

Packaged, Integrally Geared Centrifugal Air Compressors for Petroleum, Chemical, and Gas Industry Services

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Contents

	Page
1 Scope	1
2 Normative References.....	1
3 Terms, Definitions, Acronyms, and Abbreviations	4
3.1 Terms and definitions	4
3.2 Acronyms and Abbreviations	10
4 General	12
4.1 Unit Responsibility	12
4.2 Nomenclature.....	12
5 Requirements.....	12
5.1 Units of measurement.....	12
5.2 Statutory Requirements	12
5.3 Document Requirements	13
6 Basic Design	13
6.1 General	13
6.2 Pressure Casings	18
6.3 Casing Connections	18
6.4 External Forces and Moments	19
6.5 Rotating Elements	20
6.6 Seals and Sealing Systems	21
6.7 Dynamics	21
6.8 Bearings and Bearing Housings	23
6.9 Lubrication	24
6.10 Materials	25
6.11 Nameplates and Rotation Arrows	27
6.12 Additional Basic Design Requirements for Special Duty Packages Only	28
7 Accessories	30
7.1 Drivers.....	30
7.2 Couplings and Guards	31
7.3 Baseplate/Support Structure	33
7.4 Controls and Instrumentation	34
7.5 Piping	41
7.6 Intercoolers and Aftercoolers	42
7.7 Inlet Air Filter	43
7.8 Discharge Blowoff Silencer	43
7.9 Special Tools	43
7.10 Additional Accessories Requirements for “Special Duty” Packages Only	44
8 Inspection, Testing, and Preparation for Shipment.....	45
8.1 General	45
8.2 Inspection.....	46
8.3 Testing	46
8.4 Preparation for Shipment.....	49
8.5 Additional Inspection, Testing, and Preparation for Shipment Requirements for “Special Duty” Packages Only	50
9 Vendor’s Data.....	51
9.1 General	51

Contents

	Page
Annex A (informative) Typical Datasheets.	52
Annex B (informative) Illustrations of Typical Package Mounting Configurations	65
Annex C (normative) Dynamics	68
Annex D (informative) Contract Documents and Engineering Design Data	84
Annex E (informative) Compressor Control—Inlet Throttle Butterfly	96
Annex F (normative) Determination of Residual Imbalance	97
Annex G (normative) Inspector’s Checklist	105
Annex H (informative) Nomenclature for Integrally Geared Centrifugal Air Compressors	108
Annex I (normative) External Forces and Moments	113
Bibliography	114
Figures	
A.1 Typical Datasheets for Centrifugal Air Compressors	53
B.1 Package with Full Drain-rim Base	65
B.2 Package with Open-channel Structural Base	65
B.3 Package with Foot Mounted Base.	66
B.4 Package with Base Integral with Casing	66
B.5 Package with Split Base (Separate Exchanger Skid)	67
B.6 Package with Three-point Spherical Bearings Supports	67
C.1 Undamped Critical Speed Map	69
C.2 Mode Shapes	71
C.3 Unbalance Placement and Mode Shapes for Overhung Machines	72
C.4 Typical Rotor Response Plot	73
C.5 Plot of Applicable Speed Range of Vibration Limit	74
C.6 Level 1 Stability Sensitivity Plot	79
C.7 Stability Experience Plot	79
D.1 VDDR for Packaged, Integrally Geared Centrifugal Air Compressors	89
D.2 Description of VDDR	91
E.1 Typical Performance Curve Showing BFV vs IGV Control	96
F.1 (Blank) Residual Unbalance Work Sheet	99
F.2 (Blank) Residual Unbalance Polar Plot Work Sheet	100
F.3 Sample Residual Unbalance Work Sheet for Left Plane	101
F.4 Sample Residual Unbalance Polar Plot Work Sheet for Left Plane	102
F.5 Sample Residual Unbalance Work Sheet for Right Plane	103
F.6 Sample Residual Unbalance Polar Plot Work Sheet for Right Plan	104
G.1 Inspector’s Checklist	105
H.1 Section of Axially (horizontally) Split Compressor	108
H.2 Section of Radially Split Compressor	109
H.3 Nomenclature of Package Components, Part 1	110
H.4 Nomenclature of Package Components, Part 2	111
H.5 Nomenclature of Package Components, Part 3	112

Contents

	Page
Tables	
1	Equipment Monitoring 39
D.1	VDDR for Packaged, Integrally Geared Centrifugal Air Compressors..... 90
D.2	VDDR for Packaged, Integrally Geared Centrifugal Air Compressors..... 92
G.1	Inspector’s Checklist..... 106

Introduction

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

Annex A contains data sheets which purchasers are encouraged to use.

Annex B contains illustrations of typical mounting configurations.

Annex C specifies requirements for lateral analysis.

Annex D contains forms which may be used to indicate vendor drawing and data requirements.

Annex E shows the impact for inlet throttle control vs inlet guide vanes.

Annex F specifies requirements for determining residual unbalance.

Annex G contains an inspector's checklist.

Annex H contains illustrations of nomenclature for integrally geared centrifugal air compressors.

Annex I contains information relative to allowable nozzle loads from purchaser's piping.

This standard requires the purchaser to specify certain details and features. A bullet (•) at the beginning of a paragraph indicates that either a decision by, or further information from, the purchaser is required. Further information should be shown on the data sheets (see example in Annex A) or stated in the quotation request and purchase order.

In this standard, U.S. customary units (USC) are included in brackets for information.

Packaged, Integrally Geared Centrifugal Air Compressors for Petroleum, Chemical, and Gas Industry Services

1 Scope

1.1 This standard covers the minimum requirements for constant-speed, packaged, general purpose, integrally-geared centrifugal air compressors, including their accessories for use in the petroleum, chemical, and gas industry services. This standard is not applicable to machines that develop a pressure rise of less than 0.35 bar (5.0 psi) above atmospheric pressure, which are classed as fans or blowers.

NOTE Special purpose and process applications, including Process Air Services, are covered by API 617.

- **1.2** Equipment covered by this standard is considered non-critical, usually spared and may be either of two classifications, basic or special duty. The purchaser shall specify which of the two classifications applies.

Basic packages are vendors' standard packages of proven design, and include minimal additional requirements.

Special duty packages are typically specified for installations that require higher availability, and include additional features and requirements.

1.3 Additional or overriding requirements applicable only to packages that have been specified as "Special Duty" are noted at the end of each section (see 6.12, 7.10, 8.5, D.2.5, and D.3.5.5).

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) available at the agreed time, applies. Standards referenced in the documents are undated but refer to the specific editions referenced in this section.

ANSI/API Standard 541, Form-Wound Squirrel Cage Induction Motors—500 Horsepower and Larger

ANSI/API Standard 546, Brushless Synchronous Machines—500 kVA and Larger

API Standard 547, General-purpose Form-wound Squirrel Cage Induction Motors 250 Horsepower and Larger

API Standard 611, General-purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services

API Standard 614, Lubrication, Shaft-sealing, and Control-oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services

ANSI/API Standard 670, Machinery Protection Systems

AGMA 6011 ¹, Specification for High Speed Helical Gear Units

AGMA 9000-C90, Flexible Couplings—Potential Unbalance Classification

AGMA 9002-B04, Bores and Keyways for Flexible Couplings (Inch Series)

ASME B1.1 ², Unified Inch Screw Threads (UN and UNR Thread Form)

¹ American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia, 22314, www.agma.org.

² ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.

