

Petroleum, Petrochemical, and Natural Gas Industries—Steam Turbines—Special-purpose Applications

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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 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 standard and provide details.

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

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

Petroleum, Petrochemical, and Natural Gas Industries—Steam Turbines— Special-purpose Applications

1 Scope

This standard specifies the minimum requirements for steam turbines for special-purpose applications for use in the petroleum, petrochemical, and gas industry services. It is not applicable to general purpose steam turbines, which are covered in API 611.

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) applies. Standards referenced in the text portion of the document are undated but refer to the specific editions referenced in this section.

API Standard 520 (all parts), *Sizing, Selection, and Installation of Pressure-relieving Devices*

API Standard 526, *Flanged Steel Pressure-relief Valves*

ANSI ¹ /API Standard 614, *Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries, Fifth Edition, April 2008 (Errata, May 2008)*

ANSI/API Standard 670, *Machine Protection Systems, Fourth Edition, December 2000*

ANSI/API Standard 671, *Special Purpose Couplings for Petroleum, Chemical and Gas Industry Services, Fourth Edition, August 2007*

API Recommended Practice 551, *Process Measurement*

API Recommended Practice 686, *Recommended Practice for Machinery Installation and Installation Design, Second Edition, December 2009*

API Recommended Practice 691, *Risk-based Machinery Management, First Edition, June 2017*

ANSI /AWS D1.1/D1.1M ², *Structural Welding Code—Steel*

ASME B1.1-2003 ³, *Unified Inch Screw Threads (UN and UNR Thread Form)*

ASME B1.3M-1986, *Screw Thread Gaging Systems for Dimensional Acceptability—Inch and Metric Screw Threads (UN, UNR, UNJ, M and MJ)*

ASME B1.13M-2005, *Metric Screw Threads: M Profile*

ASME B16.5-2009, *Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard*

ASME B16.47-2011, *Large Diameter Steel Flanges: NPS 26 through NPS 60 Metric/Inch Standard*

ASME B17.1 (R2008), *Keys and Keysets*

ASME B31.3-2010, *Process Piping*

¹ American National Standards Institute, 1899 L Street, NW, 11th Floor, Washington, DC 20036, www.ansi.org.

² American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.

³ American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990, www.asme.org.

ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications

ASME Boiler and Pressure Vessel Code, Section V: Nondestructive Examination

ASME Boiler and Pressure Vessel Code: Section VIII: Pressure Vessels

ASME Performance Test Code (PTC) 6, Steam Turbines

ASTM A193/A193M⁴, *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 A247, *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings*

ASTM A388/A388M, *Standard Practice for Ultrasonic Examination of Steel Forgings*

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

ASTM A418/A418M, *Standard Practice for Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings*

ASTM A437/437M-15, *Standard Specification for Stainless and Alloy-Steel Turbine-Type Bolting Specially Heat Treated for High-Temperature Service*

ASTM A472/A472M, *Standard Specification for Heat Stability of Steam Turbine Shafts and Rotor Forgings*

ASTM A563, *Standard Specification for Carbon and Alloy Steel Nuts*

ASTM A578/A578M, *Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications*

ASTM A609/A609M, *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

ASTM D4304(REV A 2006), *Standard Specification for Mineral Lubricating Oil Used in Steam or Gas Turbines*

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

ASTM E94-(2010), *Standard Guide for Radiographic Examination*

ASTM E125, *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*

ASTM E165/E165M, *Standard Practice for Liquid Penetrant Examination for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E1417/E1417M, *Standard Practice for Liquid Penetrant Testing*

EN 1092-1⁵, *Flanges and their joints—Circular flanges for pipes, valves, fittings and accessories, PN designated—Part 1: Steel flanges*

⁴ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁵ European Committee for Standardization, Rue de la Science 23, B-1040 Brussels, Belgium, www.cen.eu.

- IEC 60072 (all parts)⁶, *Dimensions and output series for rotating electrical machines*
- IEC 60079 (all parts), *Explosive atmospheres*
- IEC 60529, *Degrees of protection provided by enclosure (IP Code)*
- IEC 60953 (all parts), *Rules for steam turbine thermal acceptance tests*
- IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*
- IEC 61511 (all parts), *Functional safety—Safety instrumented systems for the process industry sector*
- ISO 261:1998⁷, *ISO general purpose metric screw threads—General plan*
- ISO 3117, *Tangential keys and keyways*
- ISO 3448:1992, *Industrial liquid lubricants—ISO viscosity classification*
- ISO 3744:1994, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Engineering methods for an essentially free field over a reflecting plane*
- ISO 6708:1995, *Pipework components—Definition and selection of DN (nominal size)*
- ISO 8068:2006, *Lubricants, industrial oils and related products (class L)—Family T (Turbines)— Specification for lubricating oils for turbines*
- ISO 8501 (all parts), *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness*
- 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 10721-2:1999, *Steel structures—Part 2: Fabrication and erection*
- ISO 15607:2005, *Specification and qualification of welding procedures for metallic materials—General rules*
- ISO 21940-32, *Mechanical vibration—Rotor balancing—Part 32: Shaft and fitment key convention*
- MSS SP-55⁸, *Quality Standard for Steel Castings for Valves, Flanges, Fittings, and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*
- NEMA 250:2014⁹, *Enclosures for Electrical Equipment (1000 Volts Maximum)*
- SSPC-SP6/NACE No. 3^{10 11}, *Commercial Blast Cleaning*

⁶ International Electrotechnical Commission, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iec.ch.

⁷ International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

⁸ Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, NE, Vienna, Virginia 22180, <https://msshq.org>.

⁹ National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.

¹⁰ The Society for Protective Coatings, 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, www.sspc.org.

¹¹ NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

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 activated to warn of a condition that requires corrective action.

3.1.2

alloy steel

Steel that is alloyed with a variety of elements in total amounts between 1.0 % and 50 % by weight.

3.1.3

anchor bolts

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

cf. hold down bolts (3.1.20)

3.1.4

approve

Provide written documentation confirming an agreement.

