.2.3 The supplier shall coordinate the mounting of hubs.

NOTE Hubs can be mounted by equipment suppliers or by others in the field if required.

5.2.4 The purchaser of the coupling shall provide or include a moment simulator, as required for the mechanical running test.

5.2.5 * If specified, the supplier shall provide ring and plug gauges in accordance with ISO 10441. The purchaser shall specify whether lapping tools are also required.

NOTE 1 API 671:2010 is identical to ISO 10441:2007.

NOTE 2 Refer to API RP 687 for procedures to repair shaft end tapers using lapping tools.

5.2.6 When hydraulically fitted couplings are provided, the supplier shall provide all necessary mounting tools to hydraulically remove and install each coupling. A common mounting fixture used for all couplings is preferred.

5.3 Lubrication and sealing systems

5.3.1 If required, a pressurized oil system or systems shall be furnished to supply oil at a suitable pressure or pressures, as applicable, to the following:

a) the bearings of the driver and of the driven equipment (including any gear);

b) the continuously lubricated couplings

c) the governing and control-oil system;

d) the shaft seal-oil system;

e) the purchaser's control system (if hydraulic).

5.3.2 Housings that enclose moving lubricated parts (such as bearings and shaft seals), highly polished parts, instruments, and control elements shall be designed to minimize contamination by moisture, dust, and other foreign matter during periods of operation or idleness.

5.3.3 Unless otherwise specified, pressurized oil systems shall conform to the requirements of ISO 10438-1 and ISO 10438-2.

NOTE 1 API 614 5th edition is identical to ISO 10438 (all parts):2007.

NOTE 2 Expander-compressors utilize pressurized bearing housings and reservoirs. These details are covered in ISO 10439-4.

5.4 Mounting plates

5.4.1 General

5.4.1.1 The equipment shall be furnished with soleplates or a baseplate, as specified.

5.4.1.2 Mounting plates (baseplates and soleplates) shall comply with the requirements of 5.4.1.2.1 to 5.4.1.2.17.

5.4.1.2.1 Mounting plates shall be furnished with horizontal (axial and lateral) jackscrews. The lugs holding these jackscrews shall be attached to the mounting plates in such a manner that they do not interfere with the installation of the equipment, jackscrews, or shims. Means for moving the equipment vertically for removal or insertion of shims shall be provided. Precautions shall be taken to prevent vertical jackscrews (if provided) in the equipment feet from marring the shimming surfaces. Supports and alignment bolts shall be rigid enough to permit the machine to be moved by the use of lateral and axial jackscrews provided on the mounting plate. Alternative methods of lifting the equipment for the removal or insertion of shims or for moving the equipment horizontally, such as provision for the use of hydraulic jacks, may be proposed. Such arrangements should be proposed for equipment that is too heavy to be lifted or moved horizontally using jackscrews. Alignment jackscrews shall be plated for rust resistance.

5.4.1.2.2 The alignment shims shall be provided by the supplier in accordance with API RP 686 and shall straddle the hold-down bolts and vertical jackscrews and be at least 5 mm (1/4 in) larger on all sides than the equipment feet.

5.4.1.2.3 All machinery mounting surfaces on the mounting plate shall be machined flat and parallel to the axial plane(s) of the machinery mounting feet after fabrication and shall extend at least 25 mm (1 in) beyond the outer three sides of the equipment feet. These mounting surfaces shall meet the following requirements:

a) each mounting surface shall be machined to a finish of 6 µm (250 µin) *Ra* or better;

b) to prevent a soft foot, when the machine is installed on the mounting plate, all mounting surfaces in the same horizontal plane shall be within 25 µm (0,001 in);

c) each mounting surface shall be machined within a flatness of 40 µm per linear m (0,000 5 in per linear ft) of mounting surface;

d) different mounting planes shall be parallel to each other within 50 µm (0,002 in).

5.4.1.2.4 Machinery mounting plates and supports shall be designed to have sufficient strength and rigidity to limit coupling movement (caused by imposing allowable forces and moments) to 50 µm (0,002 in).

NOTE Refer to ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable for allowable piping loads.

5.4.1.2.5 Unless otherwise specified, anchor bolts shall be furnished by the purchaser.

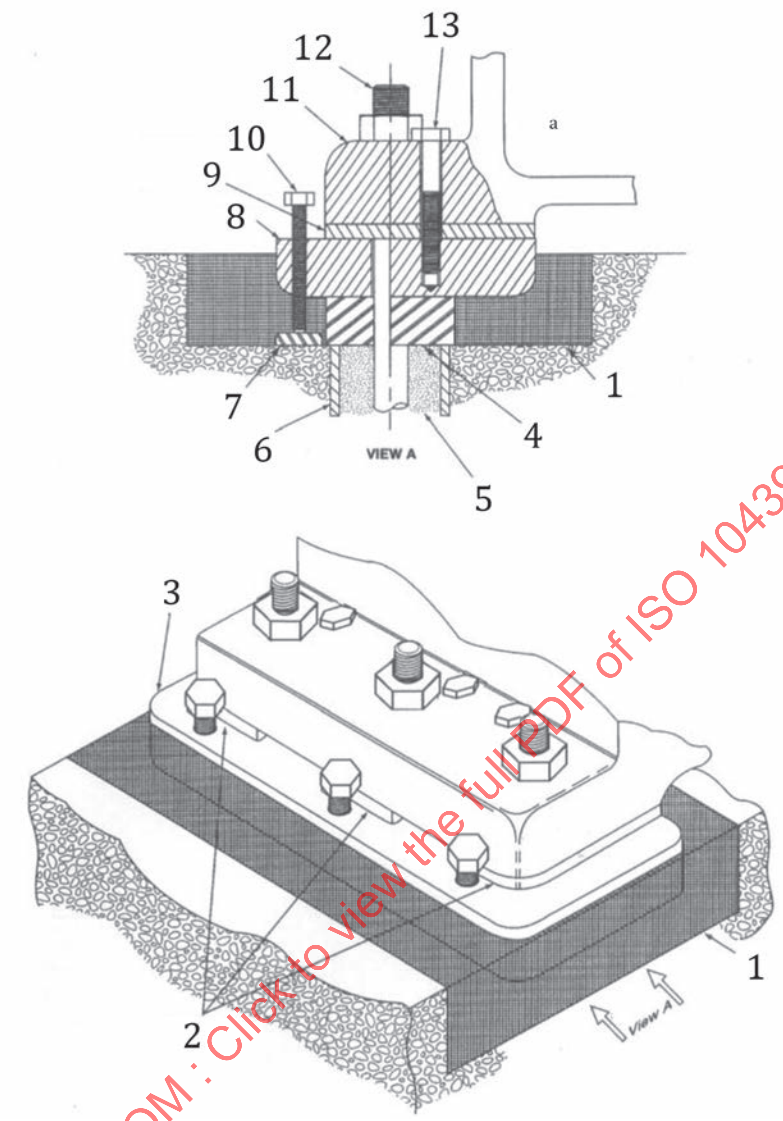
5.4.1.2.6 Anchor bolts shall not be used to fasten machinery to the mounting plates.

5.4.1.2.7 Grouted mounting plates shall be adequately sized to limit the static loading to 690 kN/m^2 (100 psi) on the grout.

5.4.1.2.8 Diametrical clearance between anchor bolts and the anchor bolt holes in the mounting plates shall be a minimum of 6 mm (1/4 in).

5.4.1.2.9 Unless otherwise specified, mounting plates shall be supplied with vertical leveling screws for field leveling. A leveling screw shall be provided near each anchor bolt. If the equipment and mounting plates are too heavy to be lifted using leveling screws, alternate methods shall be provided by the equipment supplier. The design of the alternate method shall be included in the proposal.

5.4.1.2.10 Mounting plate surfaces that are embedded in grout shall have 50 mm (2 in) radiused minimum outside corners (in the plan view). The embedded edges shall be chamfered or rounded. See Figure 5.



Key

1 epoxy grout
2 chock block locations
3 mounting plate (soleplate/rail)
4 non-bonding anchor bolt sleeve seal
5 non-bonding fill
6 anchor bolt sleeve
7 leveling plate
8 rail or soleplate
9 chock block
10 leveling jackscrew
11 frame
12 anchor bolt
13 cap screw

Figure 5 — Typical mounting plate arrangement

5.4.1.2.11 Machinery hold-down bolts and fasteners for attaching the equipment to the mounting shall be provided by the equipment supplier.

5.4.1.2.12 Adequate working clearance shall be provided at the hold-down and jack bolt locations to allow the use of standard socket or box wrenches to achieve the specified torque.

5.4.1.2.13 * The purchaser shall specify the manufacturer and specific type of epoxy grout used for field installation.

NOTE Specific types of epoxy grouts have different recommended primers.

5.4.1.2.14 Unless otherwise specified, the equipment supplier shall prepare the mounting plates by commercially abrasive blasting all grout contacting surfaces in accordance with ISO 8501 Grade Sa2 (SSPC SP 6) and shall precoat these surfaces with a primer compatible with the specified epoxy grout.

NOTE Epoxy primers have a limited life after application.

5.4.1.2.15 The equipment supplier shall provide details of the actual epoxy primer used.

5.4.1.2.16 All mounting surfaces that are not grouted shall be coated with a rust preventive immediately after machining.

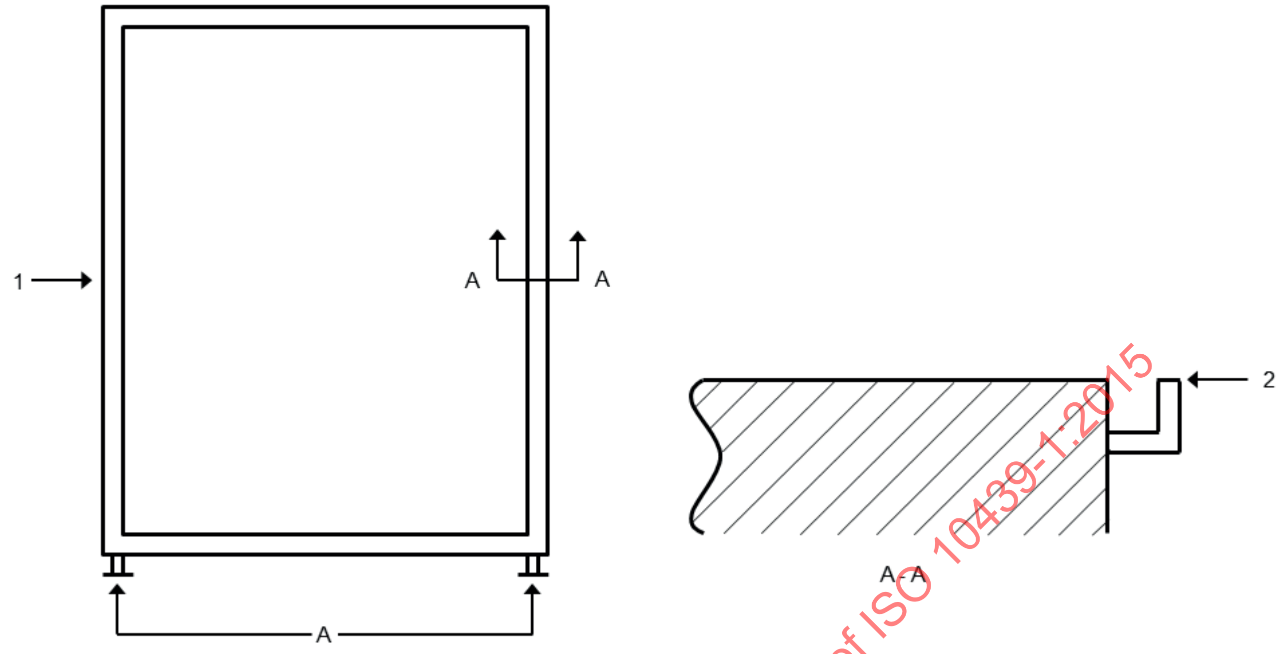
5.4.1.2.17 Unless otherwise specified, mounting plates shall not be drilled for components mounted by others.

5.4.2 Baseplates

5.4.2.1 * When a baseplate is specified, the purchaser shall indicate the major equipment mounted on it. A baseplate shall be a single fabricated steel unit, unless the purchaser and the supplier agree that it may be fabricated in multiple sections. Unless otherwise specified, multiple-section baseplates shall have machined and doweled mating surfaces which shall be bolted together to ensure accurate field reassembly.

NOTE A baseplate with a nominal length of more than 12 m (40 ft) or a nominal width of more than 4 m (12 ft) can require fabrication in multiple sections because of shipping restrictions.

5.4.2.1.1 * If specified, base plates shall be equipped with a drip rim (see Figure 6). One minimum drain connection of at least 40 mm (NPS 1-1/2 in) size shall be supplied to ensure proper drainage of possible leakage of the base plate mounted equipment.



Key

A drains

1 slop to drain

2 level with baseplate to avoid tripping hazard

Figure 6 — Drip rim

5.4.2.2 Unless otherwise specified, the underside mounting surfaces of the baseplate shall be in one plane to permit use of a single-level foundation.

5.4.2.3 All joints, including deck plate and structural members, shall be continuously seal welded to prevent crevice corrosion. Stitch welding, top or bottom, is unacceptable.

5.4.2.4 * If specified, non-skid decking or grating covering all walk and work areas shall be provided on the top of the baseplate. When grating is provided, it shall be removable.

NOTE If, after grouting, the purchaser plans to completely fill the baseplate with cement as a finished surface, decking or grating is not required.

5.4.2.4.1 * If specified, horizontal solid-decked surfaces shall be sloped to avoid collection of liquid.

5.4.2.5 * If specified, the baseplate shall be designed for mounting on structural columns and shall be sufficiently rigid without continuous grouting. The purchaser and the supplier shall agree on the baseplate design.

5.4.2.6 * If specified, the baseplate shall be designed to facilitate the use of optical, laser, or other instruments for field leveling during installation. Design details are described in 5.4.2.6.1 to 5.4.2.6.2. The purchaser and the supplier shall agree on the final design.

5.4.2.6.1 When leveling pads or targets are provided, the pads or targets shall be located close to the machinery support points and be accessible for field leveling with the equipment mounted and the baseplate on the foundation. The leveling pads and targets shall have protective removable covers.

5.4.2.6.2 For baseplates longer than 6 m (20 ft), additional pads and targets shall be provided at intermediate points.

5.4.2.7 The baseplate shall be provided with lifting lugs for at least a four-point lift. Lifting lugs attached to the equipment shall be designed using a maximum stress of one-third of the minimum yield strength of the material. Welding applied to lifting lugs shall be continuous welds and be in accordance with ISO 15614, AWS D1.1 or other agreed structural welding code. The welds shall be 100 % NDE tested in accordance with the applicable code. Lifting the baseplate complete with all equipment mounted shall not permanently distort or otherwise damage the baseplate or the equipment mounted on it.

5.4.2.8 When the baseplate is intended for grouting onto a concrete foundation, adequate access shall be provided into each compartment so all load carrying structural members can be properly grouted. It shall be provided with at least one grout hole having a clear area of at least 100 cm^2 (16 in^2) and no less than 75 mm (3 in) in each bulkhead section. These holes shall be located to permit grouting under all load carrying structural members. Where practical, the holes shall be accessible for grouting with the equipment installed. Vent holes at least 13 mm (1/2 in) in size shall be provided at the highest point and located to vent the entire cavity of each bulkhead section of the baseplate.

5.4.2.9 Support for the equipment shall be located directly beneath the equipment feet and shall extend in line vertically to the bottom of the baseplate.