ASME B1.3, *Screw Thread Gaging Systems for Acceptability: Inch and Metric Screw Threads (UN, UNRm UNJ, M, MJ)*

ASME B1.13M, *Metric Screw Threads: M Profile*

ASME B16.1, *Cast Iron Pipe Flanges and Flanged Fittings Classes 125 and 250*

ASME B16.5, *Pipe Flanges and Flanged Fittings NPS 1/2 Through NPS 24 Addenda A*

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 Addenda A*

ASME B17.1, *Keys and Keyseats*

ASME B31.3, *Process Piping*

ASME, *Boiler and Pressure Vessel Code (BPVC)*

— Section VIII, *Division 1: Rules for Construction of Pressure Vessels*

— Section IX, *Welding and Brazing Qualifications*

ASME PTC-10, *Performance Test Code on Compressors and Exhausters*

ASTM A193/A193M³, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194/A194M, *Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

ASTM A275/A275M, *Standard Test Method for Magnetic Particle Examination of Steel Forgings*

ASTM A395/A395M, *Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*

ASTM A515/A515M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A536, *Standard Specification for Ductile Iron Castings*

ASTM B111/B111M, *Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock*

ASTM D4304, *Standard Specification for Mineral and Synthetic Lubricating Oil used in Steam or Gas Turbines*

ASTM D5445-05, *Standard Practice for Pictorial Markings for Handling of Good*

ASTM E94, *Standard Guide for Radiographic Examination*

³ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM E186, *Standard Reference Radiographs for Heavy-Walled (2 to 4 1/2-in. (51 to 114-mm) Steel Castings*

ASTM E446, *Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness*

AWS D1.1/D1.1M ⁴, *Structural Welding Code—Steel Errata*

ANSI/B11 Standards B11.19-2010 ⁵, *Performance Criteria for Safeguarding*

EN 953 ⁶, *Safety of machinery—Guards—General requirements for the design and construction of fixed and movable guards*

European Union ATEX Directive 94/9/EC ⁷

IEC 60079 (all parts) ⁸, *Electrical apparatus for explosive atmospheres*

IEEE 841 ⁹, *Standard for Petroleum and Chemical Industry-Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors-Up to and Including 370 kW (500 hp)*

ISA S12.4 ¹⁰, *Instrument Purging for Reduction of Hazardous Area*

ISO 7-1:1994 ¹¹, *Pipe threads where pressure-tight joints are made on the threads*

ISO 261:1998, *ISO General Purpose Metric Screw Threads—General Plan Second Edition*

ISO 1328-1, *Cylindrical Gears-ISO System of Accuracy—Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth*

ISO 1940-1, *Mechanical vibration—Balance quality requirements for rotors in a constant (rigid) state—Part 1: Specification and verification of balance tolerances*

ISO 3117:1977, *Tangential Keys and Keyways*

ISO 3448:1992, *Industrial Liquid Lubricants—ISO Viscosity Classification Second Edition*

ISO 5389, *Turbocompressors—Performance Test Code*

ISO 6708, *Pipework Components—Definition and Selection of DN (Nominal Size) Second Edition*

ISO 8068:2006, *Lubricants, industrial oils and related products (class L)—Family T (Turbines)—Specification for lubricating oils for turbines*

ISO 8501, *Preparation of Steel Substrates Before Application of Paints and Related Products—Visual Assessment of Surface Cleanliness*

⁴ American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.

⁵ B11 Standards Inc., P.O. Box 690905, Houston, Texas 77269

⁶ European Committee for Standardization, Avenue Marnix 17, B-1000 Brussels, Belgium, www.cen.eu.

⁷ European Parliament and the Council, Rue de la Loi, 175 B-1048, Brussels, Belgium

⁸ International Electrotechnical Commission, 3 rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

⁹ International Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854

¹⁰ International Society for Automation, 67 T. W. Alexander Drive, Research Triangle Park, NC 237709

¹¹ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 8821:1989, *Mechanical Vibration—Balancing—Shaft and Fitment Key Convention*

ISO 9606-1:2012, *Qualification testing of welders—Fusion welding—Part 1: Steels*

ISO 14120, *Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards*

ISO 15607:2005, *Specification and qualification of welding procedures for metallic materials—General rules*

MSS SP-55¹², *Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

NEC Article 110¹³, *Requirements for Electrical Installations*

NEMA SM23, *Steam Turbines for Mechanical Drive Service*

NEMA 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

NFPA 70¹⁴, *National Electrical Code*

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*

SSPC SP6¹⁵, *Commercial Blast Cleaning NACE No. 3-2000 (Steel Structures Painting Manual, Chapter 2—Surface Preparation Specifications)*

TEMA¹⁶, *TEMA Book of Standards*, Ninth Edition

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and definitions

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

3.1.1

alarm point

Preset value of a measured parameter at which an alarm is actuated to warn of a condition that requires corrective action.

3.1.2

anchor bolts

Bolts used to attach the equipment to the support structure (concrete foundation or steel structure).

cf. hold-down bolt (3.1.15).

3.1.3

approve

Written documentation confirming an agreement.

¹² Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, www.mss-hq.com.

¹³ National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.

¹⁴ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

¹⁵ The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.

¹⁶ Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, New York 10591

3.1.4**axially split joint**

Joint split with the principal face parallel to the shaft centerline.

3.1.5**bearing housing**

All bearing enclosures, including the gear casing.

3.1.6**Birmingham wire gauge****BWG**

Standard series of sizes arbitrarily indicated by numbers, used in specifying and describing the thickness of sheet metal.

3.1.7**certified point**

Point to which the performance tolerances will be applied.

NOTE This is usually the normal operating point and the vendor will normally require that this point is within the preferred selection range.

3.1.8**commercial fastener**

Fastener manufactured to published consensus standards and stocked by manufacturers or distributors.

3.1.9**critical speed**

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

3.1.10**delivered flow****free air delivered****FAD**

Flow rate determined at the discharge of the aftercooler, or at the compressor discharge if an aftercooler is not provided.

3.1.11**design**

Manufacturer's calculated parameter.

NOTE A term that is typically 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.

3.1.12**gear service factor (SF)**

Factor that is applied to the tooth pitting index and the bending stress number, depending on the characteristics of the driver and the driven equipment, to account for differences in potential overload, shock load, or continuous oscillatory torque characteristics, or a combination thereof.

3.1.13**gear wheel****bull gear**

Low-speed rotor of a gear set.

3.1.14 **general purpose application**

Application that is usually spared or is in non-critical service.

3.1.15 **hold down bolts** **mounting bolts**

Bolts holding the equipment to the mounting plate.

3.1.16 **hydrodynamic bearings**

Bearings that use the principles of hydrodynamic lubrication.

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

3.1.17 **informative**

Information only.

cf normative (3.1.27).

NOTE An informative reference or Annex provides advisory or explanatory information. It is intended to assist the understanding or use of the document.

3.1.18 **inlet volume flow**

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

NOTE Inlet volume flow is a specific example of Actual Volume Flow. Actual Volume Flow is the volume flow at any particular location such as interstage, impeller inlet, discharge or compressor discharge.

3.1.19 **local**

Position of devices on or near the equipment or console.

3.1.20 **material certificate of compliance**

Document by which the vendor certifies that the material represented has been produced and tested in accordance with the requirements of the basic material specification shown on the certificate.

3.1.21 **maximum allowable temperature** **MAT**

Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating pressure (not at the MAWP).

3.1.22 **maximum allowable working pressure** **MAWP**

Maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating temperature (not at the MAT).

3.1.23**maximum discharge pressure**

Maximum suction pressure plus the maximum differential pressure the compressor is able to develop, when operating with the furnished impeller(s) and the fluid with the maximum density.

NOTE Refer to 3.1.25 for the definition of maximum suction pressure.

3.1.24**maximum sealing pressure**

Highest pressure the seals are required to seal during any specified static or operating condition.

3.1.25**maximum suction pressure**

Highest suction pressure the compressor will be subject to in service.

3.1.26**mounting plate**

Device used to attach equipment to foundations; this is either a baseplate or soleplate.

3.1.27**normative**

Required.

cf informative (3.1.17)

NOTE A normative reference or annex enumerates a requirement or mandate of the specification.

3.1.28**NPS****nominal pipe size**

Dimensionless value approximately equal to the diameter in inches.

EXAMPLE NPS $\frac{3}{4}$.

3.1.29**NPT****American National Standard Pipe Taper**

Thread form designation for pipe threads.

EXAMPLE $\frac{3}{4}$ -14 NPT.

NOTE It is comprised of a number representing nominal pipe size followed by the number of threads per inch and the letters NPT representing the thread series.