3.1.5

axially split joint

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

3.1.6

baseplate

skid

Fabricated steel structure designed to support the complete steam turbine and/or the driven equipment and other ancillaries that may be mounted upon it.

cf. mounting plate (3.1.38)

3.1.7

combined trip and throttle valve

A dedicated valve (separate from governor valve) that stops steam flow to the turbine in shutdown conditions and provides intermediate valve positioning for use during start-up or during abnormal conditions.

3.1.8

complex stiffness

The 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.

3.1.9

control mechanism

All equipment between the speed governor and the governor-controlled valve(s) (such as linkages, pilot valves, and power servos).

3.1.10

critical speed

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

3.1.11**DN****diamètre nominal**

Alphanumeric designation of size for components of a pipework system.

EXAMPLE DN20.

NOTE 1 Adapted from ISO 6708:1995.

NOTE 2 The letters DN are followed by a dimensionless whole number that is indirectly related to the physical size, in millimeters, of the bore or outside diameter of the end connection.

NOTE 3 The number following the letters DN does not represent a measurable value.

3.1.12**design**

Manufacturer's calculated parameter.

NOTE 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.

3.1.13**duplex**

The provision of two microprocessors instead of one in situations where a fail-over function is required.

NOTE Availability of duplex system is typically in the 99 % range.

3.1.14**enclosure**

Compartment designed to provide noise protection or weather protection, or both.

NOTE A compartment can include walls, doors, and a roof.

3.1.15**fail safe**

System or component that will cause the equipment to revert to a permanently safe condition (shutdown and/or depressurized) in the event of a component failure or failure of the energy supply to the system.

3.1.16**field changeable**

Design feature that permits alteration of a function after the equipment has been installed.

NOTE The alteration can be accomplished by the following:

- a) soldering jumper leads to terminal pins especially provided for this purpose,
- b) employing circuit-board-mounted switches or potentiometers,
- c) using a shorting or diode-pin-type matrix board,
- d) using prewired shorting plugs,
- e) using authorized controlled access.

3.1.17**gauge board**

Bracket or plate used to support and display gauges, switches, and other instruments.

cf. panel (3.1.47)

NOTE A gauge board is not a panel. A gauge board is open and not enclosed. A panel is an enclosure.

3.1.18

general purpose application

Application that is usually spared or is in noncritical service.

3.1.19

governor-controlled valve

Device that controls the flow of steam into or out of the turbine in response to the speed governor.

3.1.20

hold down bolts

mounting bolts

Bolts holding the equipment to the mounting plate.

3.1.21

hydrodynamic bearings

Bearings that rely on the differential speed of the journal relative to the stator to pressurize a lubricating fluid in a wedge between the surfaces.

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.

3.1.22

hysteresis or internal friction damping

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.

3.1.23

idling adapter

(solo plate)

Device designed to rigidly hold in alignment the floating parts of certain types of couplings to allow uncoupled operation of the driving or driven machine without dismounting the coupling hub.

3.1.24

informative

For advice only.

cf. normative (3.1.43)

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

3.1.25

local

<Position of devices> on or near the equipment or console.

3.1.26

maximum allowable speed

Highest speed at which the manufacturer's design will permit continuous operation.

NOTE The maximum allowable speed of turbine is independent of the specified operating conditions and usually set by rotor stress values. See Figure 4 for the location of maximum allowable turbine speed in the overspeed testing range.

3.1.27**maximum allowable temperature**

Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) for handling the specified fluid (steam) at the specified maximum operating pressure.

NOTE Maximum allowable temperature in extraction steam turbine can depend on the extraction flow in addition to the specified maximum operating pressure.

3.1.28**maximum allowable working pressure**

Maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) for handling the specified fluid (steam) at the specified maximum operating temperature.

3.1.29**maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the turbine, as built and tested, is capable of continuous operation.

3.1.30**maximum exhaust casing pressure**

Highest exhaust steam pressure that the purchaser requires the casing to contain, with steam supplied at maximum inlet conditions.

NOTE The turbine casing will be subjected to the maximum temperature and pressure under these conditions.

3.1.31**maximum exhaust pressure**

Highest exhaust pressure at which the turbine is required to operate continuously.

NOTE The maximum exhaust pressure for steam turbines is determined by site steam conditions and is usually set by the purchaser.

3.1.32**maximum inlet pressure and temperature**

Highest specified inlet steam pressure and temperature conditions, at the inlet to trip valve or at the inlet to combined trip and throttle valve, the turbine will be subject to.

3.1.33**maximum allowable momentary rotor overshoot speed**

Maximum momentary speed determined by the manufacturer at which no damage will occur to the turbine rotor that will require immediate maintenance intervention.

3.1.34**maximum sealing pressure**

Highest pressure the turbine seals are required to seal during any specified static or operating condition and during start-up and shutdown.

3.1.35**minimum allowable speed**

Lowest speed (revolutions per minute) at which the manufacturer's design will permit continuous operation.

3.1.36**minimum exhaust pressure**

Lowest exhaust pressure at which the turbine is required to operate continuously.

3.1.37**minimum inlet steam pressure and temperature**

Lowest inlet steam pressure and temperature conditions at which the turbine is required to operate continuously.

3.1.38**mounting plate**

Device used to attach equipment to concrete foundations or steel supports. This is either a baseplate(s), soleplates, or chockplates.

3.1.39**normal operating point**

Point at which usual operation is expected and optimum efficiency is desired. This point is usually the point at which the turbine vendor certifies the steam rate.

3.1.40**normal power**

Turbine power at the normal operating point.

3.1.41**normal speed**

Rotational speed (revolutions per minute) corresponding to the conditions of the normal operating point.

3.1.42**normally open****normally closed**

<Manual hand valve> state during normal operation (see 7.7.2.5.3).

3.1.43**normative**

Required.

cf. informative (3.1.24)

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

3.1.44**NPS****nominal pipe size**

Value equal to a diameter in inches.

EXAMPLE NPS 3/4.

NOTE 1 Refer to ASME B31.3.