5.4.2.10 * If specified, the bottom of the baseplate shall have machined mounting pads. These pads shall be machined in a single plane after the baseplate is fabricated.

NOTE These machined mounting pads are necessary when the baseplate is mounted on sub-soleplates or structural steel members to facilitate field leveling.

5.4.2.11 * If specified, sub-sole plates shall be provided by the supplier.

5.4.2.12 Unless otherwise specified, oil reservoirs shall be separate from the baseplate.

5.4.2.13 When the machine is properly aligned on the mounting plate in the shop, each hold-down bolt shall have a minimum clearance of 1,5 mm (1/16 in) between the bolt and the bolt hole.

NOTE Hold-down bolts need adequate clearance within the bolt holes so the machinery can be moved laterally during final field alignment without becoming bolt bound.

5.4.3 Soleplates and sub-soleplates

5.4.3.1 When soleplates are specified, they shall meet the requirements of 5.4.3.1.1 to 5.4.3.1.5.

5.4.3.1.1 Soleplates shall be steel plates that are thick enough to transmit the expected loads from the equipment feet to the foundation, but in no case shall the plates be less than 40 mm (1-1/2 in) thick.

5.4.3.1.2 Soleplates shall be large enough to extend beyond the feet of the equipment in all directions and shall be designed such that the anchor bolts are not covered by machine feet.

5.4.3.1.3 * If specified, sub-sole plates shall be provided by the supplier.

5.4.3.1.4 When sub-sole plates are used, soleplates shall be fully machined top and bottom.

5.4.3.1.5 When sub-sole plates are specified, they shall be steel plates at least 25 mm (1 in) thick. The finish of the sub-sole plates' mating surfaces shall match that of the soleplates.

5.5 Controls and instrumentation

5.5.1 General

5.5.1.1 The supplier shall provide sufficient machine performance data (in accordance with Clause 7) to enable the purchaser to properly design a control system for start-up, for all specified operating conditions, and for surge prevention.

5.5.1.2 * If specified, the supplier shall review the purchaser's overall machine control system for compatibility. The scope of this review shall be agreed.

5.5.1.3 The supplier shall supply information relevant to the purchased equipment as needed by the purchaser to design a control system.

5.5.1.4 * The purchaser shall specify which controls and instruments are designed for outdoor or indoor installation.

5.5.1.5 * The purchaser shall specify required construction and installation standards for controls (see 5.5.1.6)

5.5.1.6 Controls which are installed outside shall have a minimum ingress protection level of IP 65 as detailed in IEC 60529 or a NEMA 4 minimum rating per NEMA Standard Publication 250. When IP 65 protection level is specified, the controls and instrumentation, equipment, and wiring shall comply with the construction requirements of IEC 60079.

5.5.1.7 * Terminal boxes shall have a minimum ingress protection level of IP 66 as detailed in IEC 60529 or a NEMA 4X minimum rating per NEMA Standard Publication 250, as specified.

5.5.1.8 All conduit, armoured cable, and supports shall be designed and installed so that they can be easily removed without damage and shall be located so that they do not hamper removal of bearings, seals, or equipment internals.

5.5.2 Control systems

5.5.2.1 * The purchaser shall specify the method of control, the source of the control signal, its sensitivity and range, and the equipment furnished by the supplier.

NOTE Compressor control can be accomplished by suction throttling, variable inlet guide vanes, variable stator vanes, speed variation, a cooled bypass from discharge to suction, discharge blowoff, or discharge throttling.

5.5.2.2 * If specified, an anti-surge system shall be provided. The scope of supply shall be agreed.

NOTE 1 See Annex G.

NOTE 2 Anti-surge systems are generally required to prevent operating in unstable regions which can cause damage to the compressor. The scope of supply for these systems is process dependent.

5.5.2.3 * If specified, the supplier shall supply the anti-surge valve. The supplier shall identify the following information associated with the valve sizing.

a) the supplier shall identify the conditions upstream and downstream of the anti-surge valve;

b) the supplier shall identify the per cent open valve position used during the sizing;

c) the supplier shall identify the time required to stroke the valve from full closed to full open.

The pressure drop between the valve and the compressor inlet and the valve and the compressor discharge shall be defined by the purchaser at maximum design recycle volume to properly size the valve.

5.5.2.4 * If specified, the supplier shall supply the results of an anti-surge system transient response simulation.

The purchaser shall supply information on the process components such as piping, coolers, vessels, etc., their volumes and associated pressure drops to develop a simulation model.

5.5.3 Instrument and control panels

Refer to ISO 10438 for details on instrument and control panels.

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

5.5.4 Instrumentation

Refer to ISO 10438 for details on instrumentation and API 670 for details on instrumentation and installation.

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

5.5.5 Alarms, shutdowns, and control systems

Refer to ISO 10438 and API 670 for details on alarms, shutdowns, and control systems.

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

5.5.6 Electrical systems

Refer to ISO 10438 for details on electrical systems.

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

5.5.7 Vibration, position, and bearing temperature detectors

Vibration, position, and bearing temperature detectors shall be covered in ISO 10439-2:2015, 5.5, ISO 10439-3:2015, 5.5, and ISO 10439-4:2015, 5.5.

5.6 Piping and appurtenances

5.6.1 General

5.6.1.1 Auxiliary piping shall be in accordance with ISO 10438.

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

5.6.1.2 Auxiliary systems furnished shall be in accordance with ISO 10438-2 and ISO 10438-4.

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

5.6.1.3 Auxiliary systems are defined in ISO 10438.

NOTE 1 Casing connections are discussed in 4.6.4.

NOTE 2 API 614 5th edition is identical to ISO 10438 (all parts):2007.

5.6.1.4 Auxiliary piping to the machine shall have breakout spools to allow for maintenance and for removal of the entire machine.

5.6.1.5 Provision shall be made for bypassing the bearings (and seals if applicable) of all equipment in the train during oil system flushing operations.

NOTE Generally, this is accomplished by short spool pieces at the equipment.

5.6.1.6 Provision shall be made for bypassing the dry gas seals to allow blowing of the supply lines prior to operation.

5.6.2 Instrument piping

Instrument piping, if furnished, shall be in accordance with ISO 10438-2.

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

5.6.3 Process piping

Process piping, if furnished, shall be in accordance with ISO 10438

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

5.7 Special tools

5.7.1 When special tools or fixtures are required to disassemble, assemble, or maintain the equipment, they shall be included in the quotation and furnished as part of the initial supply of the equipment. For multiple-unit installations, the requirements for quantities of special tools and fixtures shall be agreed between purchaser and supplier. These special tools shall be used, and their use demonstrated, during shop assembly and post-test disassembly of the equipment.

5.7.2 When special tools are provided, they shall be packaged in a separate, rugged box(es) and shall be marked "special tools for (tag/item number)." Each tool shall be stamped or metal tagged to indicate its intended use.

5.7.2.1 * If specified, the purchaser shall identify packaging requirements for special tools such as metal boxes or other specific packaging.

5.7.2.2 The supplier shall supply a complete list of special tools and instructions for proper use.

6 Inspection, testing, and preparation for shipment

6.1 General

6.1.1 After advance notification to the supplier, the purchaser's representative shall have entry to all supplier and subsupplier plants where manufacturing, testing, or inspection of the equipment is in progress.

6.1.2 The supplier shall notify subsuppliers of the purchaser's inspection and testing requirements.

6.1.3 * The purchaser shall specify the amount of advance notification required for a witnessed or observed inspection or test.

6.1.4 * The purchaser shall specify the extent of his participation in the inspection and testing.

6.1.4.1 When shop inspection and testing have been specified, the purchaser and the supplier shall coordinate manufacturing hold points and inspectors' visits.

6.1.5 Equipment materials and utilities required for the specified inspection and tests shall be provided by the supplier.

6.1.6 * If specified, the purchaser's representative, the supplier's representative, or both shall indicate compliance in accordance with the inspector's checklist (ISO 10439-2:2015, Annex E, ISO 10439-3:2015, Annex E, or ISO 10439-4:2015, Annex E as applicable) by initialling, dating, and submitting the completed form before shipment.

6.1.7 The purchaser's representative shall have access to the supplier's quality control program for review.

6.1.8 Unless otherwise agreed, witnessed mechanical running or performance tests require written confirmation of a successful preliminary test.

NOTE See 6.1.3; notification need not wait until the successful preliminary test is completed.

6.2 Inspection

6.2.1 General

6.2.1.1 The supplier shall keep the following data available for at least 20 years:

a) necessary certification of materials, such as mill test reports, for pressure containing parts and rotating elements;

b) test data and results to verify that the requirements of the specification have been met;

c) fully identified records of all heat treatment whether performed in the normal course of manufacture or as part of a repair procedure;

d) results of quality control tests and inspections;

e) details of all repairs;

f) as-built assembly and maintenance clearances;

g) other data specified by the purchaser or required by applicable codes and regulations (see 4.2 and 7.3.1.1);

h) purchase specifications for all major items on bills of materials.

6.2.1.2 Pressure-containing parts shall not be painted until hydrotest of the parts is completed. When a helium leak test after hydrotest is required (see 6.3.2), this requirement shall also apply.

6.2.1.3 * In addition to the requirements of 4.5.1.4 and the materials specifications, the purchaser shall identify

a) parts that shall be subject to surface and subsurface examination;

b) the type of examination required, such as magnetic particle, liquid penetrant, radiographic, or ultrasonic examination.

NOTE Material specifications contain mandated and may also contain supplemental inspections.

6.2.1.4 During assembly of the equipment, each component (including integrally cast in passages) and all piping and appurtenances shall be inspected to ensure they have been cleaned and are free of foreign materials, corrosion products, and mill scale.

6.2.1.5 * If specified, the equipment and all piping and appurtenances shall be inspected for cleanliness, before heads are welded onto vessels, openings in vessels or exchangers are closed or piping is finally assembled.

6.2.1.6 * If specified, the hardness of parts, welds, and heat-affected zones shall be verified as being within the allowable values by testing. The method, extent, documentation, and witnessing of the testing shall be agreed.

6.2.2 Material inspection

6.2.2.1 General

6.2.2.1.1 When radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds or materials is required or specified, the recommended practices in 6.2.2.2 to 6.2.2.5 shall apply unless other corresponding procedures and acceptance criteria have been specified.

6.2.2.1.2 Cast iron may be inspected in accordance with 6.2.2.4 and/or 6.2.2.5.

6.2.2.1.3 Welds, cast steel, and wrought material may be inspected in accordance with 6.2.2.2 to 6.2.2.5.

NOTE 1 The material inspection of pressure-containing parts is covered in 4.6.3; impellers, in 4.7.10.7.

NOTE 2 Since the specification for the actual component being inspected depends on metallurgy, component geometry, and method of manufacture, specific procedures and acceptance standards for the application are normally covered by written standards, developed by the manufacturer for the specific application.

6.2.2.1.4 Acceptance standards for 6.2.2.2 to 6.2.2.5 shall be agreed.

NOTE API RP 687:2001, Chapter 1, Section 3, Table of Generalized NDE Acceptance Criteria can be consulted and used as a guide.

6.2.2.2 Radiographic inspections

Radiography shall be based upon the procedures of ASTM E94, or appropriate country codes and standards.

6.2.2.3 Ultrasonic inspection

Ultrasonic inspection shall be based upon the procedures ASTM A609 (castings), ASTM A388 (forgings), or ASTM A578 (plate), or appropriate country codes and standards.

6.2.2.4 Magnetic particle inspection

Both wet and dry methods of magnetic particle inspection shall be based upon the procedures of ASTM E709 or appropriate country codes and standards.

6.2.2.5 Liquid penetrant inspection

Liquid penetrant inspection shall be based upon the procedures of ASTM E165 or appropriate country codes and standards.

6.3 Testing

6.3.1 General

6.3.1.1 Equipment shall be tested in accordance with 6.3.2 to 6.3.6. Other tests that may be specified by the purchaser are described in 6.3.7.

6.3.1.2 Notification requirements are covered in 6.1.3; however, hydro and running test requirements shall not be less than 5 working days before the date the equipment shall be ready for testing. If the testing is rescheduled, the supplier shall contact the purchaser within 5 working days and the new date shall be agreed.

6.3.2 Hydrostatic test

6.3.2.1 Pressure casings shall be tested hydrostatically with liquid at a minimum of 1-1/2 times the maximum allowable working pressure. The minimum hydrotest pressure shall not be less than 1,5 bar (20 psi).

6.3.2.2 Tests shall be maintained for a sufficient period of time to permit complete examination of parts under pressure. The hydrostatic test shall be considered satisfactory when neither leaks nor seepage through the casing or casing joint is observed for a minimum of 30 min. Large, heavy castings may require a longer testing period as agreed by the purchaser and the supplier. Seepage past internal closures required for testing of segmented cases and operation of a test pump to maintain pressure is acceptable.

6.3.2.3 The chloride content of liquids used to test austenitic stainless steel materials shall not exceed 50 mg/kg (50 parts per million). To prevent deposition of chlorides on austenitic stainless steel as a result of evaporative drying, all residual liquid shall be removed from tested parts at the conclusion of the test.

6.3.3 Overspeed test

6.3.3.1 Impeller overspeed test

Each impeller shall be subjected to an overspeed test at not less than 115 % of maximum continuous speed for a minimum duration of 1 min. Impeller dimensions identified by the manufacturer as critical (such as bore, eye seal, and outside diameter) shall be measured before and after each overspeed test. All such measurements and the test speeds shall be recorded and submitted for the purchaser's review following the test. Any permanent deformation of the bore or other critical dimension outside drawing tolerances might be cause for rejection.

NOTE The manufacturer can consider additional margin in the event that speed needs to be increased as a result of a performance test.

6.3.3.2 Axial blading

Axial blading requirements are covered in ISO 10439-2.

6.3.4 Dry gas seals

Dry gas seals shall be tested at seal supplier's shop per the requirements of Annex F.

6.3.5 Mechanical running test

NOTE For additional specifics regarding mechanical running tests, see ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable.

6.3.5.1 All contract proximity probe and accelerometers shall be used during the test and their measurements shall be the basis for acceptance. Matched sets consisting of oscillator-demodulators and cables shall be either the contract equipment or shop equipment.

6.3.5.2 Shop test facilities shall include the capability of continuously monitoring, displaying, recording, and printing vibration displacement and phase, vibration spectra, Bode plots, and shaft orbits.

6.3.5.2.1 * If specified, the user may furnish their own vibration equipment to record baseline readings.

6.3.5.2.2 The vibration characteristics determined using the instrumentation specified in 5.5 shall be the basis for acceptance or rejection of the machine (see 4.8.8.8).

6.3.5.3 At least 6 weeks prior to the first scheduled running test, the supplier shall submit to the purchaser detailed procedures for the mechanical running test and all specified running optional tests including acceptance criteria.

6.3.5.4 For units with oil seals, no individual shaft end seal shall have a leakage rate greater than 70 % of the total expected leakage from all shaft seals in a single machine.

6.3.5.5 All joints and connections shall be checked for tightness, and any leaks shall be corrected.

6.3.5.6 All warning, protective, and control devices used during the test shall be checked and adjusted as required.

6.3.5.7 All instrumentation used for the tests shall have valid calibration at the time of the test.

6.3.5.8 Entrance of oil into the machine(s) during the mechanical running test is prohibited.

NOTE Typically, buffer gas or other facilities are provided to accomplish this.