3.1.30**observed**

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.

3.1.31**operating stability**

Operating range from the compressor rated point to surge at constant speed expressed as a percentage.

3.1.32**owner**

Final recipient of the equipment who may delegate another agent as the purchaser of the equipment.

3.1.33**panel**

Enclosure used to mount, display and protect gauges, switches, and other instruments.

3.1.34**pinion**

High-speed rotor(s) in a gear set.

3.1.35**PMI****positive material identification testing**

Physical evaluation or test of a material to confirm that the material is consistent with the selected or specified alloy material designated.

NOTE Typically this is only a consideration for high-alloy materials.

3.1.36**pressure casing**

Composite of all stationary pressure containing parts of the unit, including all nozzles and other attached parts.

3.1.37**pressure rise to surge**

Difference between the discharge pressure at the rated operating point and discharge pressure at the surge point when the unit is operating at rated inlet conditions, and with a constant inlet guide vane position.

3.1.38**purchaser**

Agency that issues the order and specification to the vendor.

NOTE The purchaser is sometimes the owner of the plant in which the equipment is to be installed, but is often the owner's appointed agent.

3.1.39**radially split**

Split with the joint perpendicular to the shaft centerline.

3.1.40**rated point**

Maximum specified flow rate at the specified discharge pressure when operating at the specified inlet conditions and coolant temperature.

3.1.41**rated speed****100 % speed**

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

3.1.42**relief valve set pressure**

Pressure at which a relief valve starts to lift.

3.1.43**remote**

Location of a device when located away from the equipment or console, typically in a control room.

3.1.44**shutdown set point**

Preset value of a measured parameter at which automatic or manual shutdown of the system or equipment is required.

3.1.45**soleplate**

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

3.1.46**special tool**

Tool which is not a commercially available catalog item.

3.1.47**standard volume flow**

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

ISO Standard Conditions

Flow:	Cubic meters per hour (m ³ /h) Cubic meters per minute (m ³ /min)
Pressure:	(01.3 kpa (1.013 bar(a))
Temperature:	15 °C
Relative Humidity:	Dry

U.S. Standard Conditions

Flow:	Standard cubic feet per minute (scfm) Million standard cubic feet per day (mmscfd)
Pressure:	14.7 PSI(a)
Temperature:	60 °F
Relative Humidity:	Dry

3.1.48**standby**

Service state in which a piece of equipment is normally idle or idling and is capable of immediate automatic or manual start-up for continuous operation.

3.1.49**surge**

Volume flow capacity below which a centrifugal compressor becomes aerodynamically unstable.

3.1.50**TIR****total indicator reading****total indicated 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 For a cylindrical surface, the indicated runout implies an eccentricity equal to half the reading. For a flat face, the indicated runout implies an out-of squareness equal to the reading. If the measured surface in question is not cylindrical or flat, the interpretation of the meaning of TIR is more complex, and can represent orality or surface irregularities.

3.1.51

trip speed

Electric motor driver speed (revolutions per minute) corresponding to the synchronous speed of the motor at maximum supply frequency at the motor terminals.

3.1.52

trip speed

Steam turbine driver speed at which the independent emergency overspeed device operates to shut down the driver.

3.1.53

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.

3.1.54

Ultimate load rating

Load that will produce the minimum acceptable oil film thickness without inducing failure during continuous service ,or the load that will 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.

3.1.55

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.

3.1.56

vendor supplier

Manufacturer or manufacturer's agent that supplies the equipment.

3.1.57

verified

Purchaser's review and acceptance of vendor's certification or documentation of successful completion of the inspection or test.

3.1.58

witnessed

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 Acronyms and Abbreviations

ABMA	American Bearing Manufacturers Association
AC	alternating current
AENOR	Spanish Association for Standardization and Certification
AF	amplification factor
ANSI	American National Standards Institute
API	American Petroleum Institute

ASME	American Society of Mechanical Engineers
BPVC	<i>Boiler and Pressure Vessel Code</i>
PTC	power test code
ASTM	American Society for Testing and Materials
ATEX	ATmospheres EXplosives
AWS	American Welding Society
B11	B11 Standards Inc.
BFV	butterfly valve
BSI	British Standards Institute
BTH	below the hook
BWG	Birmingham wire gauge
CEN	European Committee for Standardization
cf	(Latin conferre) confer or compare—cross reference
CSA	Canadian Standards Association
DBSE	distance between shaft ends
DC	direct current
DCS	distributed control system
DIN	Deutsches Institut für Normung
DN	nominal diameter
EEA	European Economic Area
EN	European normal standard
ES	extended surface
EU	European Union
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGV	inlet guide vanes
IP	ingress protection
IPF	instrumented protective functions
ISO	International Organization for Standardization
MAWP	maximum allowable working pressure
MDMT	minimum design metal temperature
MSS	Manufacturers Standardization Society
NACE	National Association of Corrosion Engineers
NDT	nondestructive testing
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPS	nominal pipe size
PLC	programmable logic controller
PMI	positive material identification

Ra	arithmetic average roughness
RF	radio frequency
RTD	resistance temperature detector
SI	international system of units
SPL	sound pressure level
SSPC	Society for Protective Coatings
TC	thermocouple
TEMA	Tubular Exchanger Manufacturers Association
UN	United Nations
UNC	unified thread—course
UNF	unified thread—fine
UNRC	unified thread—rolled course
UNS	unified numbering system
USC	U.S. customary units
VDDR	vendor drawing and data requirements

4 General

4.1 Unit Responsibility

4.1.1 The compressor vendor shall assume unit responsibility for all equipment and auxiliary systems included in the scope of the order, and shall ensure that all sub-vendors comply with the requirements of this standard and all reference documents.

4.1.2 The technical aspects to be considered by the compressor vendor include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications and testing of components.

4.2 Nomenclature

Informative guides to integrally-gear air compressor nomenclature can be found in Annex B and Annex H.

5 Requirements

• 5.1 Units of measurement

The purchaser will specify whether data and drawings, supplied to this standard shall use the SI or USC system of measurements.

NOTE Dedicated data sheets for SI units and for USC are provided in Annex A.

5.2 Statutory Requirements

The purchaser and the compressor vendor 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.

Equipment installed in the European Economic Area (EEA) shall comply with all applicable European Union Directives.

NOTE The European Economic Area in 2013 includes the countries of the European Union plus Norway, Iceland and Liechtenstein.

• 5.3 Document Requirements

The hierarchy of documents shall be specified by the purchaser.

NOTE Typical documents include company and industry specifications, meeting notes, and modifications to these documents.

6 Basic Design

6.1 General

6.1.1 Equipment Reliability

6.1.1.1 Only equipment that is considered field proven is acceptable.

NOTE Purchasers can use their engineering judgment in determining what equipment is field proven.

- 6.1.1.2 If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed is “field proven”.

6.1.1.3 In the event no such unit is available, the vendor shall submit an explanation of how their proposed equipment can be considered field proven.

NOTE A possible explanation can be that all components comprising the assembled machine satisfy the field proven definition.

- 6.1.1.4 If specified, an installation/reference list shall be submitted for the proposed compressor model noting analogous operating conditions.

6.1.1.5 Purchaser shall specify the period of required uninterrupted continuous operation. Shutting down the equipment to perform planned maintenance or inspection during the specified uninterrupted operation is not acceptable.

NOTE 1 It is realized that there are some services where this objective is easily attainable and others where it is difficult.

NOTE 2 Auxiliary system design and design of the process in which the equipment is installed are very important in meeting this objective.

NOTE 3 Paragraph D.2.3.1k requires the vendor to identify any component or maintenance requirement that would result in the need to shut down the equipment within the uninterrupted operational period.

6.1.1.6 Vendor shall advise in the proposal any component designed for finite life.

NOTE It is recognized that these are design criteria.

6.1.2 Operating Conditions

- 6.1.2.1 The purchaser shall specify all operating conditions as well as the certified point.
- 6.1.2.2 In the specification of operating conditions, either a realistic relative humidity at rated conditions or the maximum operating inlet temperature related dew point shall be specified.