NOTE 2 The letters NPS are followed by a value that is related to an approximate diameter of the bore, in inches, for piping up to and including 12 in. diameter. For piping over 12 in. (NPS 12), the NPS value is the nominal outside diameter (OD).

3.1.45**observed**

A classification of inspection or test where the purchaser is notified of the schedule and the inspection or test is performed even if the purchaser or their representative is not present.

3.1.46**owner**

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

3.1.47**panel**

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

cf. gauge board (3.1.17)

3.1.48**PMI****positive material identification (PMI) testing**

Any physical evaluation or test of a material to confirm that the material that has been or will be placed into service is consistent with the selected or specified alloy material designated by the owner/user. These evaluations or tests can provide either qualitative or quantitative information that is sufficient to verify the nominal alloy composition.

NOTE Adapted from API 578:2010.

3.1.49**PN****nominal pressure**

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

EXAMPLEPN 100.

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

3.1.50**potential maximum power**

Maximum power to which a steam turbine may be uprated at the specified normal speed and steam conditions if it is furnished with larger or additional nozzles and, possibly, with a larger governor-controlled valve or valves.

3.1.51**predicted momentary rotor overshoot speed**

The speed that is expected to be achieved following an overspeed trip event.

3.1.52**pressure casing**

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

3.1.53**purchaser**

Agency that issues the order and specification to the vendor.

NOTE The purchaser can be the owner of the plant in which the equipment is to be installed or the owner's appointed agent.

3.1.54**Ra****roughness magnitude**

Arithmetic average of the absolute value of the profile height deviations recorded within the evaluation length and measured from the mean line.

NOTE 1 Adapted from ASME B46.1-2009 para 1-4.1.1.

NOTE 2 It is the average height of the entire surface, within the sampling length, from the mean line.

3.1.55**radially split**

Split with the joint perpendicular to the shaft centerline.

3.1.56**rated power**

Maximum specified steam turbine power output and its corresponding speed; it includes all the margin required by the specifications of the driven equipment.

3.1.57**rated speed****100 % speed**

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

NOTE Rated speed of steam turbine corresponds to its rated output power.

3.1.58**relief valve set pressure**

Pressure at which a relief valve starts to lift.

3.1.59**remote**

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

3.1.60**separation margin**

Margin between a critical speed and the nearest required operating speed.

3.1.61**shutdown**

Condition as determined by the equipment user that requires action to stop the equipment.

3.1.62**shutdown (HH) set point**

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

3.1.63**slow roll**

Speed less than 5 % of the normal operating speed or the minimum speed permitted by design of components in the driver-driven train.

NOTE 1 Slow roll allows warm-up and initial check of equipment integrity prior to full speed operation.

NOTE 2 Slow roll speed in steam turbine driven centrifugal compressor train can be limited by design of dry gas seals.

3.1.64**soleplate**

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

3.1.65**spark resistant material**

Material that is not prone to generate impact sparks under conditions of use.

NOTE Adapted from FM 7910 "Approval Standard for Spark Resistant Tools."

3.1.66**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.

NOTE Special-purpose steam turbine application is not limited by steam conditions, power, or turbine speed.

3.1.67**special tool**

Tool that is not a commercially available catalog item.

3.1.68**stability analysis**

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

3.1.69**stage**

Refers to an individual turbine blade row.

NOTE A turbine stage consists of one set of stationary and rotating blade rows.

3.1.70**support stiffness and damping**

The equivalent oil film to ground complex stiffness characteristics. Pivot stiffness should be included in the oil film characteristics.

3.1.71**structure stiffness and damping**

Refers to the bearing housing to ground equivalent complex stiffness.

3.1.72**synchronous tilt pad coefficients**

Derived from the complex frequency dependent coefficients with the frequency equal to the rotational speed of the shaft.

3.1.73**steam rate**

Quantity of steam required by the turbine per unit of power output measured at the output shaft of the turbine.

3.1.74**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 total indicated runout implies an eccentricity equal to half the reading. For a flat face, the total indicated runout implies an out-of-square equal to the reading.

3.1.75**TMR****triple modular redundancy**

The provision of three microprocessors instead of one in situations where continuing functioning is required.

NOTE Availability of triple modular redundant system is typically in the 99.9 % range.

3.1.76**trip**

Automated shutdown to ensure personnel safety (safety critical).

NOTE Shutdown such as turbine overspeed is considered a safety critical trip.

3.1.77**trip speed**

<Turbine> speed at which the independent emergency overspeed device or shutdown system operates to shut down the steam turbine.

3.1.78**trip valve**

A dedicated valve (separate from governor valve) that stops steam flow to the turbine in shutdown conditions (see 7.7.2.5.1).

3.1.79**ultimate load rating (hydrodynamic thrust bearing)**

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.

3.1.80**unit responsibility**

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

3.1.81**vendor**

Manufacturer or manufacturer's agent that supplies the equipment.

3.1.82**witnessed**

A classification of 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

AF	amplification factor
cf.	(Latin conferre) confer or compare—cross-reference
ID	inner diameter
NDE	nondestructive examination
NPS	nominal pipe size
OD	outer diameter
PMI	positive material identification
PWHT	post-weld heat treatment
RTD	resistance temperature detector
SDS	safety datasheet
SI	the International System of Units (Système International d'Unités)
SPL	sound pressure level
USC	US customary

VDDR vendor drawing and data requirements

● 4 Unit Responsibility

If specified, the turbine vendor shall assume unit responsibility and shall ensure that all subvendors comply with the requirements of this standard and all reference documents.

NOTE The purchaser usually identifies the unit responsibility for machinery train. For generator drive application, the unit responsibility is generally assigned to the turbine vendor.

5 Requirements

● 5.1 Units of Measure

Purchaser's use of an SI datasheet indicates the SI (Système International d'Unités) system of measurements shall be used for all data, drawings, and maintenance dimensions. Purchaser's use of a USC datasheet indicates the US customary (USC) system of measurements shall be used.

NOTE 1 Informative steam turbine datasheets in SI units and USC units are provided in Annex A.1 and Annex A.2.