6.3.5.9 During the mechanical running test, the requirements of 6.3.5.9.1 to 6.3.5.9.6 shall be met.

6.3.5.9.1 During the mechanical running test, the mechanical operation of all equipment being tested and the operation of the test instrumentation shall be satisfactory.

6.3.5.9.2 The measured unfiltered vibration shall not exceed the limits of 4.8.8.8 and shall be recorded throughout the operating speed range.

6.3.5.9.3 Synchronous vibration amplitude and phase angle versus speed during deceleration shall be plotted before and after the 4 h run. Both the synchronous (one per revolution) and overall vibration levels shall be plotted. The speed range covered by these plots shall be from trip speed to 400 r/min.

6.3.5.9.3.1 * If specified, these data shall also be furnished in polar form. The speed range covered by these plots shall be from trip speed to 400 r/min.

6.3.5.9.4 * If specified, all real-time vibration data as agreed by the purchaser and supplier shall be recorded and a copy provided to the purchaser.

6.3.5.9.5 The following seal flow data shall be taken during the compressor mechanical running test:

a) for compressors with oil seals, inner oil leakage shall be measured at each seal;

b) for single dry gas seals, flow in the vent line from each seal shall be measured;

c) for tandem dry gas seals, flow in the primary and secondary vent line from each seal shall be measured;

d) for double dry gas seals, the total flow to each seal shall be measured.

NOTE 1 Dry gas seal performance at contract conditions is normally demonstrated in separate tests by the seal manufacturer (see Annex F for the requirements).

NOTE 2 Flow in the vents of single or tandem seals can include buffer or separation gas, in addition to seal leakage.

6.3.5.9.6 * If specified, lube-oil and seal-oil inlet pressures and temperatures shall be varied through the range specified in the compressor operating manual. This shall be done during the 4-h test. This option, when specified, does not constitute a waiver of the other specified test requirements.

6.3.5.9.7 When the lube oil specified on the data sheet is not available, the test may be conducted using shop lube oil conditioned to a viscosity equivalent to that of the specified oil at site operating conditions.

6.3.5.10 Unless otherwise specified, the requirements of 6.3.5.10.1 to 6.3.5.10.4 shall be met after the mechanical running test is completed.

6.3.5.10.1 All hydrodynamic bearings shall be removed, inspected, and reassembled after the mechanical running test is completed.

6.3.5.10.2 If replacement or modification of bearings or seals or dismantling of the case to replace or modify other parts is required to correct mechanical or performance deficiencies, the initial test shall not be acceptable, and the final shop tests shall be run after these replacements or corrections are made. A mechanical retest is not required when the compressor case shall be dismantled to comply with the requirements of 6.3.5.10.1.

6.3.5.10.3 If minor scuffs and scratches occur on bearings, cosmetic repairs of these parts are not a cause for rerunning the test.

6.3.5.10.4 For liquid film seals, minor scratches due to dirt particles which do not dimensionally change nor affect functionality of the part are not a cause for rerunning the test.

6.3.5.11 * If specified, shaft end seals shall be removed for inspection following a successful running test.

NOTE Inspection of cartridge seals can require that the seal be returned to the seal manufacturer's facility.

6.3.6 Assembled machine gas leakage test

For assembled gas leak testing, refer to ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable.

6.3.7 Optional tests

NOTE Additional optional tests are covered in ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable.

6.3.7.1 * Performance test

Performance testing requirements for specific equipment types are covered in ISO 10439-2, ISO 10439-3, or ISO 10439-4 as applicable.

6.3.7.2 * Field performance testing

6.3.7.2.1 The purchaser shall advise the supplier of any plans to verify compressor performance by site testing of the installed compressor train. The testing shall be conducted with the compressor in as new condition and gas conditions conforming to specification as nearly as practical. Testing shall be in accordance with an agreed performance test code.

NOTE 1 As a guide, on-site testing can be conducted in accordance with ASME PTC-10 or ISO 5389.

NOTE 2 There is no expander-compressor test code. Field performance testing of expander-compressors will be as agreed.

6.3.7.2.2 Testing tolerances shall be jointly determined and applied to test results.

6.3.7.3 * Gas test after hydro

The compressor casing shall be tested for gas leakage with helium at the maximum allowable working pressure. The test shall be conducted with the casing submerged in water. The maximum allowable working pressure shall be maintained for a minimum of 30 min., with no bubbles permitted. As an alternative, a non-submerged soap-bubble test may be performed if approved by the purchaser. This test is done immediately after hydrotest.

6.3.7.4 * Sound-level test

The sound-level test shall be performed in accordance with purchaser requirements.

NOTE This test cannot reflect field sound levels due to shop test environment.

6.3.7.5 * Auxiliary-equipment test

Auxiliary equipment such as oil systems and control systems shall be tested in the supplier’s shop. Details of the auxiliary-equipment tests shall be developed jointly by the purchaser and the supplier.

6.3.7.6 * Post-test inspection of compressor internals

The compressor shall be dismantled, inspected, and reassembled after satisfactory completion of the mechanical running test. The gas test shall be performed after the post-test inspection.

NOTE The merits of post-test inspection of compressor internals can be evaluated against the benefits of shipping a unit with proven mechanical assembly.

6.3.7.7 * Full-pressure/Full-load/Full-speed test

The details of the full-pressure/full-load/full-speed test shall be developed jointly by the purchaser and the supplier. This test may be substituted for the mechanical running test.

6.3.7.8 * Post-test inspection of the hydraulic coupling fit

After the running tests, hydraulically mounted couplings shall be inspected by comparing hub/shaft match marks to ensure that the coupling hub has not moved on the shaft during the tests.

6.3.7.9 * Spare-parts test

Spare parts such as rotors, gears, diaphragms, bearings, and seals shall be tested as specified.

6.4 Preparation for shipment

6.4.1 Equipment shall be prepared for the type of shipment specified, including blocking of the rotor when necessary. Blocked rotors shall be identified by means of corrosion-resistant tags attached with stainless steel wire. The preparation shall make the equipment suitable for 6 months of outdoor storage from the time of shipment, with no disassembly required before operation, except for inspection of bearings and seals. If storage for a longer period is contemplated, the purchaser shall consult with the supplier regarding the recommended procedures for the equipment.

6.4.2 The supplier shall provide the purchaser with the instructions necessary to preserve the integrity of the storage preparation after the equipment arrives at the job site and before start-up.

NOTE API RP 686:2009 Chapter 3 defines the minimum requirements for protecting project machinery and related components from deterioration while in field storage, after installation, and during the period prior to commissioning.

6.4.3 The equipment shall be prepared for shipment after all testing and inspection have been completed and the equipment has been released by the purchaser. The preparation shall include that specified in 6.4.3.1 to 6.4.3.14 (see ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, and ISO 10439-4:2015, Annex B).

6.4.3.1 Except for machined surfaces, all exterior surfaces that may corrode during shipment, storage, or in service, shall be given at least one coat of the manufacturer's standard paint. The paint shall not contain lead or chromates.

NOTE Austenitic stainless steels are typically not painted.

6.4.3.2 Exterior-machined surfaces except for corrosion-resistant material shall be coated with a rust preventive.

6.4.3.3 The interior of the equipment shall be clean and free from scale, welding spatter, and foreign objects. The selection and application of preservatives or rust preventives shall be agreed.

6.4.3.4 Internal surfaces of bearing housings and carbon steel oil systems' components shall be coated with an oil-soluble rust preventive that is compatible with the lubricating oil.

6.4.3.5 Flanged openings shall be provided with metal closures at least 5 mm (3/16 in) thick with elastomer gaskets and at least four full-diameter bolts. For studded openings, all nuts needed for the intended service shall be used to secure closures. Each opening shall be car sealed so that the protective cover cannot be removed without the seal being broken.

6.4.3.6 Threaded openings shall be provided with steel caps or round-head steel plugs. In no case shall non-metallic (such as plastic) caps or plugs be used.

NOTE These are shipping plugs; permanent plugs are covered in 4.6.4.3.8.5.

6.4.3.7 Openings that have been bevelled for welding shall be provided with closures designed to prevent entrance of foreign materials and damage to the bevel.

6.4.3.8 Lifting points and lifting lugs shall be clearly identified on the equipment or equipment package. The recommended lifting arrangement shall be described in the installation manual.

6.4.3.9 The equipment shall be identified with item and serial numbers. Material shipped separately shall be identified with securely affixed, corrosion-resistant metal tags indicating the item and serial number of the equipment for which it is intended. Crated equipment shall be shipped with duplicate packing lists, one inside and one on the outside of the shipping container.

6.4.3.10 A spare rotor, when purchased, shall be prepared for unheated indoor storage for a period of at least 3 years. It shall be treated with a rust preventive and shall be housed in a vapour-barrier envelope with a slow-release volatile-corrosion inhibitor. The rotor shall be crated for domestic or export shipment as specified.

6.4.3.10.1 * If specified, spare rotors shall be shipped in a container capable of nitrogen pressurization and suitable for long term vertical or horizontal storage. Rotors shall have rust preventative coatings unless otherwise specified.

NOTE 1 Relying on nitrogen for long-term storage protection requires that the owner provide PPM to ensure that a nitrogen source is constantly available. This may also require outdoor storage due to hazards associated with leaking nitrogen in an enclosed area.

NOTE 2 Some process gases are not compatible with rust preventative coatings.

6.4.3.11 A suitable resilient material 3 mm (1/8 in) thick [not tetrafluoroethylene (TFE) or polytetrafluoroethylene (PTFE)] shall be used between the rotor and the cradle at the support areas. The rotor shall not be supported on journals. The probe target areas shall be identified and protected.

NOTE TFE and PTFE are not recommended as cradle support liners since they could flow and impregnate into the surface.

6.4.3.12 * If specified, the rotor shall be prepared for vertical storage. It shall be supported from its coupling end with a fixture designed to support a minimum of 1,5 times the rotor's weight without damaging the shaft. Instructions on the use of the fixture shall be included in the installation, operation, and maintenance manuals.

6.4.3.13 * If specified, the fit-up and assembly of machine-mounted piping and intercoolers shall be completed in the supplier's shop prior to shipment.

6.4.3.14 Exposed shafts and shaft couplings shall be wrapped with waterproof, mouldable waxed cloth or volatile-corrosion inhibitor paper. The seams shall be sealed with oil-proof adhesive tape. The shaft end shall be protected against incidental mechanical damage.

6.4.4 Auxiliary piping connections furnished on the purchased equipment shall be impression stamped or permanently tagged to agree with the supplier's connection table or general arrangement drawing. Service and connection designations shall be indicated.

6.4.5 Connections on auxiliary piping removed for shipment shall be match marked for ease of reassembly.

6.4.6 One copy of the manufacturer's standard installation instructions shall be packed and shipped with the equipment.

6.4.7 Wood used in export shipping shall comply with the requirements of ISPM Pub. No.15 FAO, Rome.

7 Supplier's data

7.1 General

7.1.1 The information furnished by the supplier is specified in 7.2 and 7.3.

7.1.2 The data shall be identified on transmittal (cover) letters, title pages and in title blocks, or other prominent position on the drawings, with the following information:

a) the purchaser/owner's corporate name;

b) the job/project number;

c) the equipment item number and service name;

d) the inquiry or purchase order number;

e) any other identification specified in the inquiry or purchase order;

f) the supplier's identifying proposal number, shop order number, serial number, or other reference required to completely identify return correspondence.

7.1.3 A coordination meeting shall be held, preferably at the supplier's plant, within an agreed time after the purchase commitment. The supplier shall prepare and distribute an agenda prior to this meeting, which, as a minimum, shall include discussion of the following items:

a) the purchase order, scope of supply, unit responsibility, sub-supplier items, and lines of communication;

b) the data sheets;

c) applicable specifications and previously agreed exceptions;

d) schedules for transmittal of data, production, and testing;

e) the quality assurance program and procedures;

f) inspection, expediting, and testing;

g) schematics and bills of material for auxiliary systems;

h) the general arrangement of equipment, piping, and auxiliary systems (operating and maintenance access areas shall be reviewed and access for any parts required for maintenance shall be detailed);

i) coupling selections and rating;

j) thrust- and journal-bearing sizing, estimated loading and specific configurations;

k) seal operation and controls;

l) the rotor dynamics analysis and data (lateral, torsional, and transient torsional, as required);

m) machine performance for normal and other specified conditions and other operating conditions, such as start-up, shutdown, and any operating limitations;

n) instrumentation and controls;

o) items for design reviews;

p) other technical items.

7.1.4 * If specified, in addition to the coordination meeting, a design audit/review meeting shall be held at the supplier's plant sufficiently after the coordination meeting to allow for a detailed technical information review. The purchaser shall prepare a list of items required for review and distribute the agenda prior to the meeting.

7.2 Proposals

7.2.1 General

The supplier shall forward the original proposal with the specified number of copies, to the addressee specified in the inquiry documents. The proposal shall include, as a minimum, the data specified in 7.2.2 to 7.2.4, and a specific statement that the equipment and all its components are in strict accordance with this standard. If the equipment or any of its components or auxiliaries is not in strict accordance, the supplier shall include a list that details and explains each deviation. The supplier shall provide sufficient detail to enable the purchaser to evaluate any proposed alternative designs. All correspondence shall be clearly identified in accordance with 7.1.2.

7.2.2 Drawings

7.2.2.1 The drawings indicated on the Supplier Drawing and Data Requirements or (VDDR form see ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, or ISO 10439-4:2015, Annex B as applicable) shall be included in the proposal. As a minimum, the following shall be included:

a) A general arrangement or outline drawing for each machine train or skid-mounted package, showing overall dimensions, maintenance clearance dimensions, overall weights, erection weights, and the largest maintenance weight for each item. The direction of rotation and the size and location of major purchaser connections shall also be indicated.

b) Cross-sectional drawings of major equipment showing the details of the proposed equipment.

c) Representative schematics of all auxiliary systems including, lube oil, seal oil, or self-acting dry gas, control, and electrical systems. Bills of material shall be included.

d) Sketches that show methods of lifting the assembled machine or machines, packages, and major components and auxiliaries. [This information may be included on the drawings specified in item a) above.]

7.2.2.2 If typical drawings, schematics, and bills of material are used, major design deviations shall be clearly marked on the drawings. They shall also be marked up to show the expected weight and dimensions to reflect the actual equipment and scope proposed.