NOTE 1 A relative humidity of 100 % does not occur at the maximum operating inlet temperature, but rather only after the temperature has dropped substantially. Dew point higher than 92 °F (33 °C) seldom occurs anywhere.

NOTE 2 Volume flow increases to account for overstated moisture content can result in oversized equipment and compromised performance.

6.1.2.3 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, settle-out, trip, and startup.

6.1.3 Sound Pressure Level

- **6.1.3.1** Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor having unit responsibility. The equipment furnished by the vendor shall conform to the maximum allowable sound pressure level specified. In order to determine compliance, the vendor shall provide expected values for maximum sound pressure level data per octave band for the equipment in steady state operation. ISO 3740, ISO 3744 and ISO 3746 or ASME PTC 36, may be consulted for guidance.

6.1.3.2 The vendor shall indicate what special silencing measures, if any, are proposed in order to meet the specified levels.

6.1.3.3 If noise enclosures are supplied, the enclosure design shall ensure full access to the equipment for operational and maintenance purposes. The design of the enclosure shall not obstruct any required cooling of the equipment. The final enclosure design shall be agreed by purchaser and vendor.

6.1.4 Packaged Equipment

The final scope of the package and supply of any loose shipped components shall be agreed between the purchaser and the vendor. Pending agreement, the default shall be that the compressor package shall be supplied fully assembled, and shall include:

- a) integrally geared centrifugal air compressor;
- b) coupling and coupling guard;
- c) baseplate (or structural framework);
- d) intercoolers, moisture separators (if required), drain system, and aftercooler;
- e) lubrication oil system;
- f) instrumentation;
- g) unit control panel;
- h) driver;
- i) inlet air filter;
- j) inlet throttle device (suction throttle valve or inlet guide vanes);
- k) interstage air piping;
- l) discharge blowoff valve;
- m) discharge blowoff silencer;
- n) discharge check valve;

- o) inlet and discharge expansion joints;
- p) other accessories as noted in this standard.

NOTE Inlet piping from air inlet filter to compressor inlet control device, discharge piping between compressor package flange and discharge check valve, piping to blowoff valve, and mounting of accessory components is typically supplied by the purchaser. The aftercooler is often shipped loose. The blowoff valve and discharge check valve are typically shipped loose for field installation by the purchaser.

• 6.1.5 Environmental Conditions

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

6.1.6 Cooling Water Systems

Unless otherwise specified, cooling water system or systems shall be designed for the following conditions:

Water Velocity over heat exchange surfaces	1.5 to 2.5 m/s	5 to 8 ft/s
Maximum allowable working pressure (MAWP)	≥ 700 kPa (7 bar)	≥ 100 psig
Test Pressure (≥ 1.5 MAWP)	≥ 1050 kPa (10.5 bar)	≥ 150 psig
Maximum pressure drop	≥ 100 kPa (1 bar)	15 psi
Maximum inlet temperature	30 °C	90 °F
Maximum outlet temperature	50 °C	120 °F
Maximum temperature rise	20 °C	30 °F
Minimum temperature rise	10 °C	20 °F
Water side fouling factor	0.18 m ² K /kW	0.001 hr-ft ² - °F/Btu
Corrosion allowance for carbon steel shells	1.5 mm	¹ / ₁₆ in.

The vendor shall notify the purchaser if the criteria for minimum temperature rise, and velocity over heat exchanger surfaces result in conflict. The criterion for velocity over heat exchange surfaces is intended to minimize water-side fouling; the criterion for minimum temperature rise is intended to minimize the use of cooling water. If such a conflict exists, the purchaser shall approve the final selection.

NOTE Based on site coolant conditions and user experience, the purchaser will sometimes specify a different coolant-side fouling factor. For example, for a closed loop glycol system, 0.0005 hrft² °F/Btu is usually adequate; conversely, for poorer quality coolant, 0.002 hrft² °F/Btu (or higher) can be prudent.

6.1.7 Package Arrangement

6.1.7.1 The arrangement of the package (including piping coolers, pumps, and controls) shall provide adequate clearance areas and safe access for operation and maintenance.

6.1.7.2 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 shoulders, cylindrical dowels, or keys.

6.1.7.3 Provisions shall be made for complete venting and draining of liquid-filled systems.

6.1.7.4 All utility and auxiliary customer piping connections are to be located as near as possible to the edge of the skid.

NOTE The intent is to allow clear and easy access to customer connections.

6.1.8 Motors and Electrical Components

- **6.1.8.1** Motors, 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 the applicable sections of specified standards such as IEC60079 or NFPA 70 (NEC), Articles 500, 501, 502, 504 and 505, as well as local codes. Purchaser will advise on applicability of European Union (EU) ATEX Directive 94/9/EC.

6.1.8.2 Locations for installed equipment can be classified as hazardous electrical areas or they can be unclassified. An unclassified area is considered non-hazardous; therefore, motors, electrical instrumentation, equipment, components, and electrical installations for unclassified areas are not governed by hazardous area electrical codes.

6.1.8.3 If an installation location is classified as hazardous, motors, electrical instrumentation, equipment, components, and electrical installations shall be suitable for the hazardous electrical area classification designation specified.

- **6.1.8.4** All applicable electrical codes shall be specified. Local electrical codes that apply shall be provided by the purchaser upon request.

6.1.9 Performance Criteria

6.1.9.1 The equipment (compressor, driver and ancillary equipment) shall perform on the test stand(s) and on their permanent foundation within the specified acceptance criteria. After installation, the performance of the package shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

6.1.9.2 The compressor total head curve shall be developed from the differential pressure measurement between the compressor inlet flange and the compressor final-stage discharge flange. The purchaser and vendor shall agree on the pressure drop considerations for the inlet filter, aftercooler, check valves, and associated piping.

6.1.9.3 At rated operating conditions, the overall performance shall provide a minimum of 10 % continuous pressure rise from rated capacity to surge.

6.1.10 Purchaser Connections

All openings or nozzles for purchaser connections shall be DN 12 ($1/2$ NPS) or larger and shall be in accordance with ISO 6708. Sizes DN 32, DN 65, DN 90, DN 125, DN 175 and DN 225 ($1\ 1/4$, $2\ 1/2$, $3\ 1/2$, 5, 7, and 9 NPS) shall not be used.

6.1.11 Bolting and threads

- **6.1.11.1** The threading shall conform to ASME B1.1, ASME B1.13M, or ISO 261 as specified.

NOTE 1 ASME B 1.1 covers general inch series screw threads, ASME B1.13M and ISO 261 covers general metric screw threads.

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

Glossary of terms for screw threads can be found in ASME B 18.12-2001.

6.1.11.1.1 If ASME B1.1 threads have been specified, the thread series shall be variable pitch series UNC or UNRC, or constant pitch series 4, 6, or 8-UN or UNR. Diameters shall be selected from Table 2 Column 1 of ASME B 1.1. The threads shall be Class 2 for bolting, studs and nuts. For other threads and nuts they shall be Class 2 or 3.

In order to prevent galling, when ASME B 1.1 Class 3 external threads are used, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

6.1.11.1.2 If ISO 261 has been specified, the thread series shall be coarse or 3, 4, 6 or 8 pitch. Diameters shall be selected from Table 2, Column 1 of ISO 261. The threads shall be Class 6g for bolting and studs, and Class 6H for nuts. For other threads, they shall be Class 6g or 4h for external threads, and Class 6H or 5H for internal threads.

In order to prevent galling, when ISO class h/H position is specified for mating components, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

6.1.11.2 Type J profile threads shall not be used.

6.1.11.3 Thread gaging shall meet requirements of 6.1.11.3.1 through 6.1.11.3.3.

6.1.11.3.1 Inspection or gaging requirements of threads shall be identified in accordance with ASME B 1.1, 1989, *Section 6—Screw Thread Designation*.