NOTE 2 Informative project design datasheets in SI units and USC units are provided in Annex A.3 and Annex A.4.

5.2 Statutory Requirements

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

● 5.3 Documentation Requirements

The hierarchy of documents shall be specified.

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

6 Basic Design

6.1 General

- 6.1.1 The purchaser shall specify the period of uninterrupted continuous operation. Shutting down the equipment to perform required maintenance or inspection during the specified uninterrupted operation period 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 important in meeting this objective.

6.1.2 The vendor shall advise in the proposal if any components are designed for a finite life.

NOTE 1 It is recognized that these are design criteria.

NOTE 2 Annex B includes a guide to steam turbine nomenclature.

- 6.1.3 Only equipment that is field proven is acceptable. The purchaser shall specify the technology readiness level (TRL) from API 691 for qualified equipment.

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

- **6.1.3.1** If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

6.1.3.2 In the event no such equipment 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.

- **6.1.4** The purchaser shall specify the equipment's normal operating point and any other required operating points, including the inlet and exhaust steam conditions and any extraction or induction steam quantities and conditions. The purchaser shall also specify the maximum and minimum values of the inlet, exhaust, and extraction/induction steam conditions.

6.1.4.1 The purchaser shall inform the vendor of any unusual process conditions that may cause the driven equipment to drive the turbine opposite its normal direction of rotation following a turbine trip (see 6.9.1.4).

6.1.4.2 Steam purity limits shall be in accordance with Annex C. The purchaser shall advise if there are any corrosive agents in the steam, or the environment, that exceed the levels specified in Annex C, including contaminants that may cause stress corrosion cracking.

NOTE Contaminants in steam systems typically include sodium hydroxide, chlorides, aluminum, phosphates, copper, and lead.

6.1.4.3 Variations from maximum inlet steam pressure, maximum inlet steam temperature, and maximum exhaust pressure may be expected for short durations. Allowable swings and time durations over a 12-month period are defined in Annex C. Turbine shall be capable of withstanding these variations.

NOTE Some steel flange standards do not state that flange ratings consider variations in pressure and temperature for short durations. In these situations, turbine flanges with higher rating can be needed.

6.1.5 Turbine shall be capable of the following:

- a) operation at normal power and speed with normal steam conditions, with the steam rate certified by the manufacturer at these conditions;
- b) delivering rated power at its corresponding speed with coincident minimum inlet and maximum exhaust conditions specified; the purchaser may specify normal power or a selected percentage of rated power instead of rated power at these steam conditions to prevent oversizing or to obtain higher operating efficiency or both;
- c) continuous operation at maximum continuous speed Nmc and at any other speed within the range specified;
- d) continuous operation at rated power and speed with maximum inlet steam conditions and either maximum or minimum exhaust steam conditions;
- e) continuous operation at the lowest speed at which maximum torque is required with minimum inlet and maximum exhaust conditions, with the purchaser specifying both the speed and torque values required;
- f) continuous operation at specified conditions for extraction and/or induction;
- g) operation with variations from maximum inlet steam conditions (pressure and temperature), maximum exhaust steam pressure, and steam purity limits specified in Annex C (see 6.1.4.2 and 6.1.4.3);
- h) operation uncoupled with maximum inlet steam conditions.

NOTE 1 Governing instability and high acceleration rates can occur during uncoupled operation and controlling action such as throttling of the inlet pressure can be needed.

NOTE 2 Operation of the turbine at no load (in any turbine section) and high speed or uncoupled usually needs reducing the inlet temperature to keep exhaust and/or extraction temperature within acceptable limits for the turbine, piping, and condenser (if applicable).

6.1.6 Turbine shall be designed for operation at speeds up to the trip speed without damage. This requirement shall not be construed to allow continuous operation above maximum continuous speed.

6.1.7 The turbine trip speed shall be 110 % of the maximum continuous speed (116 % of the rated speed).

6.1.8 For generator drive, the turbine trip speed shall be 10 % above the synchronous speed.

6.1.9 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.

6.1.9.1 The equipment furnished by the vendor shall conform to the maximum allowable SPL specified.

6.1.9.2 The vendor shall provide expected values for maximum SPL per octave band for the equipment.

NOTE 1 The installed SPL depends on the installation.

NOTE 2 The SPL varies depending on the environment in which the source is located as well as the distance from the source.

6.1.10 Cooling water systems shall be designed on the water side based on the criteria in API 614.

6.1.10.1 The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity over heat exchange surfaces result in a 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.

6.1.10.2 Provision shall be made for complete venting and draining of the system or systems.

6.1.11 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor.

6.1.12 This arrangement shall provide the purchaser-defined adequate clearance areas and safe access for operation and maintenance.

6.1.13 Electrical Classification

6.1.13.1 Locations for installed equipment are classified as hazardous electrical areas or as unclassified. An unclassified area is considered nonhazardous; therefore, motors, electrical instrumentation, equipment, components, and electrical installations for unclassified areas are not governed by hazardous area electrical codes.

- **6.1.13.2** If an installation location is classified as hazardous, motors, electrical equipment, instrumentation, components, and electrical installations shall be suitable for the hazardous electrical area classification designation specified.
- **6.1.13.3** All applicable electrical codes shall be specified. Local electrical codes that apply shall be provided by the purchaser upon request.

NOTE The vendor can request from the purchaser any governmental requirements. The purchaser generally has other equipment at the site and is more familiar with the local governmental regulations.

6.1.14 Housings that enclose moving lubricated parts (bearings), shaft seals, highly polished parts, instruments, and control elements shall be designed for protection from moisture, dust, and other foreign matter during periods of operation and idleness.

NOTE Inert gas purge, seals and, or deflectors can be used for this purpose.

6.1.15 Major parts, such as casing components and bearing housings, shall be designed and manufactured with the use of shouldering dowels or keys to ensure accurate alignment on reassembly.