7.2.3 Technical data

The following data shall be included in the proposal:

a) The purchaser's data sheets with complete supplier's information entered thereon and literature to fully describe details of the offering.

b) The predicted noise data (4.4.1.10).

c) The supplier drawing and data requirements form (see ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, or ISO 10439-4:2015, Annex B as applicable) indicating the schedule according to which the supplier agrees to transmit all the data specified.

d) A schedule for shipment of the equipment, in weeks after receipt of an order.

e) A list of major wearing components, showing any interchangeability with the owner's existing machines.

f) A list of spare parts recommended for start-up and normal maintenance purposes.

g) A list of the special tools furnished for maintenance

h) A description of any special weather protection and winterization required for start-up, operation, and periods of idleness, under the site conditions specified on the data sheets. This description shall clearly indicate the protection furnished by the purchaser, as well as that included in the supplier's scope of supply.

i) A complete tabulation of utility requirements, e.g. steam, water, electricity, air, gas, lube oil (including the quantity and supply pressure of the oil required and the heat load removed by the oil), and the nameplate power rating and operating power requirements of auxiliary drivers. Approximate data shall be clearly indicated as such.

j) A description of any optional or additional tests and inspection procedures for materials as required.

k) A description of how special requirements are addressed, whether specified in the purchaser's inquiry or as mandated in this standard.

l) A list of machines, similar to the proposed machine(s), that have been installed and operating under conditions analogous to those specified in the inquiry.

m) Any start-up, shutdown, or operating restrictions required to protect and operate the equipment.

n) List of any components that can be construed as being of alternative design, hence requiring purchaser's acceptance (see 7.2.1).

o) A summary of the materials of construction, including hardness for materials exposed to H_2S (see 4.5.1.6) and a detailed description of the impeller (type of construction, materials, and method of attachment to the shaft) or blade.

p) If oil seals are supplied, the maximum seal-gas rates and rated or expected inner seal-oil leakage rates, if applicable, shall be supplied. The inner seal-oil leakage shall be given on the basis of volume per day per machine at design gas or oil differential pressures and normal machine speed.

q) If self-acting dry gas seals are supplied, expected seal gas(es) requirements and vent flows shall be given for all specified operating conditions including start-up, shutdown, and settling-out.

r) If clearance seals are supplied, expected and guarantee buffer injection and eduction flows as applicable shall be supplied for all specified operating conditions including start-up, shutdown, and settling-out.

s) Maximum and minimum allowable seal pressures for each compressor.

t) If interstage coolers or aftercoolers are furnished by the supplier, data for the purchaser's heat and material balances shall be supplied.

u) Drawings, details, and descriptions of the operations of instrumentation and controls, as well as the makes, materials, and types of auxiliary equipment. The supplier shall also include a complete description of the alarm and shutdown facilities provided.

v) The minimum length of straight pipe required for proper flow characteristics at the inlet and at any side inlet connection.

w) A statement of the manufacturer's capability regarding testing (including performance testing) of the compressor and any other specified items on the train. Details of each optional test specified shall be included.

7.2.4 Curves

Performance curves shall be submitted for each process section of each casing, as well as an overall curve for the train. These curves shall encompass the map of operations, with any limitations indicated thereon. All curves shall be marked "PREDICTED".

NOTE A process section is one or more impellers separated by an inlet or extraction connection to process or intercoolers.

7.2.4.1 Curves for variable-speed compressors shall include the following: discharge pressure, power, polytropic head, and polytropic efficiency versus inlet capacity (from predicted surge point to overload) at minimum operating speed and 80 %, 90 %, 100 %, and 105 % speed and indicating the effect of specified inlet pressures, temperatures, and molecular weights. Any specified operating points shall be noted within the envelope of the performance curve predicted.

7.2.4.2 Curves and data for fixed-speed compressors shall include the following:

a) Discharge pressure, power, polytropic head, and polytropic efficiency versus capacity (from surge point to overload) at normal speed, indicating the effect of specified molecular weights, suction pressures, and temperatures. Alternate operating conditions requiring throttling shall be shown.

b) Speed versus torque required for acceleration of the train to operating speed. Moment of inertia (referenced to motor speed) and initial starting conditions assumed shall be recorded on the curve.

c) Motor torque versus speed at rated voltage and at 80 % of rated voltage.

d) Motor current versus speed at rated voltage and at 80 % of rated voltage.

e) Estimated times for acceleration to rated speed for throttled suction and for open suction at 80 % of the nameplate motor voltage unless otherwise specified.

f) Curves showing performance of AIGV's at variable vane settings covering the entire allowable map of operation (if supplied).

7.2.5 Optional tests

The supplier shall furnish an outline of the procedures used for each of the special optional tests that have been specified by the purchaser or proposed by the supplier.

7.3 Contract data

7.3.1 General

7.3.1.1 Contract data shall be furnished by the supplier in accordance with the agreed VDDR form (ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, or ISO 10439-4:2015, Annex B as applicable).

7.3.1.2 Each drawing shall have a title block in the lower right-hand corner with the date of drawing certification, identification data specified in 7.1.2, revision number, and date and title. Similar information shall be provided on all other documents including subsupplier items.

7.3.1.3 The drawings and data furnished by the supplier shall contain sufficient information so that together with the manuals specified in 7.3.5, the purchaser can properly install, operate, and maintain the equipment covered by the purchase order. All contract drawings and data shall be clearly legible (8 point minimum font size, even if reduced from a larger size drawing), shall cover the scope of the agreed VDDR form and shall satisfy the applicable detailed descriptions in Annex D of the applicable chapter.

7.3.1.4 The purchaser shall review the supplier's data within the agreed time frame. This review shall not constitute permission to deviate from any requirements in the order unless specifically agreed in writing. After the data have been reviewed and accepted, the supplier shall furnish supplier certified copies.

7.3.1.5 A complete list of supplier data shall be included with the first issue of major drawings. This list shall contain titles, drawing numbers, and a schedule for transmittal of each item listed. This list shall cross-reference data with respect to the VDDR form in ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, or ISO 10439-4:2015, Annex B as applicable.

7.3.2 Curves and datasheets

7.3.2.1 Curves

7.3.2.1.1 The supplier shall provide complete performance curves to encompass the allowable map of operations, with any limitations indicated. The curves shall comply with the requirements of 7.3.2.1.2 to 7.3.2.1.6.

NOTE The allowable map of operations can include multiple operating speeds, variable stationary components such as stators or guide vanes, or other means to create a complete operating map.

7.3.2.1.2 All curves submitted prior to final performance testing shall be marked "PREDICTED".

7.3.2.1.3 If a performance test is specified, the supplier shall provide test data and curves when the test has been completed. The surge points shall be shown on the performance curves. These curves shall be marked "TESTED".

7.3.2.1.4 For compressors that have a back-to-back impeller arrangement, the supplier shall furnish a curve showing the expected loading on each side of the thrust bearing versus any combination of the differential pressures across the low-pressure and high-pressure sections of the casing.

7.3.2.1.5 * If specified, the supplier shall supply curves of balance piston line differential pressure versus thrust load.

7.3.2.1.6 * If specified, the supplier shall supply balance piston leakage based on design clearances and twice design clearances for the rated condition.

7.3.2.2 Data sheets

The supplier shall provide full information to enable completion of the data sheets for the train and auxiliary equipment, first for "as-purchased," and then for "as-built." This should be done by the supplier correcting and filling out the data sheets and submitting copies to the purchaser. Datasheets are available in ISO 10439-2:2015, Annex A, ISO 10439-3:2015, Annex A, or ISO 10439-4:2015, Annex A as applicable.

7.3.3 Progress reports

7.3.3.1 * The supplier shall submit progress reports to the purchaser at the intervals specified. Planned and actual dates and the percentage completed shall be indicated for each milestone in the schedule.

7.3.3.2 * If specified, one week prior to the start of assembly the supplier shall issue a "Tail End Schedule", bi-weekly including scheduled and actual completion dates of major activities.

NOTE The schedule can include major assemblies, sub-assemblies, test setup, testing, paint, packing, and shipment preparation.

7.3.4 Parts lists and recommended spares

7.3.4.1 The supplier shall submit complete parts lists for all equipment and accessories supplied. These lists shall include part names, manufacturers' unique part numbers, and materials of construction (identified by applicable international standards). Each part shall be completely identified and shown on appropriate cross-sectional, assembly-type cutaway, or exploded-view isometric drawings. Interchangeable parts shall be identified as such. Parts that have been modified from standard dimensions or finish to satisfy specific performance requirements shall be uniquely identified by part number. Standard purchased items shall be identified by the original manufacturer's name and part number.

7.3.4.2 The supplier shall indicate on each of these complete parts lists all those parts that are recommended as start-up or maintenance spares and the recommended stocking quantities of each. These should include spare parts recommendations of subsuppliers that were not available for inclusion in the supplier's original proposal.

7.3.5 Installation, operation, maintenance, and technical data manuals

7.3.5.1 General

7.3.5.1.1 The supplier shall provide sufficient written instructions and all necessary drawings to enable the purchaser to install all of the equipment covered by the purchase order. This information shall be compiled in a manual or manuals with a cover sheet showing the information listed in 7.1.2, a table of contents, and an index sheet for each section, a complete list of the enclosed drawings by title, drawing number, and revision. The manual pages and drawings shall be numbered. The manual or manuals shall be prepared specifically for the equipment covered in the purchase order. “Typical” manuals are unacceptable.

7.3.5.1.2 * If specified, a draft manual(s) shall be issued to purchaser 8 weeks prior to mechanical testing for review and comment.

7.3.5.1.3 Refer to the VDDR form for number of copies. Hard copies, as well as electronic copies, shall be provided.

7.3.5.2 Installation manual

All information required for the proper installation of the equipment shall be compiled in a manual. It may be separate from the operation and maintenance instructions. This manual shall contain information on alignment and grouting procedures, (normal and maximum utility requirements), centres of mass, rigging procedures, and other installation data. All drawings and data specified in 7.2.2 and 7.2.3 that are pertinent to proper installation shall be included as part of this manual. One extra manual, over and above the specified quantity, shall be included with the first equipment shipment.

NOTE Refer to API RP 686 and the VDDR for installation requirements.

7.3.5.3 Operating and maintenance manual

A manual containing all required operating and maintenance instructions shall be supplied at shipment. In addition to covering operation at all specified process conditions, this manual shall also contain separate sections covering operation under any specified extreme environmental conditions.

7.3.5.4 Technical data manual

* If specified, the supplier shall provide the purchaser with a technical data manual at shipment. See description in ISO 10439-2:2015, Annex B, ISO 10439-3:2015, Annex B, or ISO 10439-4:2015, Annex B as applicable for minimum requirements of this manual.

Annex A
(normative)

Procedure for the determination of residual unbalance

A.1 General

This annex describes the procedure used to determine residual unbalance in machine rotors. Although some balancing machines may be set up to read out the exact amount of unbalance, the calibration can be in error. The only sure method of determining is to test the rotor with a known amount of unbalance.

A.2 Residual unbalance

Residual unbalance is the amount of unbalance remaining in a rotor after balancing. Unless otherwise specified, residual unbalance shall be expressed in g-mm (g-in).

A.3 Maximum allowable residual unbalance

A.3.1 The maximum allowable residual unbalance, per plane, shall be calculated in accordance with 4.8.2.7.

A.3.2 The static weight on each journal shall be determined by physical measurement. (Calculation methods may introduce errors). It should NOT simply be assumed that rotor weight is equally divided between the two journals. There can be great discrepancies in the journal weight to the point of being very low (even negative on over-hung rotors). In the example problem, the left plane has a journal weight of 530,7 kg (1 170 lb). The right plane has a journal weight of 571,5 kg (1 260 lb).

A.4 Residual unbalance check

A.4.1 General

A.4.1.1 When the balancing machine readings indicate that the rotor has been balanced within the specified tolerance, a residual unbalance check shall be performed before the rotor is removed from the balancing machine.

A.4.1.2 To check the residual unbalance, a known trial weight is attached to the rotor sequentially in six equally spaced radial positions (60 degrees apart), each at the same radius (i.e. same moment [g-in]). The check is run at each balance machine readout plane, and the readings in each plane are tabulated and plotted on the polar graph using the procedure specified in A.4.2.

A.4.2 Procedure

A.4.2.1 Select a trial weight and radius that will be equivalent to between one and two times the maximum allowable residual unbalance [e.g. if Umax, is 488,4 g-mm [19,2 g-in], the trial weight should cause 488,4 g-mm to 976,8 g-mm (19,2 g-in to 38,4 g-in) of unbalance]. This trial weight and radius shall be sufficient so that the resulting plot in A.4.2.5 encompasses the origin of the polar plot.

A.4.2.2 Starting at a convenient reference plane (i.e. last heavy spot), mark off the specified six radial positions (60 degree increments) around the rotor. Add the trial weight near the last known heavy spot for that plane. Verify that the balance machine is responding and is within the range and graph selected for taking the residual unbalance check.

A.4.2.3 Verify that the balancing machine is responding reasonably (i.e. no faulty sensors or displays). For example, if the trial weight is added to the last known heavy spot, the first meter reading should be at least twice as much as the last reading taken before the trial weight was added. Little or no meter reading generally indicates that the rotor was not balanced to the correct tolerance, the balancing machine was not sensitive enough, or that a balancing machine fault exists (i.e. a faulty pickup). Proceed if this check behaves reasonably.

A.4.2.4 Remove the trial weight and rotate the trial weight to the next trial position (that is, 60, 120, 180, 240, 300, and 360 degrees from the initial trial weight position). Repeat the initial position as a check for repeatability on the residual unbalance worksheet. All verification shall be performed using only one sensitivity range on the balance machine.

A.4.2.5 Plot the balancing machine amplitude readout versus angular location of trial weight (NOT balancing machine phase angle) on the residual unbalance worksheet and calculate the amount of residual unbalance (refer to worksheets, Figures A.3 and A.5).

NOTE The maximum reading occurs when the trial weight is placed at the rotor's remaining heavy spot; the minimum reading occurs when the trial weight is placed opposite the rotor's heavy spot (light spot). The plotted readings are expected to form an approximate circle around the origin of the polar chart. The balance machine angular location readout will approximate the location of the trial weight. The maximum deviation (highest reading) is the heavy spot (represents the plane of the residual unbalance). Blank worksheets are Figures A.1 and A.2.

A.4.2.6 Repeat the steps described in A.4.2.1 to A.4.2.5 for each balance machine readout plane. If the specified maximum allowable residual unbalance has been exceeded in any balance machine readout plane, the rotor shall be balanced more precisely and checked again. If a balance correction is made in any balance machine readout plane, then the residual unbalance check shall be repeated in all balance machine readout planes.

A.4.2.7 For stack component balanced rotors, a residual unbalance check shall be performed after the addition and balancing of the rotor after the addition of the first rotor component and at the completion of balancing of the entire rotor, as a minimum.

NOTE 1 This ensures that time is not wasted and rotor components are not subjected to unnecessary material removal in attempting to balance a multiple component rotor with a faulty balancing machine.

NOTE 2 For large multi-stage rotors, the journal reactions can be considerably different from the case of a partially stacked to a completely stacked rotor.

Figure A.1 shows a (blank) residual unbalance worksheet.

Figure A.2 shows a (blank) residual unbalance polar plot worksheet.

Figure A.3 shows a sample residual unbalance worksheet for left plane.

Figure A.4 shows a sample residual unbalance polar plot worksheet for left plane.

Figure A.5 shows a sample residual unbalance worksheet for right plane.

Figure A.6 shows a sample residual unbalance polar plot worksheet for right plane.

The worksheets presented in Figures A.1 to A.6 are also available in electronic format via http://standards.iso.org/iso/.

Customer: ____________
Job / Project Number: ____________
OEM Equipment S / N: ____________
Rotor Identification Number: ____________
Repair Purchase Order Number: ____________
Vendor Job Number: ____________
Correction Plane (Left or Right) - use sketch ____________ (plane)

Balancing Speed		(rpm)		
Maximum Rotor Operating Speed (N)		(rpm)		
Static Journal Weight Closest to This Correction Plane (W)		(kg)		(lbs)
Trial Weight Radius (R) - the radius at which the trial weight will be placed		(mm)		(in)

Calculate Maximum Allowable Residual Unbalance (Umax):

Si Units:

Umax = (6350) X (W) / (N) = (6350) X [ ] / [ ] = [ ] (g-mm)

Customary Units:

Umax = (113.4) X (W) / (N) = (113.4) X [ ] / [ ] = [ ] (g-in)

Calculate the trial unbalance (TU):

Trial Unbalance (TU) is between (1 X Umax) and (2 X Umax)

	(1 X)		(2 X)		(Selected Multiplier is) [ ]
SI Units:	[ ]	to	[ ]	=	[ ] (g-mm)
Customary units:	[ ]	to	[ ]	=	[ ] (g-in)

Calculate the trial weight (TW):

Trial Weight (TW) = Umax / R = [ ] g-mm / [ ] mm or [ ] g-in / [ ] in = [ ] (g)

Conversion Information:

1kg = 2.2046 lbs   1 ounce = 28.345 grams

Obtain the test data and complete the table:

Test Data

Position	Trial Weight Angular Location on Rotor (degrees)	Balancing Mach Readout Amplitude (grams)	Phase Angle (degrees)
1			
2			
3			
4			
5			
6			
Repeat 1			

Sketch the rotor configuration:

Rotor Sketch

PROCEDURE:

Step 1: Plot the balancing machine amplitude versus trial weight angular location on the polar chart (Figure A-2) such that the largest and smallest values will fit.