6.1.11.3.2 All threaded products shall be visually inspected for gross defects. This visual inspection shall be made without magnification and is intended to detect such gross defects as missing or incomplete threads, defective thread profile, torn or ruptured surfaces and cracks, etc.

6.1.11.3.3 Threads used in joining casing pressure containing components shall be inspected in accordance with 6.1.11.3.3.1 or 6.1.11.3.3.2.

6.1.11.3.3.1 Commercial fasteners shall be manufactured in accordance with the requirements of ASME B 18.18.2M or shall be procured from distributors having quality plans in accordance with ASME B 18.18.2M.

6.1.11.3.3.2 All threads used on non-commercial fasteners shall be manufactured in accordance with ASME B1.3M-1986 thread gaging system 21 using GO, NO-GO gaging.

6.1.11.4 Adequate clearance shall be provided at all bolting locations to permit the use of socket, box or hex key wrenches.

6.1.11.5 Slotted-nut or spanner-type bolting shall not be used unless specifically approved by the purchaser.

6.1.11.6 Manufacturer's marking shall be located on all fasteners 6 mm ($\frac{1}{4}$ in.) and larger (excluding washers and headless set screws). For studs, the marking shall be on the nut end of the exposed stud end.

NOTE A set screw is a headless screw with an internal hex opening on one end.

6.1.12 Mounting Surfaces

Mounting surfaces on equipment shall meet the following criteria:

- a) shall be machined to a finish of 6.3 μm (250 $\mu\text{in.}$) arithmetic average roughness (Ra) or better;
- b) shall be in the same horizontal plane within 25 μm (0.001 in.) to prevent a soft foot;
- c) each mounting surface shall be machined within a flatness of 80 μm per linear meters (0.001 in. per linear foot) of mounting surface;

- d) different mounting planes shall be parallel to each other within 50 μm (0.002 in.);
- e) upper machined or spot faced surface shall be parallel to the mounting surface;
- f) hold-down bolt holes shall be drilled perpendicular to the mounting surface or surfaces;
- g) bolt holes shall be 15 mm ($1/2$ in.) larger in diameter than the hold down bolt;
- h) bolt holes shall be spot faced where necessary to accommodate washers, fasteners and tools.

NOTE Spot face is typically unnecessary if surface is perpendicular to bolting within 1 degree.

6.2 Pressure Casings

6.2.1 The allowable tensile stress used in the design of the casing for any material shall not exceed 25 % of the minimum ultimate tensile strength for that material at the maximum specified operating temperature. The vendor shall state the internationally recognized standard from which the ultimate tensile strength value is obtained. For cast materials the allowable tensile stress shall be multiplied by a casting factor of 0.8 for steel or 0.9 for cast and ductile iron unless additional casting NDE is applied. The thickness of the casing shall be suitable for the maximum working and test pressure and shall include a corrosion allowance of at least 3 mm (0.125 in.). Manufacturing data report forms, third party inspections, and stamping as specified in pressure vessel codes are not required.

6.2.2 The maximum allowable working pressure of each casing shall be at least 1.10 times the maximum discharge pressure of the stage.

6.2.3 For casing joint bolting, the allowable tensile stress determined in 6.2.1 shall be used to determine the total bolting area based on hydrostatic load and gasket preload as applicable. The bolting 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.

6.2.4 Axial clearances between impellers and casings shall be adjustable.

NOTE Due to shape of impellers and volute, changing axial clearance will also change radial clearances.

6.3 Casing Connections

6.3.1 Compressor first-stage inlet and final stage outlet connections shall be furnished with machined flanges and through bolting.

6.3.2 All openings or nozzles for piping connections on pressure casings interfacing with piping provided by the purchaser shall be DN 20 (NPS $3/4$) or larger, and shall be in accordance with ASME B31.3 or ISO 6708. Sizes NPS $1\ 1/4$, $2\ 1/2$, $3\ 1/2$, 5, 7, and 9 (DN 32, DN 65, DN 90, DN 125, DN 175 and DN 225) shall not be used.

6.3.3 Connections welded to the casing shall meet the material requirements of the casing, including impact values, corrosion allowance and temperature-pressure rating, rather than the requirements of the connected piping. All welding of connections shall be completed before the casing is hydrostatically tested (see 8.3.2).

6.3.4 For connections other than main process connections, if flanged or machined and studded openings are impractical, threaded connections for pipe sizes not exceeding DN 40 ($1\ 1/2$ NPS) may be used with purchaser's approval as follows:

- a) on non-weldable materials, such as cast iron;
- b) where essential for maintenance (disassembly and assembly).

6.3.5 Threaded openings for tapered pipe threads shall conform to ASME B1.20.1 or ISO 7-I 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 B16.5.

6.3.6 Threaded openings not required to be connected to piping shall be plugged with steel plugs in accordance with ASME B16.11. Thread tape shall not be used.

6.3.7 Flanges

6.3.7.1 Unless otherwise specified, the CLASS system applies and all flanges shall conform to ASME B16.1, B16.5, B16.42 or B16.47 Series B as applicable, except as specified in 6.3.7.1.1, 6.3.7.1.2, and 6.3.7.3. Class 200 and 400 flanges shall not be used.

- **6.3.7.1.1** If specified, ASME B 16.47 Series A steel flanges shall be provided for applicable CLASS system flanges.

6.3.7.1.2 If the CLASS system applies, cast and ductile iron flanges shall be flat faced. Class 125 flanges shall have a minimum thickness equal to Class 250 for sizes NPS 8 and smaller.

6.3.7.2 If the PN system is specified, all flanges shall conform to EN 1092-1 or EN 1092-2 as applicable, except as specified in 6.3.7.2.1 and 6.3.7.2.2.

- **6.3.7.2.1** If the PN system applies, PN 6 and PN 10 shall not be used.

6.3.7.2.2 If the PN system applies, cast and ductile iron flanges shall be flat faced. PN 16 and PN 25 flanges shall have a minimum thickness equal to PN 40 for sizes DN 200 and smaller.

6.3.7.3 Flat-faced flanges with full, raised-face thickness are acceptable on casings of all materials. Flanges in all materials that are thicker or have a larger outside diameter than required by the applicable ASME or EN standard 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.

- **6.3.8** Machined and studed connections shall conform to the facing and drilling requirements of ASME B16.1, B16.5, B16.42, B16.47, EN 1092-1 or EN 1092-2, as specified. Studs and nuts shall be provided and shall arrive installed, the first 1.5 threads at both ends of each stud shall be removed.

6.3.9 To minimize nozzle loading and facilitate installation of piping, machine flanges shall be parallel to the plane shown on the general arrangement drawing to within 0.5 degrees. Studs or bolt holes shall straddle centerlines parallel to the main axes of the equipment.

6.3.10 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.

6.4 External Forces and Moments

6.4.1 The maximum allowable forces and moments that may be imposed on the package by the purchaser's piping shall be stated in the proposal.

NOTE 1 For integrally geared compressors, it is not possible to give a formula to calculate the maximum allowable piping forces and moments on each casing flange. The limiting criteria are the gear contact pattern and the impeller/stator gap. The maximum value of the external forces and moments, which leads to acceptable deformations and therefore acceptable changes of the gear contact pattern and the impeller/casing gap, depends on various parameters. The possible combinations are nearly endless. Each manufacturer has limits based on experience for each volute size and gear case combination for a given specific machine. The values are available from the manufacturer with the quotation. See Annex I for more information.

NOTE 2 It is a common practice on integrally geared compressors to supply expansion joints in order to minimize the piping loads on the machine flanges, and to insure that piping loads are within the allowable limits for the particular unit.

6.4.2 The maximum allowable forces and moments shall be shown on the outline drawing.

6.5 Rotating Elements

6.5.1 Shafts

6.5.1.1 Shafts shall be forged or hot-rolled alloy steel, and machined throughout their entire length.

6.5.1.2 The rotor shaft sensing areas to be observed by the radial probes shall be concentric with the bearing journals and shall meet the requirements of 6.5.1.2.1 through 6.5.1.2.3.