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

6.1.17 The turbine and its accessories shall perform on the test stand(s) and on their permanent foundation within the acceptance criteria specified in 6.8.7.8. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

- **6.1.18** Many factors adversely affect site performance. These factors include such items as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site. To minimize the influence of these factors, the vendor shall review and comment on the purchaser's piping and foundation drawings. If specified, the vendor's representative shall witness the following:
 - a) a check of the piping alignment performed by unfastening the major flanged connections of the equipment;
 - b) the initial shaft alignment check at ambient conditions;
 - c) shaft alignment at operating temperature, i.e. hot alignment check.

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

- **6.1.19** The equipment, including its auxiliaries, shall be suitable for operation under the environmental conditions specified. These conditions shall include if the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum ambient temperatures, sun metal temperature, unusual humidity, and dusty or corrosive conditions.
- **6.1.20** The equipment, including its auxiliaries, shall be suitable for operation, using the utility stream conditions specified.

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

NOTE Refer to O.3.4 in Annex O for parts lists and recommended spares.

6.1.22 Any maintenance item with a mass more than 25 kg (50 lb) shall be provided with lifting lugs or similar dedicated fixed lifting point(s).

6.1.22.1 Eyebolts are only acceptable for bearing housing covers and for internal components where other lifting arrangements are impractical.

6.1.22.2 Holes for eyebolts shall be permanently marked with the correct bolt size to be used. If this marking is impractical, bolt size information shall be clearly indicated in the instruction manual.

6.1.23 Bolting and Threads

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

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

NOTE 2 For the purposes of this provision, ISO 261 is equivalent to ASME B1.13M. Specific requirements for ISO 261 equivalence are found in 6.1.23.1.2.

NOTE 3 Glossary of terms for screw threads can be found in ASME B18.12–2001.

6.1.23.1.1 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 and shall meet the following requirements.

- a) Diameters shall be selected from Table 2 Column 1 of ASME B1.1. The threads shall be Class 2 for bolting, studs, and nuts.
- b) For other threads and nuts, they shall be Class 2 or 3.
- c) To prevent galling, if ASME B1.1 Class 3 external threads are used, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ASME B1.1 Class 3 tolerance for the outer diameter (OD) of the external thread and the inner diameter (ID) of the internal thread results in zero clearances. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads do not have any allowance, and therefore even if a Class 2 nut is used with a Class 3 external thread, metal-to-metal at maximum material conditions can develop.

6.1.23.1.2 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 and shall meet the following requirements.

- a) The threads shall be class 6g for bolting and studs, and class 6H for nuts.
- b) For other threads, they shall be class 6g or 4h for external threads and class 6H or 5H for internal threads.
- c) To prevent galling, if ISO class h/H position is specified for mating components, the tolerance for maximum material conditions shall be modified to prevent zero clearance.

NOTE 1 ISO position h/H clearance for the OD of the external thread and the ID of the internal thread can result in zero clearance between the mating components. This has resulted in galling and inability to disengage the mating components.

NOTE 2 Internal threads position G in the ISO system have an allowance, and therefore a nut using position G can be used with a position h external thread, and not develop metal-to-metal contact.

6.1.23.2 Gaging

6.1.23.2.1 Inspection or gaging requirements of threads shall be identified in accordance with ASME B1.1-1989 Section 6 “Screw Thread Designation.”

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

6.1.23.2.3 Threads used to secure the positioning of components on turbine rotors shall be inspected in accordance with the following requirements.

- a) Go, No-Go gaging shall be used if thread length is less than $1\frac{1}{2}$ times the gage length.
- b) If thread length is greater than $1\frac{1}{2}$ times the gage length, they shall be checked in accordance with ASME B1.3M-1986 gaging system 22 using differential gaging.
- c) The pitch diameter and cumulative variation of thread characteristics such as lead, flank angle, taper, and roundness (functional diameter) shall be measured and shall not exceed the tolerance on pitch diameter.

- d) The major diameter of all external threads and minor diameter of all internal threads shall also be measured and shall not exceed the tolerances of the specification specified in 6.1.23.1.

6.1.23.3 Clearance shall be provided at all bolting locations to permit the use of respective socket or box wrench sizes.

6.1.23.4 Internal socket-type, slotted-nut, or spanner-type bolting shall not be used unless approved by the purchaser.

NOTE For limited space locations, integrally flanged fasteners can be needed.

6.1.23.5 The bolting that needs to be disassembled for maintenance shall be as specified in 6.1.23.1.

6.1.23.6 Fasteners (excluding washers and headless set-screws) shall have the material grade and manufacturer's identification symbols applied to one end of studs 10 mm ($\frac{3}{8}$ in.) in diameter and larger and to the heads of bolts 6 mm ($\frac{1}{4}$ in.) in diameter and larger. If the available area is inadequate, the grade symbol may be marked on one end and the manufacturer's identification symbol marked on the other end. Studs shall be marked on the exposed end.

6.2 Turbine Casings

6.2.1 The pressure casing(s) shall be designed to:

- a) operate without leakage or internal contact between rotating and stationary components while subjected simultaneously to the maximum allowable working pressure (and corresponding temperature) and the worst-case combination of maximum allowable nozzle loads applied to all nozzles;
- b) withstand the hydrostatic test;
- c) operate at the most severe coincident pressure and temperature corresponding to the specified steam conditions.

6.2.1.1 The allowable tensile stress used in the design of the pressure casing (excluding bolting) for any material shall not exceed 25 % of the minimum ultimate tensile strength or 67 % of the minimum yield strength for that material at the maximum allowable temperature.

6.2.1.2 For cast materials, the allowable tensile stress shall be multiplied by the appropriate casting factor as shown in Table 1.

Table 1—Material 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

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

6.2.1.3 A corrosion allowance of at least 3 mm (0.12 in.) shall be added to the casing thickness used in 6.2.1.1. This corrosion allowance also applies to the auxiliary connections exposed to the same steam as in the pressure containing casing. The vendor may propose alternative corrosion allowances if materials of construction with superior corrosion resistance are employed without affecting functionality, safety and reliability.

6.2.1.4 For casing joint bolting, the allowable tensile stress, as determined in 6.2.1.1 shall be used to determine the total bolting area based on hydrostatic load.