Step 2: The points located on the Polar Chart should closely approximate a circle. If it does not, then it is probabloy that the recorded data it is in error and the test should be repeated.

Step 3: Determine the maximum and minimum balancing machine amplitude readings .

Step 4: Using the worksheet, (Figure A-2), determine the Y and Z values required for the residual unbalance calculation.

Step 5: Using the worksheet, (Figure A-2), calculate the residual unbalance remaining in the rotor.

Step 6: Verify that the determined residual unbalance is equal to or less than the maximum allowable residual unbalance (Umax).

HALF KEYS USED FOR ROTOR BALANCING
(add sketch for clarification if necessary)

Location		Weight	

NOTES:

1) The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor. The preferred location is the location of the once-per-revolution mark (for the phase reference transducer).

2) The balancing machine amplitude readout for the Repeat of 1 should be the same as Position 1, indicating repeatability.

3) A primary source for error is not maintaining the same radius for each trial weight location.

Balanced By: ________   Date: ______
Approved By: ________   Date: ______

Figure A.1 — (Blank) residual unbalance worksheet

Customer: ____________________

Job / Project Number: ____________________

OEM Equipment S / N: ____________________

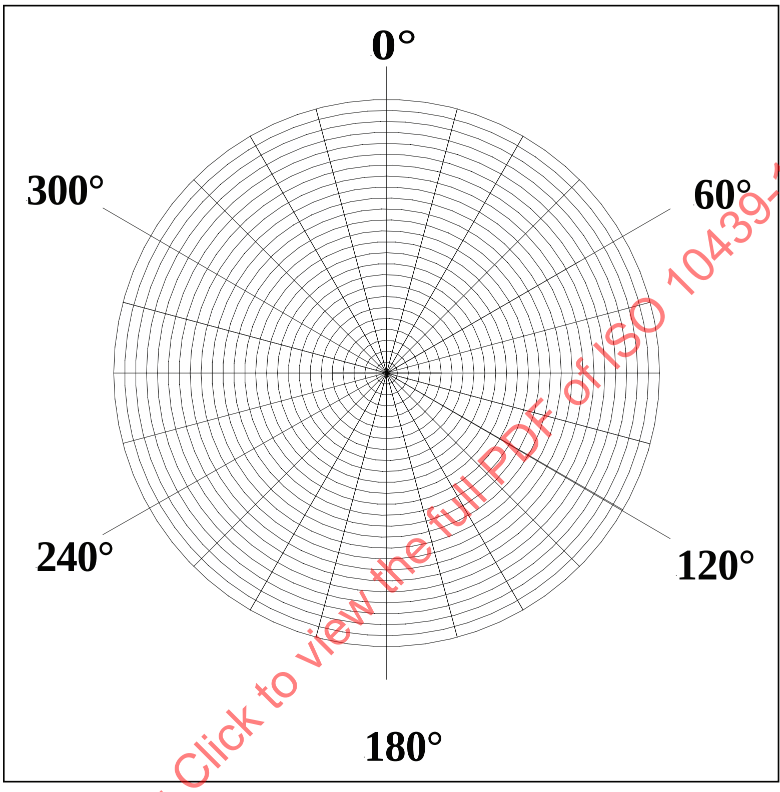
Rotor Identification Number: ____________________

Repair Purchase Order Number: ____________________

Vendor Job Number: ____________________

Correction Plane (Left or Right) - use sketch ______________ (plane)

RESIDUAL UNBALANCE POLAR PLOT



Rotor Rotation: ☐ CCW ☐ CW

Phase is layed out: ☐ CCW ☐ CW

Calculate Y and Z values:

Maximum amplitude value is: [ ] grams   Minimum amplitude value is: [ ] grams

Y = (Maximum - Minimum) / 2 ([ ] - [ ]) / 2 = [ ]

Z = (Maximum + Minimum) / 2 ([ ] + [ ]) / 2 = [ ]

Residual Unbalance

Left in Rotor = (TU) X (Y) / (Z)

SI Units: [ ] X [ ] / [ ] = [ ] gm-mm

Customary Units: [ ] X [ ] / [ ] = [ ] gm-in

Allowable Unbalance Tolerance = Umax = [ ] gm-mm [ ] gm-in

RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance?

☐ PASS ☐ FAIL

☐ As Received ☐ Final ☐ Other: ________

Balanced By: ________ Date: ________

Approved By: ________ Date: ________

Figure A.2 — (Blank) residual unbalance polar plot worksheet

Customer:	Aramco	
Job / Project Number:	7662	
OEM Equipment S / N:		
Rotor Identification Number:		
Repair Purchase Order Number:		
Vendor Job Number:		
Correction Plane (Left or Right) - use sketch	Left	(plane)

Balancing Speed	800	(rpm)		
Maximum Rotor Operating Speed (N)	9902	(rpm)		
Static Journal Weight Closest to This Correction Plane (W)	530.7	(kg)	315	(lbs)
Trial Weight Radius (R) - the radius at which the trial weight will be placed	381	(mm)	7	(in)

Calculate Maximum Allowable Residual Unbalance (Umax):

Si Units:

Umax = (6350) X (W) / (N) = (6350) X 530.7 / 9902 = 340.3 (g-mm)

Customary Units:

Umax = (113.4) X (W) / (N) = (113.4) X 315 / 9902 = 3.6 (g-in)

Calculate the trial unbalance (TU):

	(1 X)	to	(2 X)	(Selected Multiplier is)	1.6	
Trial Unbalance (TU) is between (1 X Umax) and (2 X Umax)						
SI Units:	340.3	to	680.7	is	544.5	(g-mm)
Customary units:	3.6	to	7.2	is	5.8	(g-in)

Calculate the trial weight (TW):

Trial Weight (TW) = Umax / R = 545 g-mm / 381 mm or 6 g-in / 7 in = #NAME? (g)

Conversion Information:

1kg = 2.2046 lbs 1 ounce = 28.345 grams

Obtain the test data and complete the table:

Test Data

Position	Trial Weight Angular Location on Rotor (degrees)	Balancing Mach Readout Amplitude (grams)	Balancing Mach Readout Phase Angle (degrees)
1	0	3.17	354
2	60	3.40	54
3	120	3.48	114
4	180	3.49	177
5	240	3.56	240
6	300	3.23	290
Repeat 1	0	3.40	0

Sketch the rotor configuration:

Rotor Sketch

PROCEDURE:

Step 1: Plot the balancing machine amplitude versus trial weight angular location on the polar chart (Figure A-2) such that the largest and smallest values will fit.

Step 2: The points located on the Polar Chart should closely approximate a circle. If it does not, then it is probabloy that the recorded data it is in error and the test should be repeated.

Step 3: Determine the maximum and minimum balancing machine amplitude readings .

Step 4: Using the worksheet, (Figure A-2), determine the Y and Z values required for the residual unbalance calculation.

Step 5: Using the worksheet, (Figure A-2), calculate the residual unbalance remaining in the rotor.

Step 6: Verify that the determined residual unbalance is equal to or less than the maximum allowable residual unbalance (Umax).

HALF KEYS USED FOR ROTOR BALANCING
(add sketch for clarification if necessary)

Location		Weight	

NOTES:

1) The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor. The preferred location is the location of the once-per-revolution mark (for the phase reference transducer).

2) The balancing machine amplitude readout for the Repeat of 1 should be the same as Position 1, indicating repeatability.

3) A primary source for error is not maintaining the same radius for each trial weight location.

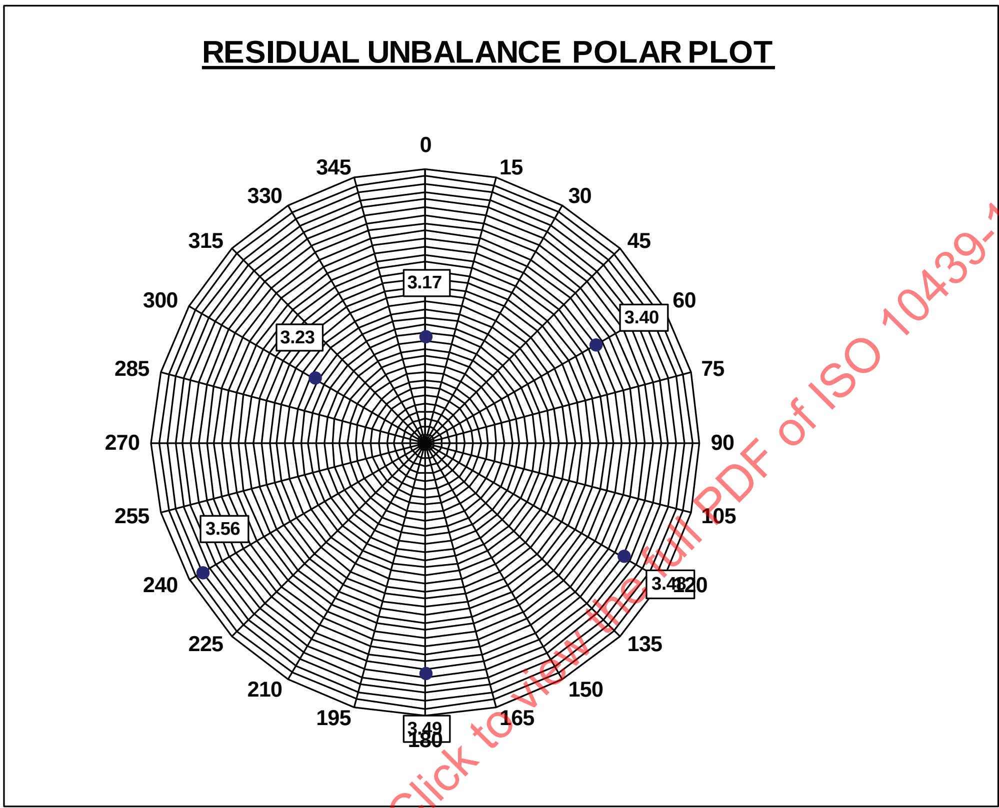
Balanced By:	CJ, TR, & RC	Date:	2000-05-24
Approved By:	CC	Date:	2000-05-24

Polar Chart Calculation Values

0	3.17
15	
30	
45	
60	3.40
75	
90	
105	
120	3.48
135	
150	
165	
180	3.49
195	
210	
225	
240	3.56
255	
270	
285	
300	3.23
315	
330	
345	

Figure A.3 — Sample residual unbalance worksheet for left plane

Customer:	Aramco
Job / Project Number:	7662
OEM Equipment S / N:	
Rotor Identification Number:	
Repair Purchase Order Number:	
Vendor Job Number:	
Correction Plane (Left or Right) - use sketch	Left (plane)



Rotor Rotation: ☒ CCW ☐ CW **Phase is layed out:** ☐ CCW ☒ CW

Calculate Y and Z values:

Maximum amplitude value is:	3.56	grams	**Minimum amplitude value is:**			3.17	grams
Y = (Maximum - Minimum) / 2	3.56	-	3.17	) / 2	=	0.2	
Z = (Maximum + Minimum) / 2	3.56	+	3.17	) / 2	=	3.4	

Residual Unbalance

Left in Rotor =	(TU)	X	(Y)	/	(Z)			
SI Units:	545	X	0.20	/	3.37	=	31.6	g-mm
Customary Units:	6	X	0.20	/	3.37	=	0.3	g-in

Allowable Unbalance Tolerance = Umax = 340.3 g-mm 3.6 g-in

RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance?

PASS

☐ As Received ☐ Final ☒ Other: w/o trim hardware

Balanced By:	CJ, TR & RC	**Date:**	2000-05-24
Approved By:	CC	**Date:**	2000-05-24

Figure A.4 — Sample residual unbalance polar plot worksheet for left plane

Customer:	Aramco	
Job / Project Number:	7662	
OEM Equipment S / N:		
Rotor Identification Number:		
Repair Purchase Order Number:		
Vendor Job Number:		
Correction Plane (Left or Right) - use sketch	Right	(plane)

Balancing Speed	800	(rpm)		
Maximum Rotor Operating Speed (N)	9902	(rpm)		
Static Journal Weight Closest to This Correction Plane (W)	571.5	(kg)	315	(lbs)
Trial Weight Radius (R) - the radius at which the trial weight will be placed	203	(mm)	7	(in)

Calculate Maximum Allowable Residual Unbalance (Umax):

Si Units:

$$Umax = \frac{(6350)\ X\ (W)}{(N)} = \frac{(6350)\ X\ 571.5}{9902} = 366.5\ \text{(g-mm)}$$

Customary Units:

$$Umax = \frac{(113.4)\ X\ (W)}{(N)} = \frac{(113.4)\ X\ 315}{9902} = 3.6\ \text{(g-in)}$$

Calculate the trial unbalance (TU):

	(1 X)		(2 X)			
Trial Unbalance (TU) is between (1 X Umax) and (2 X Umax)	(1 X)	to	(2 X)	(Selected Multiplier is)	1.6	
SI Units:	366.5	to	733.0	is	586.4	(g-mm)
Customary units:	3.6	to	7.2	is	5.8	(g-in)

Calculate the trial weight (TW):

$$\text{Trial Weight (TW)} = \frac{Umax}{R} = \frac{586\ \text{g-mm}}{203\ \text{mm}}\ \text{or}\ \frac{6\ \text{g-in}}{7\ \text{in}} = 0.8\ \text{(g)}$$

Conversion Information:

1kg = 2.2046 lbs 1 ounce = 28.345 grams

Obtain the test data and complete the table:

Test Data

Position	Trial Weight Angular Location on Rotor (degrees)	Balancing Mach Readout Amplitude (grams)	Balancing Mach Readout Phase Angle (degrees)
1	0	3.23	356
2	60	3.14	50
3	120	2.90	115
4	180		
5	240		
6	300		
Repeat 1	0		

Sketch the rotor configuration:

Rotor Sketch

PROCEDURE:

Step 1: Plot the balancing machine amplitude versus trial weight angular location on the polar chart (Figure A-2) such that the largest and smallest values will fit.

Step 2: The points located on the Polar Chart should closely approximate a circle. If it does not, then it is probabloy that the recorded data it is in error and the test should be repeated.

Step 3: Determine the maximum and minimum balancing machine amplitude readings .

Step 4: Using the worksheet, (Figure A-2), determine the Y and Z values required for the residual unbalance calculation.

Step 5: Using the worksheet, (Figure A-2), calculate the residual unbalance remaining in the rotor.

Step 6: Verify that the determined residual unbalance is equal to or less than the maximum allowable residual unbalance (Umax).

HALF KEYS USED FOR ROTOR BALANCING
(add sketch for clarification if necessary)

Location		Weight	

NOTES:

1) The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor. The preferred location is the location of the once-per-revolution mark (for the phase reference transducer).