6.5.1.2.1 All sensing areas (both radial vibration and axial position) shall be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway, for a minimum of one probe-tip diameter on each side of the probe. These areas shall not be metallized, sleeved, or plated.

6.5.1.2.2 The final surface finish shall be a maximum of 0.8 μm (32 $\mu\text{in.}$) Ra, preferably obtained by honing or burnishing.

6.5.1.2.3 These areas shall be properly demagnetized to the levels specified in API 670 or otherwise treated so that the combined total electrical and mechanical runout does not exceed:

- a) for radial sensing areas 25 percent of the maximum allowed peak-to-peak vibration amplitude or 6 μm (0.25 mil), whichever is greater;
- b) for areas to be observed by axial-position probes, 12.7 μm (0.5 mil).

6.5.1.3 Chrome plating and other methods of building up the shaft at the journal area shall not be used.

6.5.1.4 All shaft keyways shall have fillet radii conforming to ASME B17.1, ISO 3117, or other applicable national or international standard.

6.5.2 Impellers

6.5.2.1 The impeller material shall be stainless steel, of cast or forged and milled construction.

6.5.2.2 The vendor's proposal shall describe in detail the type of impeller construction and the method of attachment to the shaft.

6.5.3 Gears

6.5.3.1 Gearing shall be designed and manufactured to the tolerances specified in ISO 1328-1, Grade 5 or better.

6.5.3.2 The gear unit shall be rated in accordance with AGMA 6011 using minimum service factors of 1.4 for induction motor driven units and 1.6 for steam-turbine and synchronous motor driven units. The rating shall be based on the driver nameplate rating.

6.5.3.3 Gear wheels and pinion hardness combinations shall be in accordance with the values recommended in AGMA 6011.

6.5.3.4 The tooth portion of pinions shall be integrally forged with their shaft.

6.5.3.5 Gear wheels shall be of forged construction, and shall be assembled on the shaft with an interference fit.

6.6 Seals and Sealing Systems

6.6.1 Air and oil shaft seals shall be provided to achieve the following:

- a) contain compressed air inside the compressor casings,
- b) prevent oil from entering the compressor casings and contaminating the compressed air,
- c) prevent oil from leaking out of the bearing housing into the atmosphere,
- d) prevent contamination of the oil system or compressed air by atmospheric dirt or moisture.

6.6.2 There shall be an atmospheric space between the air and oil seals.

6.6.3 The sealing system shall be furnished complete with piping, filters, instrumentation, and necessary start-up interlocks as applicable. This system, including air consumption, shall be fully described in the proposal.

6.6.4 Seal operation shall be suitable for all specified operating conditions, including suction throttling, startup, shutdown, standby, and momentary surge. The type of standby operation shall be agreed upon by the purchaser and the vendor.

6.7 Dynamics

6.7.1 Critical Speeds

6.7.1.1 For information on critical speeds, refer to Annex C.

6.7.1.2 Resonances of structural support systems that are within the vendor's scope of supply and that affect the rotor vibration amplitude shall not occur within the specified separation margins (see C.2.4) unless the resonances are critically damped. The effective stiffness of the structural support shall be considered in the analysis of the dynamics of the rotor-bearing-support system.

NOTE Resonances of structural support systems can adversely affect the rotor vibration amplitude.

6.7.1.3 The vendor shall determine that the drive-train (turbine, gear, motor, and the like) critical speeds (rotor lateral, system torsional, blading modes, and the like) will not excite any critical speed of the machinery being supplied and that the entire train is suitable for the rated speed and any starting-speed detent (hold-point) requirements of the train. A list of all undesirable speeds from zero to trip shall be submitted for purchaser review and included in the instruction manual for purchaser guidance (see Annex D, Item 26d). These undesirable operating speeds shall comply with the separation margin stated in C.2.10.

6.7.1.4 For the purposes of this standard, resonant conditions of concern are those with an amplification factor (AF) equal to or greater than 2.5.

6.7.2 Lateral Analysis

The vendor's standard critical speed values that have been analytically derived and proven by testing of previously manufactured compressors of the same frame size are acceptable. A report is not required.

6.7.3 Torsional Analysis

6.7.3.1 The vendor's torsional critical speed values that have been analytically derived and proven by successful operation of nominally identical previously manufactured compressor drive trains are acceptable. A report is not required.

6.7.3.2 The undamped torsional natural frequencies of the complete train shall be at least 10 % above or 10 % below any possible excitation frequency unless a report is provided that shows the stresses will be acceptable. This report shall include a summary of the stress analysis, and shall demonstrate that the resonances have no adverse effect on the complete train. This report shall also include a clear statement of the assumptions made in the analysis regarding the magnitude of excitation and the degree of damping.

6.7.3.3 Torsional criticals at two or more times running speeds shall preferably be avoided or in systems in which corresponding excitation frequencies occur, shall have no adverse effect. In addition to multiples of running speeds, torsional excitations that are not a function of running speeds or that are non-synchronous in nature shall be considered in the torsional analysis when applicable, and shall have no adverse effect.

6.7.3.4 The vendor shall perform a transient torsional vibration analysis for synchronous-motor-driven units. The acceptance criteria for this analysis shall be agreed upon by the purchaser and the vendor.

6.7.4 Vibration and Balancing

6.7.4.1 Manufacturer's standard balancing procedure shall be used.

6.7.4.2 When spare rotating elements are supplied, they shall be dynamically balanced to the same tolerances as the main rotating elements.

6.7.4.3 During the shop test of the machine as assembled with balanced rotors and operating at its rated speed, the peak-to-peak amplitude of unfiltered vibration, including runout, in any plane, measured on the pinion shaft adjacent and relative to each radial bearing shall not exceed the following value or 40 μm (1.5 mils), whichever is less—See Equation (1):

In SI units:

$$A = 25.4 \times (12000/N)^{(1/2)} \quad (1)$$

In USC units,

$$A = (12000/N)^{(1/2)}$$

where

A is the amplitude of unfiltered vibration, in μms (mil) true peak to peak;

N is the rated speed, in revolutions per minute.

NOTE These limits are not to be confused with the limits specified in Annex C.3 for shop verification of unbalanced response.

6.7.4.4 Electrical and mechanical runout shall be determined and recorded by rolling the rotor in V blocks at the journal centerline while measuring runout with a non-contacting vibration probe, and with a dial indicator at the centerline of the probe location and one probe-tip diameter to either side.

6.7.4.5 Accurate records of electrical and mechanical runout for the full 360° at each probe location shall be included in the mechanical test report.

6.8 Bearings and Bearing Housings

6.8.1 Bearings—General

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

NOTE Some small, low-power units are being offered with anti-friction bearings on the bull gear.

6.8.1.2 Bearings shall be designed to prevent incorrect positioning.

6.8.1.3 As a design criteria, bearing metal temperatures shall not exceed 100 °C (212 °F) at specified operating conditions with a maximum inlet oil temperature of 50 °C (120 °F). Acceptance value during testing as well as design criteria in the case of an air-cooled machine shall be agreed prior to order.

6.8.2 Radial Bearings

6.8.2.1 Radial bearings shall be designed for ease of assembly, precision bored and of the sleeve or pad type with babbitted replaceable liners, pads, or shells. These bearings shall be equipped with anti-rotation pins and shall be positively secured in the axial direction.

6.8.2.2 The bearing design shall suppress hydrodynamic instabilities and provide sufficient damping over the entire range of allowable bearing clearances to limit rotor vibration to the maximum specified amplitudes (see 6.7.4.3) while the equipment is operating loaded or unloaded at the rated operating speed.

6.8.3 Thrust Bearings

6.8.3.1 Thrust loads from impellers and gears and couplings shall be absorbed by individual thrust bearings on pinions, or transmitted to the gear wheel thrust bearing by means of thrust rider rings fixed to the pinions and gear wheel. All specified operating conditions and start up conditions shall be evaluated for resulting thrust loads.