6.2.1.4.1 The preload stress shall not exceed 75 % of the bolting material minimum yield.

6.2.1.4.2 During hydro test, the bolting preload stress shall not exceed 90 % of the bolting material minimum yield. If the bolt preload exceeds 75 %, a positive method for measuring bolt elongation shall be used.

NOTE 1 Preloading the bolting is needed to prevent unloading the bolted joint due to cyclic (heating and cooling) operation.

NOTE 2 Thread stress in the nut or casing can be the limiting factor in the strength of the bolting.

NOTE 3 Torque wrenches are not an acceptable way to determine bolt elongation due to variations in friction factor.

6.2.1.5 The vendor shall state the source of the material properties used in 6.2.1.1, such as ASTM, ASME BPVC, etc., as well as the casting factors applied in the proposal.

6.2.1.6 Steam turbine pressure casings are outside of the scope of ASME BPVC. ASME BPVC manufacturing data report forms, and stamping are not required.

NOTE It is recognized that some other pressure vessel design codes do not exclude rotating equipment casings.

6.2.2 The vendor shall define the maximum allowable working pressure of the turbine casing and shall meet the requirements of 6.2.2.1 through 6.2.2.3.

6.2.2.1 The vendor shall define the physical limits and the maximum allowable working pressure of each part the turbine casing if it is designed as a split-pressure-level casing.

6.2.2.2 The exhaust casings of condensing turbines shall be capable of running at 150 °C (300 °F) or higher.

NOTE 1 During operation with poor vacuum or no-load testing, the exhaust temperature rises. This value is to ensure that the turbine can operate in either of these conditions.

NOTE 2 Some condensing turbines can need cooling of exhaust casing for this purpose.

6.2.2.3 For condensing turbines, the exhaust casings shall be designed for both full vacuum and for a maximum allowable working gauge pressure of at least 70 kPa (10 psi).

NOTE Refer to 7.2.2 for turbine relief valves.

6.2.3 Turbine casings shall be axially split. Turbine casings may also be split radially between high-pressure and low-pressure sections. Where possible, vertical joints in the turbine casings shall be discontinuous at the horizontal split to avoid a four-cornered joint.

6.2.4 The main joints of axially and radially split turbine casings shall use a metal-to-metal joint that is tightly maintained by bolting. Gaskets (including string type) shall not be used.

NOTE The main joint of turbine casing can incorporate a sealing compound that is suitable for the maximum specified operating conditions of steam.

6.2.5 Each axially split casing shall be sufficiently rigid to allow removal and replacement of its upper half without disturbing rotor-to-casing running clearances.

6.2.6 Casings and supports shall be designed to have sufficient strength and rigidity to limit any change in the relative position of the shaft ends at the coupling flange, caused by the worst combination of allowable pressure, torque, and piping forces and moments, to 50 µm (0.002 in.).

NOTE This paragraph does not apply to thermal growth.

6.2.7 Supports, and the design of jackscrews and their attachments, shall be rigid enough to permit the turbine to be moved by the use of its lateral and axial jackscrews without permanent deformation of the support plates and jackscrews.

6.2.8 The use of threaded holes in pressure parts shall be minimized.

6.2.9 To prevent leakage in pressure sections of casings, metal equal to at least 12 mm (0.50 in.) in addition to any allowance for corrosion, shall be left around and below the bottom of drilled and threaded holes.

6.2.10 Bolting shall be furnished as specified in 6.2.10.1 through 6.2.10.3.

6.2.10.1 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 joints, except where hexagonal head cap screws are essential for assembly purposes and have been approved by the purchaser.

6.2.10.2 The main casing joint studs and nuts shall be designed for the use of hydraulic bolt tensioning. Other methods of bolt tensioning may be used with purchaser's approval. Extent of special tooling provided by the vendor shall be agreed.

NOTE Thermal expansion of studs is another method for bolt tensioning. Torque wrenches are generally used where space does not allow use of thermal expansion or hydraulic bolt tensioning devices.

6.2.10.2.1 The vendor shall provide a schedule that detail the bolt torque or elongation requirements and tightening sequence for turbine main axial split joint, valve chest (if bolted to the casing) and exhaust casing.

NOTE Refer to ASME PCC-1 for torque tightening of ASME flanges.

6.2.10.2.2 Through bolting is preferred in areas of the turbine casing where temperature exceeds 410 °C (770 °F).

NOTE Through bolting is not possible in some areas of turbine such as steam chest.

6.2.10.3 As a minimum, the bolting for steel casings shall be high temperature alloy steel in accordance with ASTM A193 Grade B7 and carbon steel ASTM A194, Grade 2H nuts. Case hardened washers shall be provided to resist galling between the nuts and the spot faced (machined flat) surfaces on the casing. Where space is limited, ASTM A563, Grade A case hardened carbon steel nuts, as a minimum, shall be used.

6.2.11 Jackscrews, guide rods, cylindrical casing-alignment dowels and/or other appropriate devices shall be provided to facilitate disassembly and reassembly and shall meet the requirements of 6.2.11.1 through 6.2.11.3.

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

6.2.11.2 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 an improper fit caused by marring of the face.

6.2.11.3 Lifting lugs or swivel eyebolts shall be provided for lifting the top half of the turbine casing.

6.2.12 Mounting surfaces on the turbine shall meet the following criteria.

- a) They shall be machined to a finish of 6.3 µm (250 µin.) R_a or better.
- b) Each mounting surface shall be machined within a flatness of 40 µm per linear meter (0.0005 in. per linear foot) of mounting surface.
- c) They shall be in the same horizontal plane within 25 µm (0.001 in.) to prevent a soft foot.
- d) Different mounting planes shall be parallel to each other within 50 µm (0.002 in.).

- e) The 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) Holes shall be spot faced to a diameter suitable for a washer positioned eccentrically around the bolt.
- h) Holes shall be 15 mm ($1/2$ in.) larger in diameter than the hold down bolt.

6.2.13 Turbine support feet shall be provided with vertical jackscrews and shall be drilled with pilot holes that are accessible for use in final doweling.