2) The balancing machine amplitude readout for the Repeat of 1 should be the same as Position 1, indicating repeatability.

3) A primary source for error is not maintaining the same radius for each trial weight location.

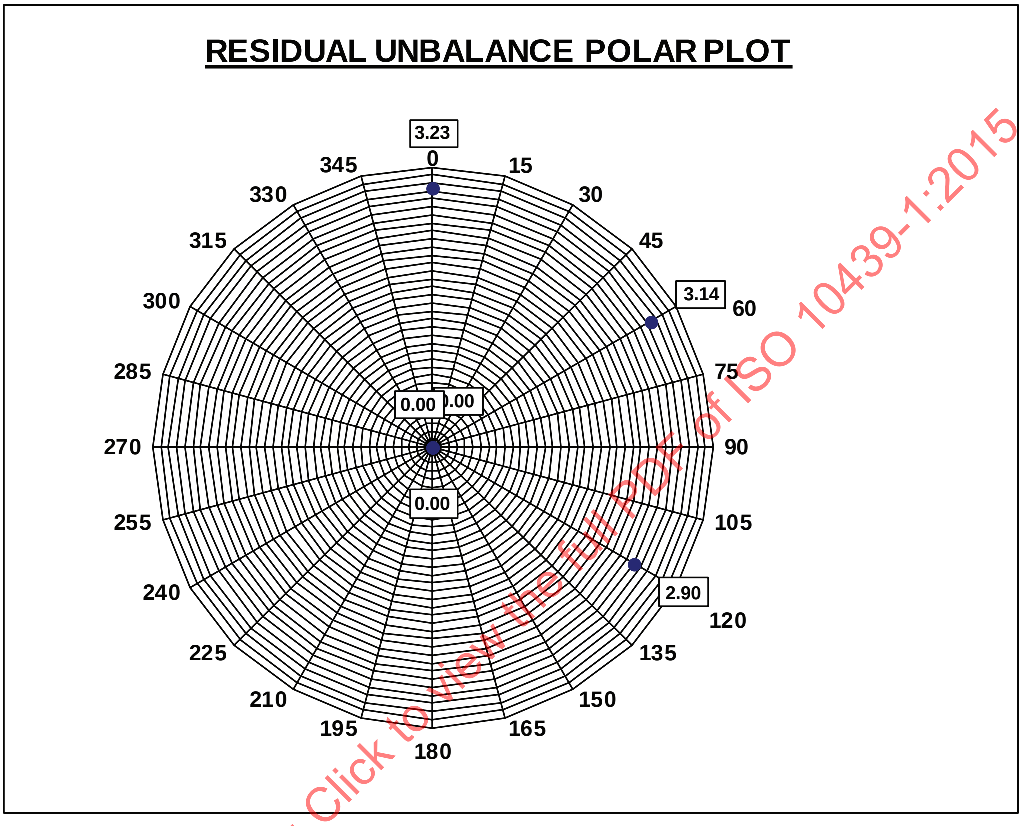
Balanced By:	CJ, TR, & RC	Date:	5/24/2000
Approved By:	CC	Date:	5/24/2000

Polar Chart Calculation Input

0	3.23
15	
30	
45	
60	3.14
75	
90	
105	
120	2.90
135	
150	
165	
180	0.00
195	
210	
225	
240	0.00
255	
270	
285	
300	0.00
315	
330	
345	

Figure A.5 — Sample residual unbalance worksheet for right plane

Customer:	ABC Refining Co.
Job / Project Number:	00 - 1234
OEM Equipment S / N:	C - 1234
Rotor Identification Number:	1234 - C - 4320
Repair Purchase Order Number:	PO 12345678
Vendor Job Number:	Shop - 00 - 1234
Correction Plane (Left or Right) - use sketch	Right (plane)



Rotor Rotation: ☒ CCW ☐ CW

Phase is layed out: ☐ CCW ☒ CW

Calculate Y and Z values:

Maximum amplitude value is:	3.23	grams	Minimum ampltude value is:			2.90	grams
Y = (Maximum - Minimum) / 2	3.23	-	2.90	) / 2	=	0.2	
Z = (Maximum + Minimum) / 2	3.23	+	2.90	) / 2	=	3.1	

Residual Unbalance

Left in Rotor =	(TU)	X	(Y)	/	(Z)			
SI Units:	586	X	0.165	/	3.065	=	31.6	g-mm
Customary Units:	6	X	0.165	/	3.065	=	0.3	g-in

Allowable Unbalance Tolerance = Umax = 366.5 g-mm 3.6 g-in

RESULT: Residual unbalance left in the rotor is equal to or less than the allowable unbalance tolerance? **PASS**

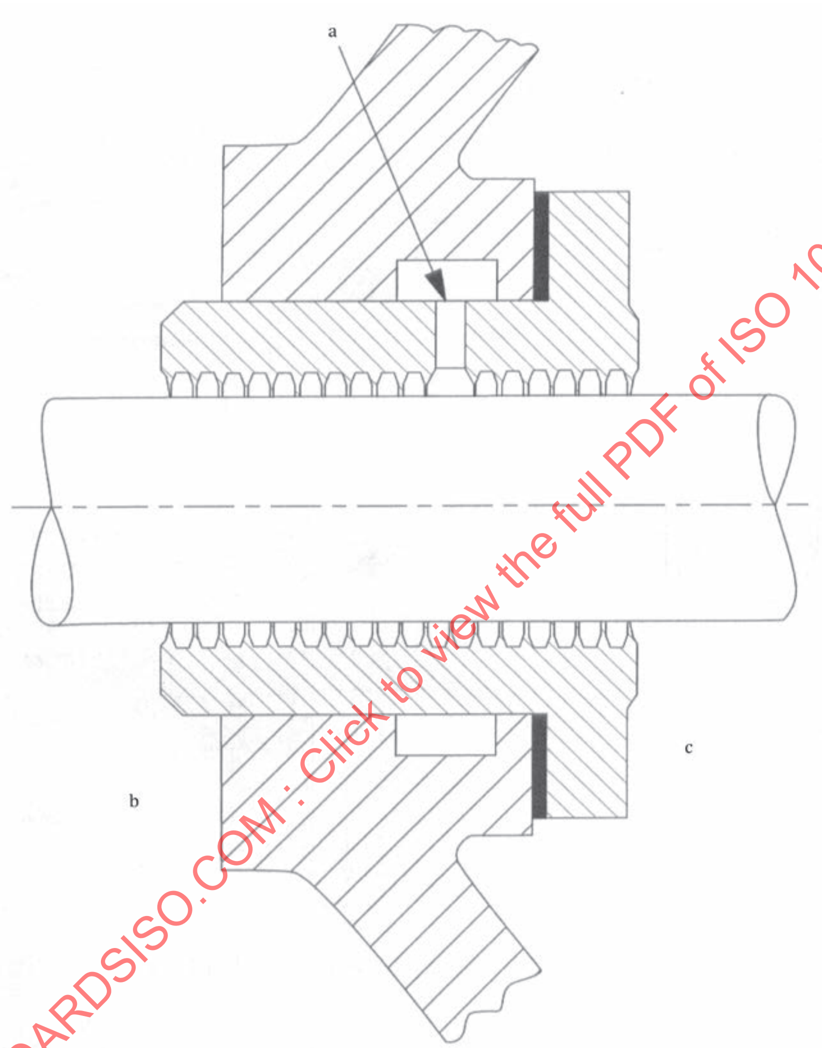
☐ As Received ☐ Final ☒ Other: w/o trim hardware

Balanced By:	CJ, TR & RC	Date:	2000-05-24
Approved By:	CC	Date:	2000-05-24

Figure A.6 — Sample residual unbalance polar plot worksheet for right plan

Annex B
(informative)

Typical shaft end seals



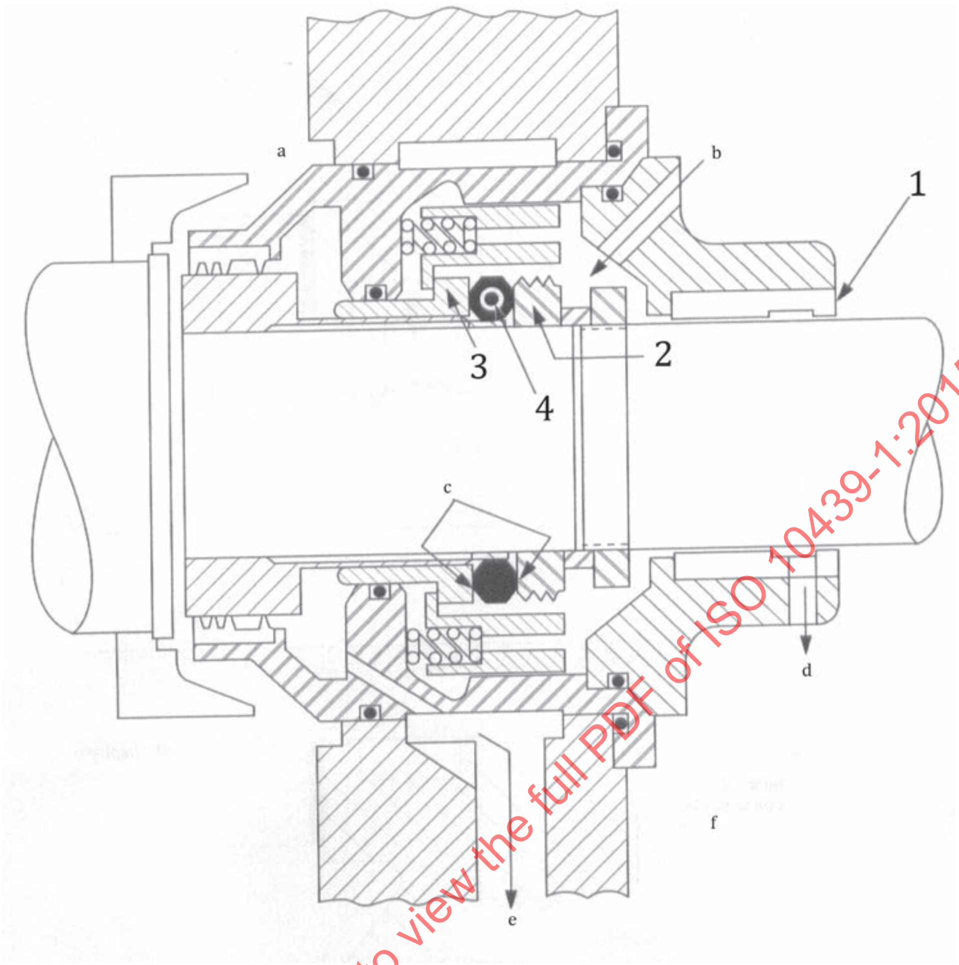
Key

a Ports may be added for scavenging and/or inert gas sealing.

b Internal gas pressure.

c Atmosphere.

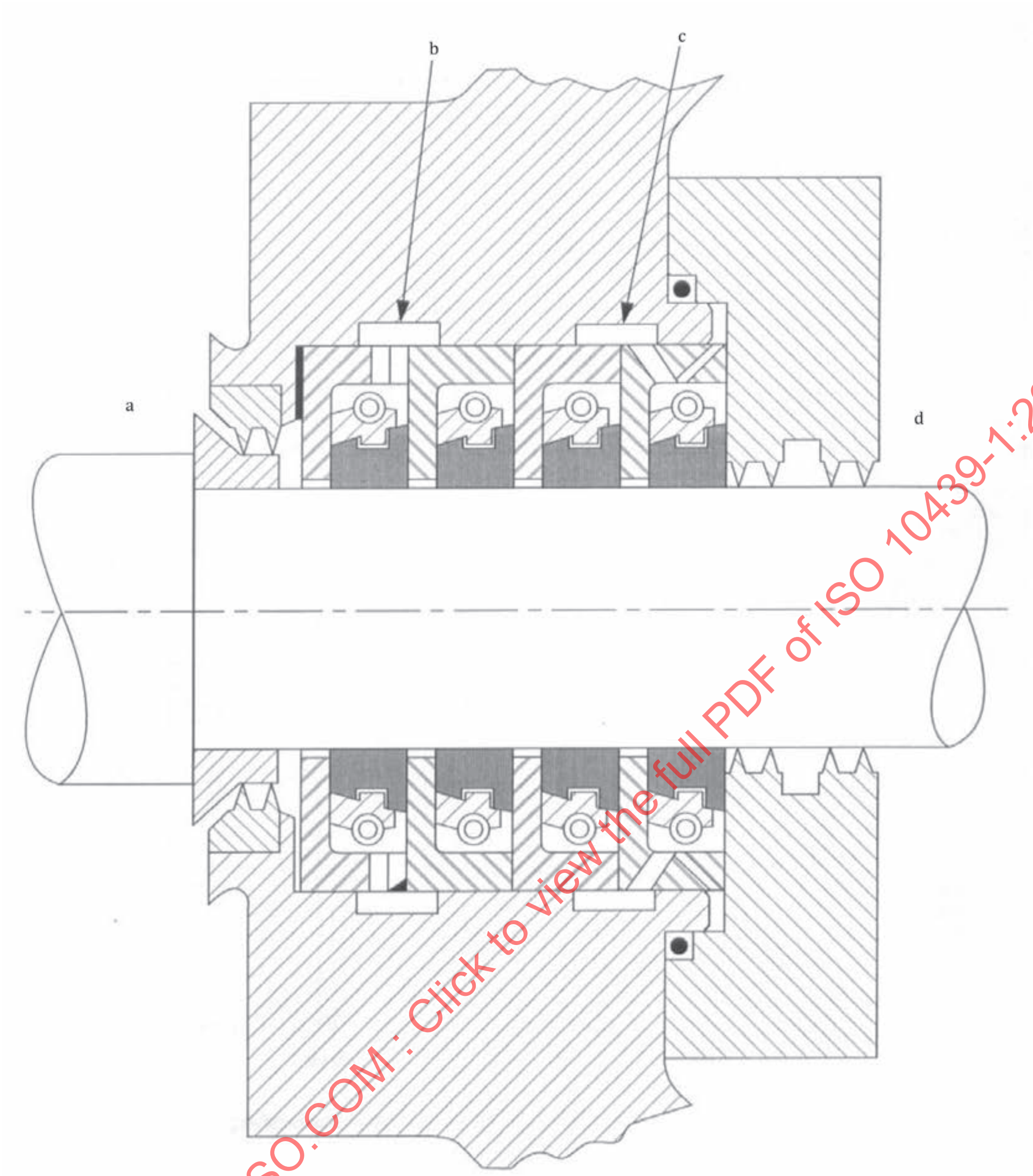
Figure B.1 — Labyrinth seal (shown with single port)



Key

1 pressure breakdown sleeve
2 rotating seat
3 carbon ring
4 stationary seat
a Internal gas pressure.
b Clean oil in.
c Running face.
d Oil out.
e Contaminated oil out.
f Atmosphere.