6.8.3.2 Thrust bearings shall be selected using manufacturer's standard criteria. In sizing thrust bearings, consideration shall be given to the following for each specific application:

- a) shaft speed;
- b) temperature of the bearing babbitt;
- c) deflection of the bearing pad;
- d) minimum oil-film thickness;
- e) feed rate, viscosity, and supply temperature of the oil;
- f) design configuration of the bearing;
- g) babbit alloy;
- h) turbulence of the oil-film.

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

6.8.3.4 If two or more rotor thrust forces are to be carried by one thrust bearing, 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.

6.8.3.5 Thrust bearings shall be babbitted and arranged for continuous pressurized lubrication. Integral thrust collars are preferred. If replaceable collars are furnished, they shall be positively locked to the shaft to prevent fretting.

NOTE Replaceable collars facilitate assembly and maintenance.

6.8.3.6 The faces of the thrust collar or rider rings shall have a surface finish of $0.4\text{ }\mu\text{m}$ ($16\text{ }\mu\text{in.}$) Ra, or better. After mounting, the axial total indicator runout of either face shall not exceed $13\text{ }\mu\text{m}$ (0.0005 in.).

6.8.4 Bearing Housings

6.8.4.1 Bearing Housings shall be arranged so that bearings can be replaced without disturbing equipment driver or mounting, and unless otherwise agreed shall not require removal of thrust collars or coupling hub(s).

NOTE 1 Bearing replacement can require removal of gear housing cover.

NOTE 2 Removal of coupling and possible adjustment of driver is necessary for removal of anti-friction bearings.

6.8.4.2 Bearing housings shall be arranged to minimize foaming. The drain system shall be adequate to maintain the oil and foam level below shaft end seals. The bearings shall be designed not to exceed $30\text{ }^{\circ}\text{C}$ ($50\text{ }^{\circ}\text{F}$) oil temperature rise and a housing oil outlet temperature of $80\text{ }^{\circ}\text{C}$ ($180\text{ }^{\circ}\text{F}$).

NOTE This is a design criteria. Housing exit temperature is not measured in actual machines.

6.8.4.3 Bearing housings shall be equipped with replaceable labyrinth-type end seals and deflectors or non-contacting carbon ring seals for high speed pinions where the shaft passes through the housing. Lip-type seals may be used with purchaser approval. The design of the seals and deflectors shall effectively retain oil in the housing and prevent entry of foreign material into the housing. This shall be achieved without the requirement for external service such as an air purge or grease.

6.9 Lubrication

6.9.1 Unless otherwise specified, bearings and bearing housings shall be designed for oil lubrication using a mineral oil in accordance with ASTM D4304 or ISO 8068 Type AR.

NOTE Some users and manufacturers prefer to apply synthetic lubricants to this equipment.

6.9.2 Unless otherwise specified, a pressurized oil system shall be supplied in accordance with API 614, except as noted in this standard.

NOTE Many basic systems are purchased with single filters, without oil heaters, without baffles in reservoir, and without indication of suction loss level in the level glass.

- **6.9.3** Lube oil shall be supplied at the required pressure or pressures, as applicable, to the following:
 - a) bearings of the integrally geared compressor,
 - b) spray nozzles for the gear teeth,
 - c) bearings of the driver if specified or required.

6.9.4 The oil reservoir shall be manufacturer's standard design and of material with an oil and coolant-compatible corrosion resistant internal coating.

NOTE In some designs, the oil reservoir is integral with the gear casing or integral with the base frame.

- **6.9.5** If specified, the oil reservoir shall be fabricated from austenitic stainless steel.

6.9.6 If a reservoir oil heater is provided, it may be controlled by an integral heater thermostat unless it is a special duty package, in which case the requirements in 6.12.15 applies.

NOTE API 614 default is controlled by a separate temperature sensing element, but standard units often use an integral thermostat.

6.10 Materials

6.10.1 General

6.10.1.1 Materials of construction shall be the manufacturer's standard for the site environmental and operating conditions specified, except as required or prohibited by this standard.

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

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

6.10.1.4 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.

- **6.10.1.5** The purchaser shall specify any agents (including trace quantities) present in the site environment, including constituents that may cause corrosion. If possible, the concentration of each agent shall be stated.

6.10.1.6 The vendor shall select materials to avoid conditions that may result in electrolytic corrosion. Where such conditions cannot be avoided, the purchaser and the vendor shall agree on the material selection and any other precautions necessary.

NOTE If dissimilar materials with significantly different electrical potentials are placed in contact in the presence of an electrolytic solution, galvanic couples that can result in serious corrosion of the less noble material can be created. The *NACE Corrosion Engineer's Reference Book* is one resource for selection of suitable materials in these situations.

6.10.1.7 If the manufacturer of studs and nuts specifies anti-seizure compounds, modified torque values shall be included in the manuals. Molybdenum disulphide lubricants shall not be used. Close tolerance mating parts, such as shaft sleeves, that are made from galling materials and that cannot be disassembled by hydraulic or thermal expansion techniques shall not rely on anti-seizure compound. These items shall have a suitable metallic coating to prevent galling.

6.10.1.8 Bolting for pressure joints shall be high-temperature alloy steel in accordance with ASTM A193 Grade B7. Carbon steel ASTM A194, Grade 2H nuts shall be used.

6.10.1.9 Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or lower temperatures. Therefore, for pressure containing parts made of steel, only fully killed, normalized steels made to fine-

grain practice are acceptable. Steel made to a coarse austenitic grain size practice (such as ASTM A515) shall not be used for pressure containing parts.

6.10.2 Castings

6.10.2.1 Castings shall be free from porosity, hot tears, shrink holes, blow holes, cracks, scale, blisters, and similar injurious defects. Surfaces of castings shall be cleaned by sandblasting, shot-blasting, chemical cleaning, or other standard methods. Mold-parting fins and the remains of gates and risers shall be chipped, filed or ground flush.

6.10.2.2 Pressure containing ferrous castings shall not be repaired except as specified in 6.10.2.2.1 through 6.10.2.2.3.

6.10.2.2.1 Weldable grades of steel castings shall be repaired by welding, using a qualified welding procedure based on the requirements of Section VIII, Division 1, and Section IX of the ASME *BPVC*, or other internationally recognized standard as approved by the purchaser. After major weld repairs, and before hydrotest, the complete repaired casting shall be given a post-weld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal, and dimensional stability during subsequent machining operations.

6.10.2.2.2 Defects in cast gray iron or ductile iron that are within allowed repair limits of ASTM A395 shall either be repaired by plugging or the part replaced. Larger defects require replacement. The holes drilled for plugs shall be carefully examined, using liquid penetrant, to ensure that all defective material has been removed. Repair by welding is not allowed.

6.10.2.2.3 All repairs that are not covered by the agreed material specification shall be subject to the purchaser's approval.

6.10.2.3 Fully enclosed cored voids, which become fully closed by methods such as plugging, welding, or assembly, shall not be used.

6.10.2.4 All Ductile (Nodular) iron castings shall be produced in accordance with ASTM A395, or other internationally recognized standard as approved by the purchaser. Standard products using gray cast iron ASTM A536 Grades such as 60-40-18 or 80-55-06 may be proposed for purchaser approval.

NOTE The industry has a long history of reliable units in such grades of ASTM A536.

6.10.3 Welding

6.10.3.1 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 1, and Section IX of the ASME *BPVC* or another purchaser approved standard such as ISO 9606 and ISO 15607 for welding procedures and welding qualification.

6.10.3.2 The vendor shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat treated and nondestructively examined for soundness and compliance with the applicable qualified procedures. Repair welds shall be nondestructively tested by the same method used to detect the original flaw.

- **6.10.3.3** If specified, documentation of major defects shall be submitted to the purchaser prior to any repairs being conducted at the manufacturer's shop and shall include the following:

- a) extent of the repair,
- b) location indicated on sketch, weld map, or drawing;
- c) size;

- d) welding procedure specification;
- e) detailed photographs of the defect prior to any preparatory work and after preparation but prior to the actual repair. If the location of the defect cannot be clearly defined by photographic means, the defect repair preparation shall be indicated on a sketch, weld map or drawing of the affected component.