6.2.14 If casing expansion keys and slide surfaces are used, the vendor shall provide a material combination that prevents sticking during transient and normal operating conditions. The vendor shall provide details regarding their design, location, and materials of construction.

NOTE Slotted holes are used in some turbine designs to allow thermal expansion of casing.

6.3 Casing Appurtenances

6.3.1 Permanent connections with valves shall be provided to monitor turbine first stage pressure.

6.3.2 The exhaust casing on condensing turbine shall have inspection opening(s) for exhaust stage blade inspection. Machined and studded or flanged connections are required for inspection openings.

- **6.3.3** If specified, casing connections with valves shall be provided for an inert gas blanket to be used for preservation of turbine during storage at site before installation.

6.4 Pressure Casing Connections

6.4.1 All openings or nozzles for piping connections on pressure casings shall be at least nominal pipe size (NPS) 3/4 (DN 20).

6.4.2 Connections shall be in accordance with ISO 6708. 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.

6.4.3 All connections shall be flanged or machined and studded, except where threaded connections are permitted by 6.4.6.

6.4.3.1 All connections shall be suitable for the maximum allowable working pressure(s) of its corresponding section. See 3.1.28 for definition of maximum allowable working pressure.

- **6.4.3.2** The purchaser shall specify the orientation of the main inlet and outlet steam connections.

6.4.3.3 Flanged connections shall be integral with the casing or, for casings of weldable material, may be formed by a socket-welded or butt-welded pipe nipple or transition piece and shall terminate with a welding-neck or socket-weld flange.

6.4.4 Connections welded to the casing shall meet the material requirements of the casing, including impact values 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.

6.4.5 Butt welded connections, size NPS 1 1/2 (DN 40) and smaller, shall be reinforced by using forged welding inserts or gussets. If gussets are provided, the piping shall be gusseted in two orthogonal planes to increase the rigidity of the piped connection, in accordance with the following criteria.

- a) Gussets shall be of a material compatible with the pressure casing and the piping and shall be made of either flat bar with a minimum cross section of 25 mm by 3 mm (1 in. by 0.12 in.) or round bar with a minimum diameter of 9 mm (0.38 in.).
- b) Gussets shall be located at or near the connection end of the piping and fitted to the closest convenient location on the casing to provide maximum rigidity. The long width of gussets made with bar shall be perpendicular to the pipe and shall be located to avoid interference with the flange bolting or any maintenance areas on the turbine.
- c) Gusset welding shall meet the fabrication requirements, including post-weld heat treatment (PWHT) if required, and the inspection requirements of this standard.

6.4.6 For connections other than main steam connections, if flanged or machined and studded openings are impractical, threaded connections for pipe sizes not exceeding NPS 11/2 (DN 40) may be used with purchaser's approval as follows:

- a) on nonweldable materials;
- b) where essential for maintenance (disassembly and assembly).

6.4.7 The first segment of pipe nipples welded to the casing shall not be more than 150 mm (6 in.) long and shall be a minimum of Schedule 160 seamless for sizes NPS 1 (DN 25) and smaller and a minimum of Schedule 80 for NPS 11/2 (DN 40).

6.4.8 The nipple and flange materials shall meet the requirements of 6.4.3.

6.4.9 Flanges

6.4.9.1 Unless otherwise specified, the CLASS system applies, and all flanges shall conform to ASME B16.5 or ASME B16.47 Series B, as applicable.

NOTE 1 ISO 7005-1 describes flanges according to PN (EN1092-1) or CLASS (ASME B16.5 or ASME B16.47). PN flanges specify size by DN numbers, and CLASS flanges use NPS.

NOTE 2 ASME BPVC Section VIII, Division 2 "Design Rules for Flanged Joints" is typically used for the design of steam turbine inlet flanges with rating class designation 2500 and flange sizes greater than NPS 12 and for the design of exhaust end flanges of condensing steam turbines for the sizes that are not covered by ASME B16.5 or ASME B16.47 standards.

- **6.4.9.2** If the PN system is specified, all flanges shall conform to EN 1092-1, except as specified in 6.4.9.3 through 6.4.9.8.

NOTE EN 1092-1 flanges are PN 6, 10, 16, 25, 40, 63, 100, 160, 250, 320, and 400.

6.4.9.3 Steel flanges shall conform to the dimensional requirements of ASME B16.5 or ASME B16.47 Series B or EN 1092-1, as applicable.

- **6.4.9.4** If specified, ASME B16.47 Series A steel flanges shall be provided for class system flanges.

NOTE 1 ASME B16.47 covers flange diameters from NPS 26 through NPS 60.

NOTE 2 ASME B16.47 Series A flanges are thicker and heavier than Series B flanges in the same size and pressure rating.

6.4.9.5 The vendor shall provide pressure and temperature ratings for materials not covered by referenced flange standards.

6.4.9.6 Flat face 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. Nonstandard (oversized) flanges shall be completely dimensioned on the arrangement drawing.

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

6.4.9.8 For all steel flanges, imperfections in the flange facing finish shall not exceed that permitted in ASME B16.5 or ASME B16.47, as applicable.

- **6.4.10** Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.5 or ASME B16.47 or EN 1092-1, as specified. Studs and nuts shall be provided installed and 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.

6.4.11 Machined and studded connections and flanges not in accordance with ASME B16.5, or ASME B16.47 or EN 1092-1 require purchaser's approval. The turbine vendor shall supply mating flanges, gaskets, studs, and nuts for these nonstandard connections.

6.4.12 To minimize nozzle loading, and facilitate installation of piping, machine flanges shall be parallel to the plane of the flange as shown on the general arrangement drawing to within 0.5°. Pairs of studs or bolt holes shall straddle centerlines parallel to the main axes of the flange.

6.4.13 All of the purchasers' connections shall be accessible for disassembly without requiring the steam turbine, or any major part of the turbine to be moved.

6.4.14 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 steam flow.

6.4.15 For socket-welded construction, there shall be a 1.5 mm ($1/16$ in.) gap between the pipe end and bottom of the socket before welding.

NOTE Refer to ASME B31.3 Figure 328.5.2B (3) and 328.5.2C.