Figure B.2 — Mechanical contact liquid film seal



Key

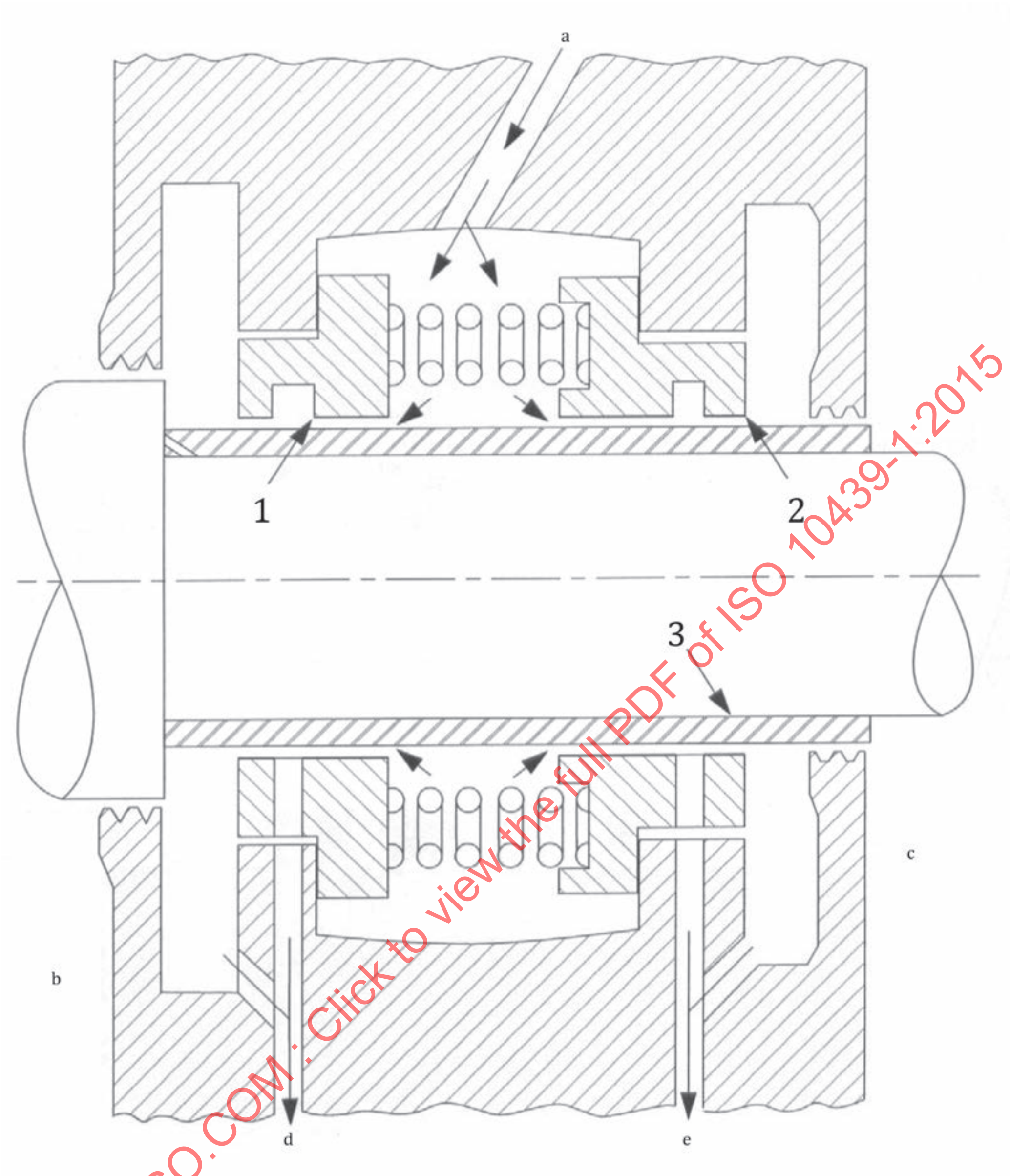
a Internal gas pressure.

b Ports may be added for sealing.

c Scavenging port may be added for vacuum application.

d Atmosphere.

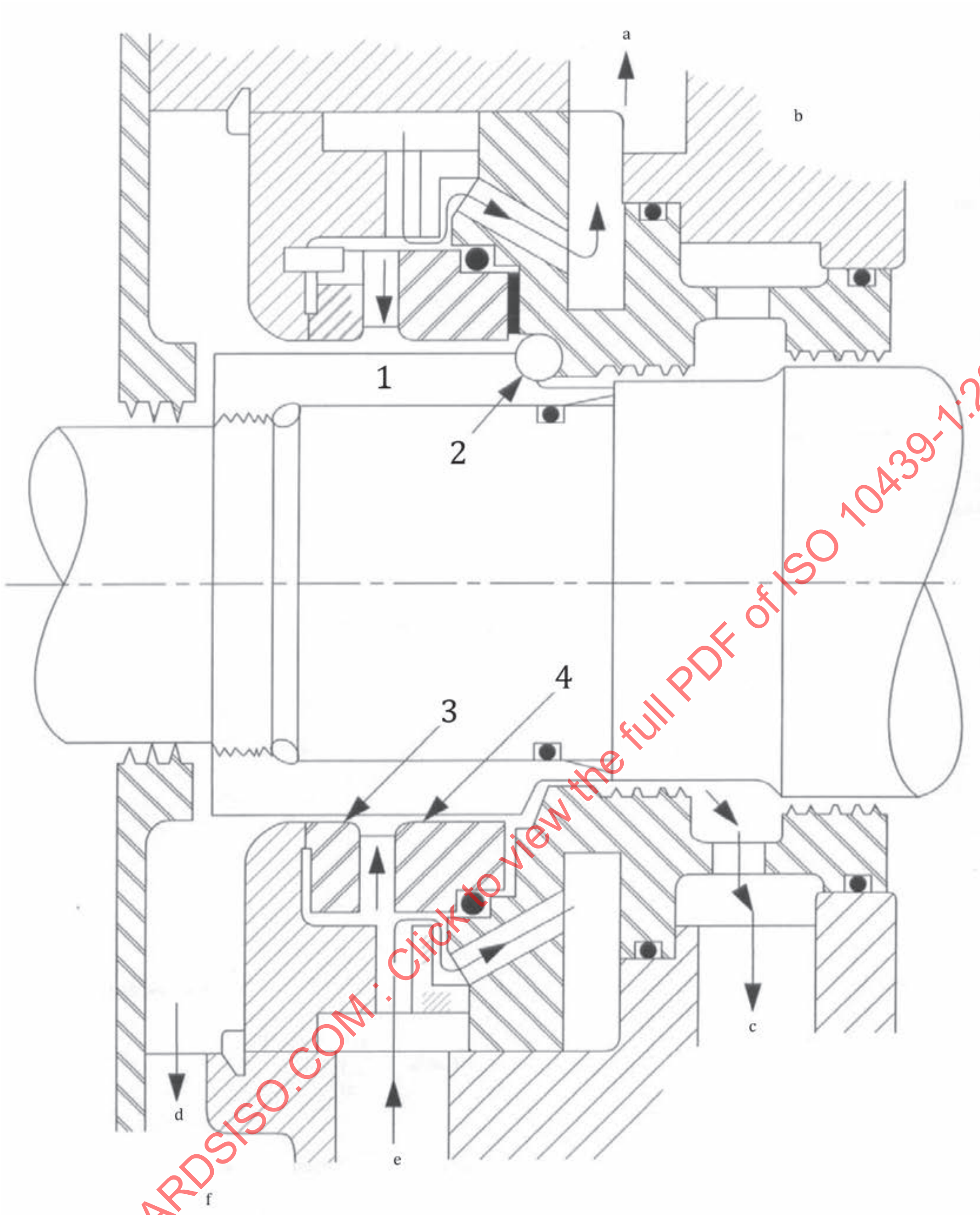
Figure B.3 — Restrictive ring seal



Key

1 inner brushing
2 outer brushing
3 shaft sleeve
a Clean oil in.
b Internal gas pressure.
c Atmosphere.
d Contaminated oil out.
e Oil out.

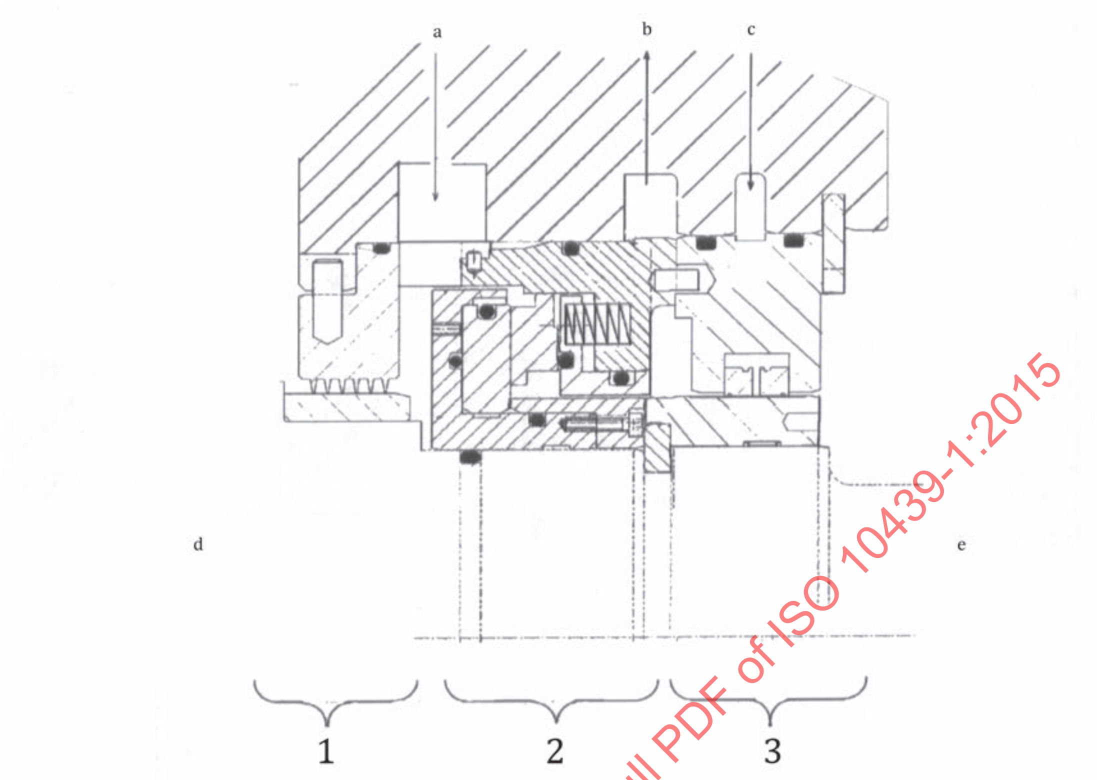
Figure B.4 — Liquid-film (bushing seal)



Key

1 shaft sleeve
2 pumping area
3 outer brushing
4 inner brushing
a Clean oil recirculation.
b Internal gas pressure.
c Contaminated oil out.
d Oil out.
e Clean oil out.
f Atmosphere.

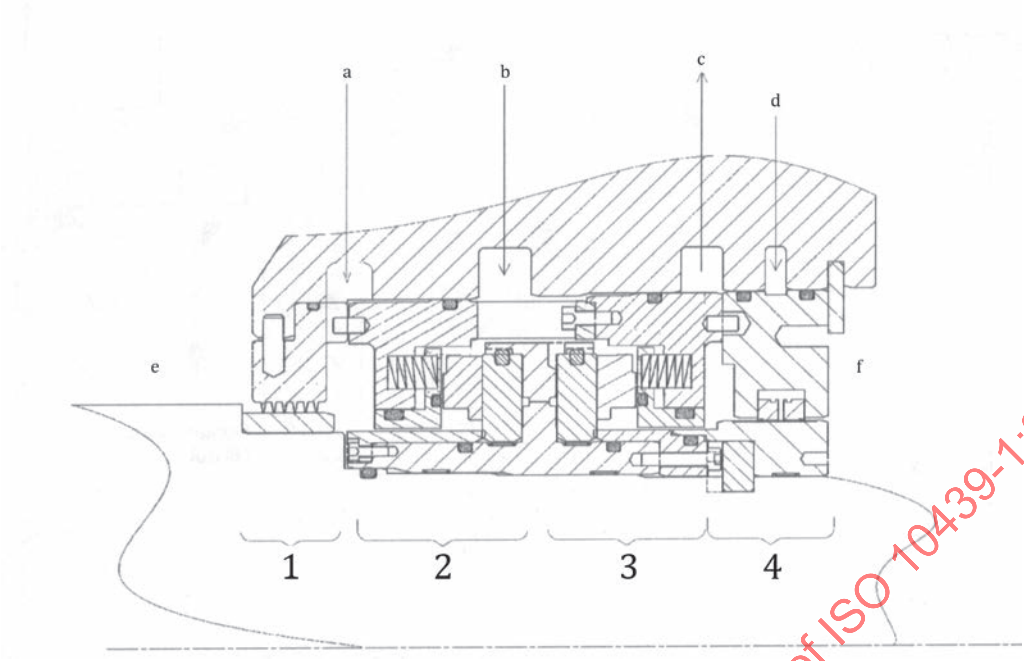
Figure B.5 — Pumping bushing liquid film seal



Key

1 inner seal
2 seal
3 separation seal
a Seal gas supply.
b Seal gas leakage.
c Separation gas.
d Process side.
e Bearing side.

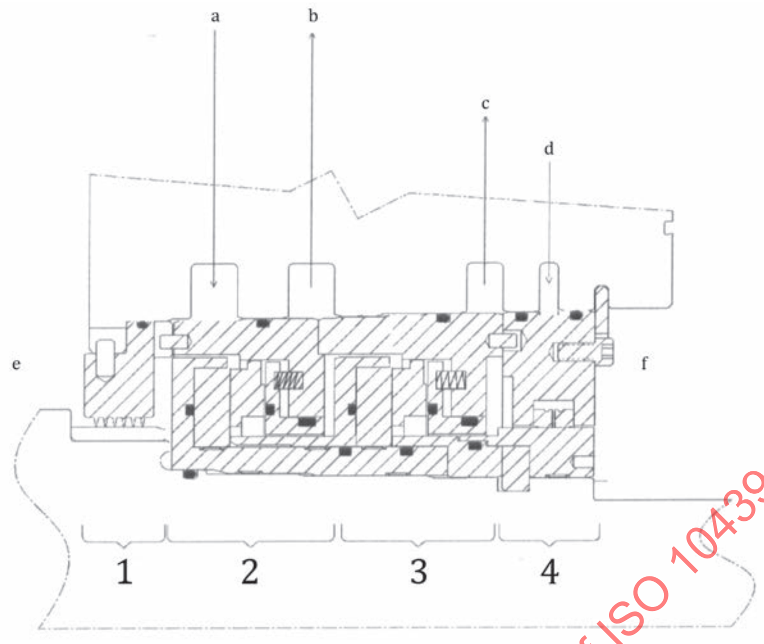
Figure B.6 — Single dry gas seal



Key

1 inner seal
2 inboard seal
3 outboard seal
4 separation seal
a Buffer gas supply.
b Seal gas supply.
c Seal gas leakage.
d Separation gas.
e Process side.
f Bearing side.