6.10.3.4 Repairs performed at the manufacturer's shop shall be considered major if any of the following conditions apply:

- a) castings leak during hydrostatic testing;
- b) depth of the repair cavity prepared for welding exceeds 50 % of the wall thickness or 25 mm (1 in.), whichever is smaller;
- c) surface area of all repairs to the part exceeds 10 % of the surface area of the part;
- d) repair cavity is longer than 150 mm (6 in.) in any direction;
- e) repair is to any rotating components.

6.10.3.5 Welding not covered by 6.10.3.1, such as welding on baseplates, non-pressure ducting, lagging, and control panels, shall be performed by welders qualified in accordance with an appropriate internationally recognized structural welding standard such as AWS D1.1 or Section IX of the ASME *BPVC* or other purchaser approved welding standard.

6.10.3.6 Connections welded to pressure casings shall be installed as specified in 6.10.3.6.1 and 6.10.3.6.2.

6.10.3.6.1 Post-weld heat treatment, if required, shall be carried out after all welds, including piping welds, have been completed.

6.10.3.6.2 All welds shall be heat treated in accordance with Section VIII, Division 1, Sections UW-10 and UW-40, of the ASME *BPVC*.

• 6.10.4 Low Temperature

The purchaser shall specify the minimum design metal temperature (MDMT) to be applied to the equipment. If the MDMT is below the minimum allowable temperature for the materials of the equipment, the vendor and the purchaser shall agree and implement measures to assure that the equipment will not be operated with pressure casing at a metal temperature below the MDMT, to avoid brittle failures.

6.11 Nameplates and Rotation Arrows

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

6.11.2 Rotation arrows shall be cast in or attached to each major item of rotating equipment at a readily visible location.

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

6.11.4 As a minimum, the following data shall be clearly stamped or engraved on the compressor nameplate:

- a) vendor's name,
- b) serial number,
- c) size, model and type,
- d) rated capacity,
- e) rated discharge pressure,
- f) purchaser's item number
- g) maximum allowable working pressure,
- h) purchase order number,
- i) compressor weight,
- j) year built,
- k) if required, Certification Markings such as ATEX or CE.

Units shall be consistent with those used on the data sheets.

6.12 Additional Basic Design Requirements for Special Duty Packages Only

6.12.1 Jackscrews, guide rods, cylindrical casing-alignment dowels, or other appropriate devices, or a combination thereof, shall be provided to facilitate disassembly and reassembly.

6.12.1.1 Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly.

6.12.1.2 Lifting lugs or eyebolts shall be provided to lift only the top half of the gear casing.

6.12.1.3 If 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 improper fit caused by marring of the face.

6.12.2 Sufficient pressure and temperature taps shall be provided to monitor or troubleshoot performance of each stage and intercoolers.

6.12.3 Gearing shall be manufactured to the gear tooth quality tolerances specified in ISO 1328-1, Grade 4.

6.12.4 Unless the vendor is able to demonstrate that functionally identical equipment has operated satisfactorily under the conditions stated in 6.7.2, a damped unbalanced response analysis to assure acceptable amplitudes of vibration at any speed from zero to trip shall be conducted as per C.2.10.

- **6.12.5** If specified, any damped unbalanced response analysis required by 6.12.4 shall be confirmed by test stand data in accordance with Annex C.

6.12.6 Unless the vendor is able to demonstrate that functionally identical equipment has operated satisfactorily under the conditions stated in Item 6.7.3.1, a torsional vibration analysis of the complete coupled train shall be

conducted as required in C.7. In this case, the vendor shall also be responsible for directing the modifications necessary to meet the requirements of 6.7.3.2 through 6.7.3.4.

6.12.7 Excitations of undamped torsional natural frequencies can come from many sources, which shall be considered in the analysis. Sources of excitation to be considered include, but are not limited to, the following:

- a) gear characteristics such as unbalance and pitch line runout, and cumulative pitch error;
- b) startup conditions such as speed detents and other torsional oscillations;
- c) torsional transients such as start-ups of synchronous electric motors and transients due to generator phase-to-phase fault or phase-to-ground fault;
- d) torsional excitation resulting from drivers;
- e) one and two times electrical line frequency;
- f) one and two times operating speeds;
- g) harmonic frequencies from variable frequency fixed speed drives.

6.12.8 Major parts of the rotating elements, such as the shaft and impellers, shall be dynamically balanced. 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 8821. A shaft with 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.

6.12.9 The rotating elements shall be multiplane dynamically balanced during assembly. This shall be accomplished after the addition of each major component. Balancing correction shall be applied only to the elements added. Balancing of impellers by welding is prohibited. 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 6.12.6) 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 work sheet (see Annex F). The maximum allowable residual unbalance per plane (journal) shall be calculated as follows:

In SI units:

$$U_{max} = 6350 W / N \text{ for } N < 25,000 \text{ rpm} \quad (2)$$

$$U_{max} = W / 3.937 \text{ for } N > 25,000 \text{ rpm} \quad (3)$$

In USC units:

$$U_{max} = 4 W / N \text{ for } N < 25,000 \text{ rpm}$$

$$U_{max} = W / 6250 \text{ for } N > 25,000 \text{ rpm}$$

where

U_{max} is the residual unbalance, in gram-mm (ounce-in.).

W is the journal static weight load, in kg (lbs.).

N is the rated speed, in revolutions per minute (rpm).

NOTE Balance tolerance above 25,000 rpm is based on an eccentricity of 0.25 μm (10 $\mu\text{in.}$) for each journal static weight load. Unbalance readings are measured at each journal-bearing position with no compensation to actual balance planes.

- **6.12.10** If specified, after the final balancing of each assembled rotating element has been completed, a residual unbalance check shall be performed and recorded in accordance with the residual unbalance work sheet (see Annex F).

6.12.11 Thrust bearings shall be selected such that at start-up or emergency trip conditions, the load does not exceed 75 % , and with any steady-state operating condition the load does not exceed 50 % of the bearing manufacturer's ultimate load rating. The ultimate load rating is the load that will produce the minimum acceptable oil-film thickness without inducing failure during continuous service or the load that will not exceed the creep-initiation or yield strength of the babbitt at the location of maximum temperature on the pad, whichever load is less.

6.12.12 Unless otherwise specified, thrust bearings and radial bearings shall be fitted with bearing-metal temperature sensors.

NOTE Some small pinion bearings do not have space for temperature sensors on the bearing.

- **6.12.13** If specified, installation of bearing-metal temperature sensors shall be in accordance with API 670.
- **6.12.14** If specified, oil cooler tubes shall have a 16 mm ($5/8$ in.) minimum outside diameter, and be made of inhibited admiralty (ASTM B111) with an average wall thickness of 18 BWG.

6.12.15 An austenitic stainless steel oil reservoir shall be supplied non-integral with the equipment casing.

6.12.16 If an electric heater is provided, it shall comply with API 614 requirements including control features.

7 Accessories

7.1 Drivers

7.1.1 General

7.1.1.1 The driver shall be of the type specified, shall be sized to meet the maximum specified operating conditions, including gear and coupling losses, and shall be in accordance with applicable specifications, as stated in the inquiry and order. The driver shall operate under the utility and site conditions specified in the inquiry.

7.1.1.2 The driver, in combination with the controls provided, shall be sized to accept any specified process variations such as changes in the pressure, temperature, relative humidity of the air, cooling water temperature, and plant start-up conditions.

- **7.1.1.3** The driver shall be capable of starting under the conditions specified and the starting method shall be agreed. The driver's starting-torque capabilities shall exceed the speed-torque requirements of the driven equipment. Purchaser shall state if starting conditions are to include minimum ambient temperature and minimum cooling water temperature.

7.1.1.4 The driver nameplate rating (exclusive of the service factor) shall be at least 110 % of the power required at the rated point.

- **7.1.1.5** If specified, the driver nameplate rating (exclusive of the service factor) shall be at least 110 % of the greatest power required for all of the specified operating conditions.

7.1.1.6 The supporting feet of compressor drivers shall be provided with vertical jackscrews.