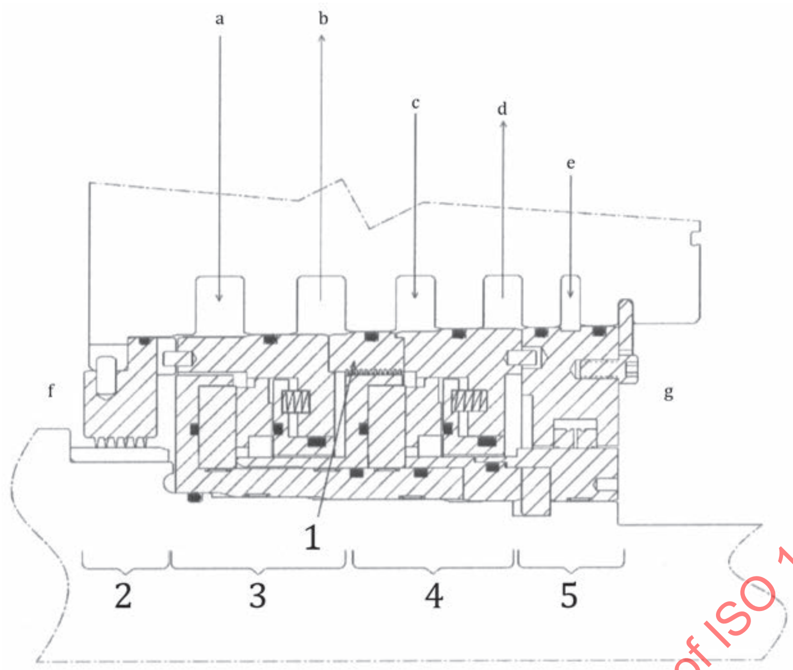
Figure B.7 — Double dry gas seal



Key

1 inner labyrinth
2 primary seal
3 secondary back-up seal
4 separation seal
a Primary seal gas supply.
b Primary seal gas leakage.
c Secondary seal gas leakage.
d Separation gas.
e Process side.
f Bearing side.

Figure B.8 — Tandem dry gas seal



Key

1 intermediate labyrinth
2 inner labyrinth
3 primary seal
4 secondary back-up seal
5 separation seal
a Primary seal gas supply.
b Primary seal gas leakage.
c Secondary seal gas supply.
d Secondary seal gas leakage.
e Separation gas.
f Process side.
g Bearing side.

Figure B.9 — Tandem dry gas seal with intermediate seal gas labyrinth

Annex C
(normative)

Requirements for lateral analysis reports

C.1 Report requirements for standard lateral and stability analyses

The following data shall be provided in the standard lateral analysis and stability report:

a) rotor model:

1) sketch of rotor model;

2) clear identification of bearing, shaft end and internal seals, probe, coupling, and disc (impellers, wheels, etc.) locations;

b) oil film bearings and liquid-film seals data (if present):

1) dynamic coefficients (plot or table) for minimum and maximum stiffness cases versus speed and power;

2) in the Level II Stability analysis, the synchronous and/or non-synchronous coefficients when used by manufacturer;

3) identification of coordinate system including direction of rotation;

4) bearing type, length, pad arc length, diameter, minimum and maximum clearance, offset, number of pads, load geometry, preload and pivot type and geometry;

5) bearing load and direction versus speed and power;

6) oil film seal configuration, length, diameter, minimum and maximum clearance, load geometry, and seal geometry;

7) oil properties and operating conditions:

i) oil viscosity (two temperature data if a non-standard ISO Grade);

ii) oil flow rate and/or inlet pressure;

iii) inlet operating temperature range;

iv) oil specific gravity;

v) seal operating conditions;

c) rolling element bearing data:

1) type and model number;

2) dynamic coefficients versus frequency and speed;

3) bearing loads and preload;

d) bearing pedestal data:

1) identify parameters versus frequency (mass, stiffness, and damping);

e) gas annular seal data:

1) coefficients (when a Level 2 analysis is required) for labyrinth seals, balance piston seal, and/or centre bushing seal;

2) seal type (labyrinth, honeycomb, hole pattern, etc.);

3) teeth on rotor, teeth on stator, or interlocking;

4) seal minimum and maximum operating clearance;

5) presence of shunt holes and/or swirl brakes;

f) squeeze film dampers:

1) dynamic coefficients (plot or table) for clearance extremes versus frequency;

2) state static position and whirl eccentricity assumptions or calculation;

3) identification of coordinate system including direction of whirl;

4) damper type, length, diameter, minimum and maximum clearance, centering device, and end seal type;

5) stiffness values for end seals and centering device (when used);

g) other forces included in the analysis (machine dependent):

1) motor stator magnetic stiffness;

2) volute fluid dynamic forces;

3) gear mesh loads;

NOTE Supplier will typically state force magnitude and basis of calculation.

h) analysis methods:

1) list computer codes used in the analysis with a brief description of the type of code, e.g. finite element, CFD, transfer matrix, etc.;

i) undamped critical speed map and mode shapes:

1) critical speed versus support stiffness;

2) curves of the support stiffness (i.e. Kxx and Kyy for minimum and maximum stiffness, where Kxx is horizontal stiffness and Kyy is vertical stiffness);

3) plot, as a minimum, the first four critical speeds with the stiffness axis extending to “rigid and soft support” regions;

4) show the minimum allowable and maximum continuous speeds;

5) the map shall be displayed as shown in Figure C.1);

6) undamped mode shapes from the rigid, expected, and soft support regions;

7) for machines that do not have similar support stiffness, the critical speed map shall indicate the specified reference bearing and its location; for each of the other bearing locations, the bearing stiffness ratio, relative to the specified reference bearing, shall be defined;

i) the supplier can substitute mode shape plots for the undamped critical speed map and list the undamped critical speeds and the support stiffness for each of the identified modes;

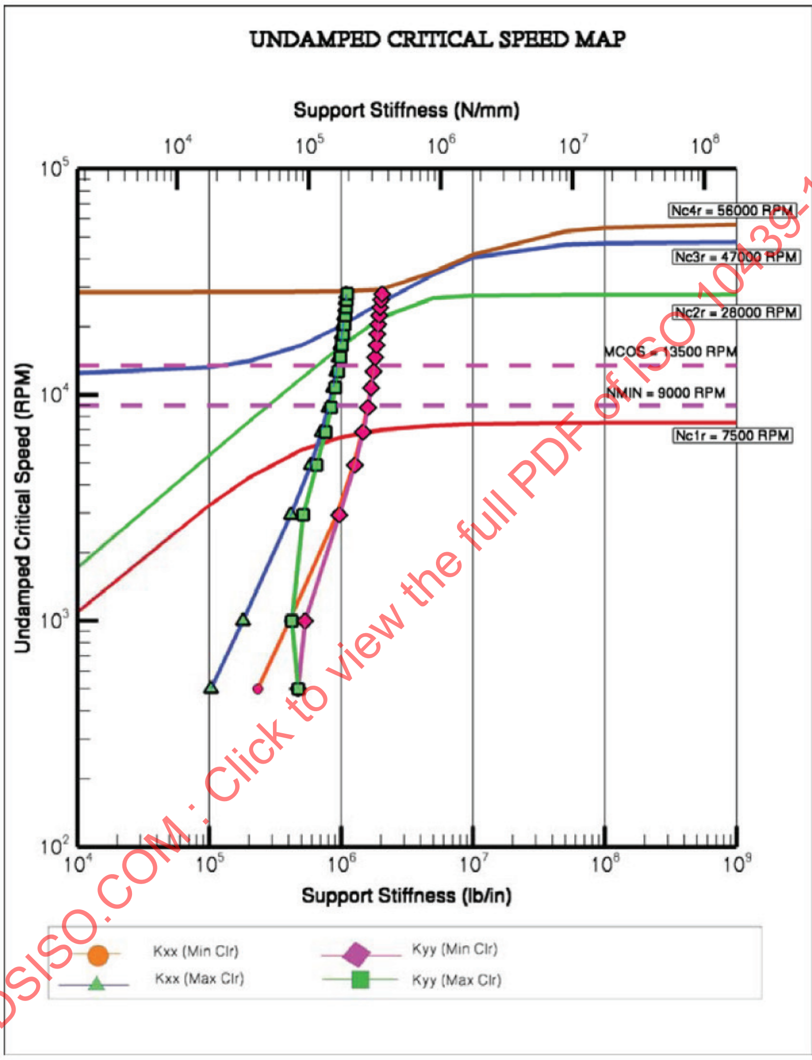


Figure C.1 — Undamped critical speed map

j) unbalance response predictions:

1) identification of the frequency of each critical speed in the range from 0 % to 150 % of N_{mc};

2) frequency, phase, and amplitude (Bode plots) at the vibration probe locations in the range 0 % to 150 % of N_{mc} resulting from the unbalances specified in 4.8.2.7 and 4.8.2.8;

i) if there are no vibration probes near a bearing centreline then the Bode plots shall be shown at the bearing centreline;

ii) minimum allowable and maximum continuous speed shown;

3) tabulation of critical speeds, amplification factor, actual and required separation margin, and scale factor;

4) axial location, amount and phase of unbalance weights for each case;

5) plots of amplitude and phase angle versus speed at probe locations:

i) for minimum and maximum bearing stiffness cases;

ii) pedestal vibration amplitudes for flexible pedestals as defined in 4.8.2.4 d);

6) plots of deflected rotor shape at critical speeds and N_{mc} (for minimum and maximum bearing stiffness cases);

7) a table of the close clearance magnitudes and locations and maximum vibration levels verifying that 4.8.2.11.1 has been met;

k) Level I stability analysis:

1) the calculated anticipated cross coupling, q_a, (for each centrifugal impeller or axial stage), total anticipated cross coupling, Q_A, log dec and damped natural frequency at anticipated cross coupling, and Q_0/Q_A;

2) Figure C.2 plot of log dec versus cross coupled stiffness for minimum and maximum bearing stiffness;

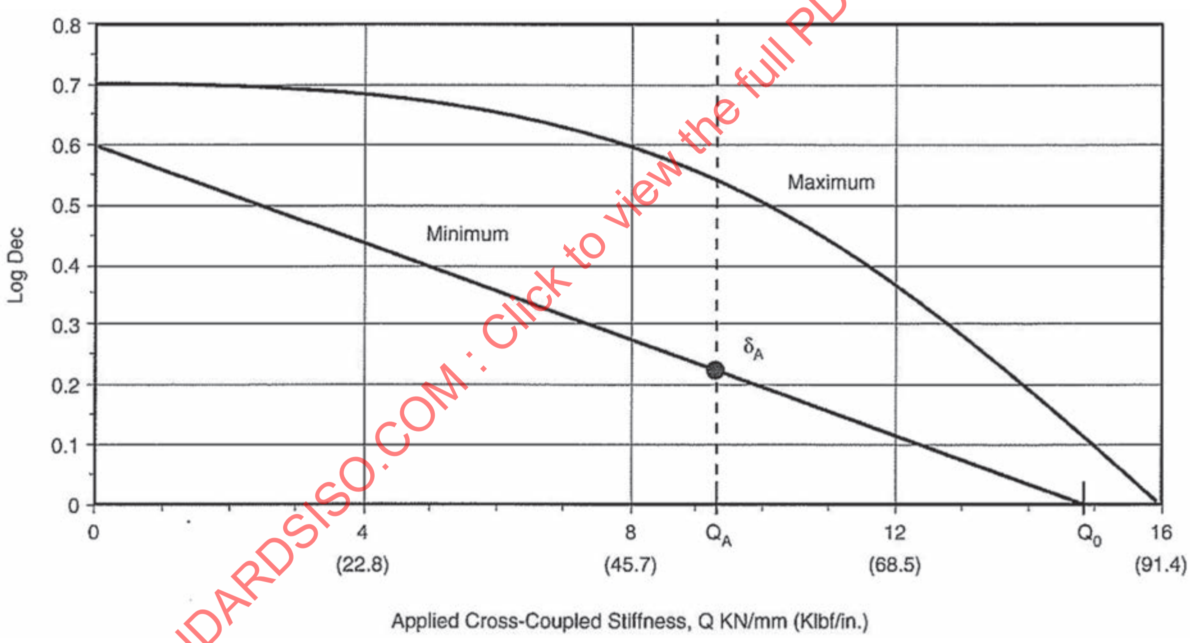


Figure C.2 — Level I stability sensitivity plot

3) Figure C.3 plot of flexibility ratio versus average gas density with application point identified on plot;

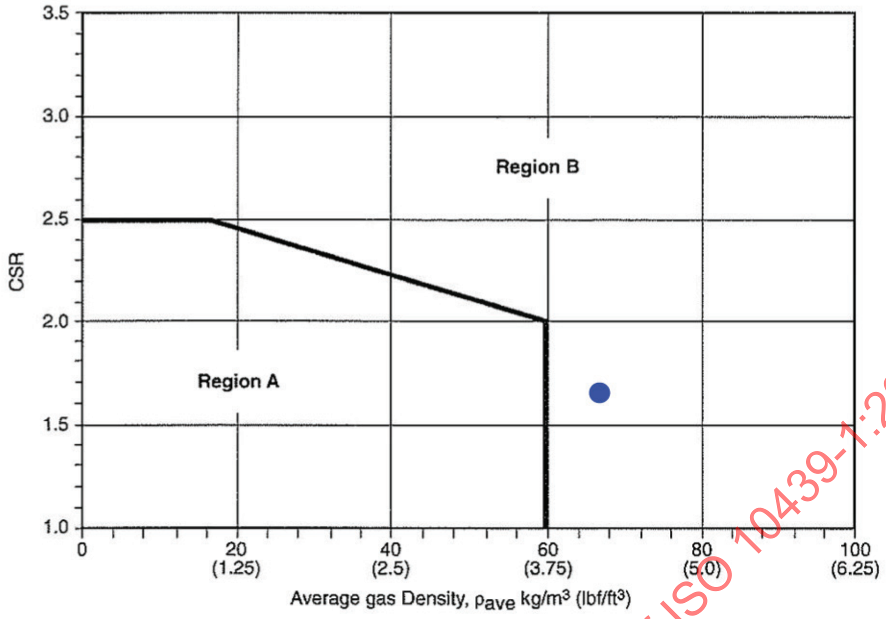


Figure C.3 — Stability experience plot

l) Level II stability analysis:

   1) description of all assumptions used in the analysis;

   2) description of all dynamic effects included in the analysis;

   3) value of log dec and frequency versus component addition for minimum and maximum bearing stiffness, defined in 4.8.6.8;

m) summary sheet that identifies compliance with API requirements.

C.2 Data required to perform independent audits of lateral analysis and stability reports

All of the requirements of C.1 shall be met. This requirement details additional data that shall be provided in conjunction with the Standard Report or as an addendum to it.

a) rotor model:

   1) model tabulation to include rotor geometry (including delineation between stiffness and mass diameter) and external masses with weight, polar, and transverse moments of inertia;

   2) the weight, polar, and transverse moments of inertia and centre of gravity of the impellers, balance piston, shaft end seals, coupling(s) and any other rotating components;

   3) shaft material properties (density and Young's Modulus with temperature dependence);

   4) axial pre-loading due to tie bolts;

5) the magnitude and direction of any additional side loads (gears forces, volutes, etc.) over the full operating range;

b) bearing and liquid-film seal:

1) data to permit independent calculation of bearing coefficients;

i) Table C.1 and Figures C.4 and C.5 indicate geometry required for tilt-pad bearings.

NOTE Similar dimensions are required for fixed pad bearings when used. API 684 can assist in the determination of the dimensions needed.

2) tilt-pad bearing and pivot material;

3) seal dimensional data;

c) internal seals (labyrinth, balance piston seal, wear rings, and centre bushing seal):

1) data to permit independent calculation of seal coefficients:

i) dimensional data;

ii) inlet swirl ratio;

iii) swirl brake type;

iv) clearance assumptions;

v) shunt hole location;

vi) gas conditions and properties at operating speed;

Table C.1 — Tilt-pad bearing dimensions and tolerances

Dimension	Nominal	Tolerance	
		(+)	(-)
Shaft diameter at journal (2*R)			
Pad machined diameter (2*R_p)			
Set bore (2*R_b)			
Pivot location (α)			
Pad arc length (β)			