6.4.16 Material Inspection of Pressure Casing

NOTE 1 Refer to 8.2.2 for inspection of nonpressure-containing parts.

NOTE 2 Refer to 3.1.52 for the definition of pressure casing.

6.4.16.1 Regardless of the generalized limits presented in this section, it shall be the vendor's responsibility to review the design limits of all materials and welds if more stringent requirements are specified. Defects that exceed the limits imposed in 6.4.16.9 shall be removed to meet the quality standards cited, as determined by additional magnetic particle or liquid penetrant inspection as applicable before repair welding.

The vendor shall identify high stress areas of turbine steam chest and pressure casing that may be prone to creep damage and conduct nondestructive microstructure analysis (surface replication test or microscopy) of these areas after manufacturing to aid future remaining life assessment. A report of this analysis shall be furnished by the vendor to the purchaser.

- **6.4.16.2** If radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds or materials is required by the ASME BPVC or specified, the procedures and acceptance criteria in Table 2 shall apply, except as required by 6.4.16.4. Alternative standards may be proposed by the vendor for approval by the purchaser.

NOTE Other national or local standards can be more stringent than ASME BPVC.

Table 2—ASME Material Inspection Standards for Pressure Casings

Type of Inspection	Methods	Acceptance Criteria	
		For Fabrications	For Castings
Radiography	Section V, Articles 2 and 22 of the ASME BPVC	Section VIII, Division 1, UW-51 (for 100 % radiography) and UW-52 (for spot radiography) of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC
Ultrasonic inspection	Section V, Articles 4, 5, and 23 of the ASME BPVC	Section VIII, Division 1, UW53 and Appendix 12 of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC
Magnetic particle inspection	Section V, Articles 7 and 25 of the ASME BPVC	Section VIII, Division 1, Appendix 6 of the ASME BPVC	See acceptance criteria in Table 3
Liquid penetrant inspection	Section V, Articles 6 and 24 of the ASME BPVC	Section VIII, Division 1, Appendix 8 of the ASME BPVC	Section VIII, Division 1, Appendix 7 of the ASME BPVC
Visual inspection (all surfaces)	Section V, Article 9 of the ASME BPVC	In accordance with the material specification and the manufacturer's documented procedures	MSS SP-55

6.4.16.3 The purchaser shall be notified for their review and approval before the vendor makes a major repair to a pressure-containing part. Major repair, for the purpose of purchaser's notification, 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.

NOTE Major repairs typically occur at the foundry level in the manufacturing process. Purchaser's review and approval of major repairs to components depends on the criticality of the part, the material and heat treatment, and the extent of repair needed.

6.4.16.4 All repairs to pressure-containing parts 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 inspection of 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 Table 2.

6.4.16.5 Plate used in fabrications shall be 100 % ultrasonic inspected prior to starting fabrication in accordance with the ASTM standard to which the plate was purchased.

6.4.16.6 Cast and Nodular iron (if used for turbine diaphragms) shall be inspected only in accordance with magnetic particle and liquid penetrant methods.

6.4.16.7 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. If spot radiograph is required, as a minimum, one spot radiograph shall be performed for each welding procedure used and each welder used for pressure-containing welds.

6.4.16.8 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.

6.4.16.9 For cast steel magnetic casing parts 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 3.

Table 3—Maximum Severity of Defects in Castings

Type	Defect	Degree
I	Linear discontinuities	1 (Code all)
II	Shrinkage	2
III	Inclusions	2 (Code 3)
IV	Chills and chaplets	1
V	Porosity	1
VI	Welds	1

6.5 External Forces and Moments

6.5.1 Turbines shall be designed to withstand external forces and moments at least equal to the values calculated in accordance with Annex D.

6.5.2 The turbine vendor shall tabulate the allowable forces and moments for each casing connection.

6.6 Rotating Elements

6.6.1 Shaft

6.6.1.1 The rotor shaft sensing areas to be observed by probes shall meet the requirements specified in API 670.

6.6.1.2 Shaft shall be capable of transmitting torque at least equal to the torque determined by potential maximum power at normal speed. The shaft end design shall conform to the requirements of API 671.

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

6.6.1.4 Keys shall be the same material as the shaft. Keys shall have chamfer at least equal to the adjacent keyway radii.

NOTE Keys for integrally forged rotors are sometimes made from material that is different from the shaft material.

6.6.1.5 Unless otherwise specified, integral flanged shaft end shall be provided. If an integral flange cannot be supplied, a keyless hydraulically fitted coupling hub shall be provided. Keyed coupling hub requires the purchaser's approval.

6.6.1.6 For mechanical drive application, the turbine vendor shall, jointly with the driven equipment vendor, establish the maximum transient torque value that may occur in the shafting system under start-up, and running conditions. All components, including couplings, and fit of coupling hub on shaft (if coupling hub is provided), shall be suitable for at least 115 % of this value.

For turbine driving a generator, a transient short circuit fault analysis shall determine that the generated stresses in the shafting shall not exceed its low cycle fatigue limit and in couplings, the torque shall not exceed the coupling vendor's peak torque rating (see 6.8.6.8).

6.6.1.7 Shaft shall not be plated or welded. Plating shall not be used to correct manufacturing errors.

6.6.1.8 Areas of shafts that are prone to damage by set-screws shall be relieved to facilitate the removal of components.

6.6.2 Rotor

6.6.2.1 The vendor shall provide a maximum allowable momentary rotor overshoot speed at which no damage would occur to the turbine rotor that would require immediate maintenance intervention.

6.6.2.1.1 The vendor shall identify the limiting component(s) at the maximum allowable momentary rotor overshoot speed.

6.6.2.1.2 The maximum allowable momentary rotor overshoot speed shall not be less than 127 % of rated speed at any specified condition for mechanical drives or 121 % of synchronous speed for generator drives.

6.6.2.1.3 The vendor shall provide the calculation of the predicted maximum momentary rotor overshoot speed following an overspeed trip event per Annex E to confirm that this speed shall not exceed the maximum allowable momentary rotor overshoot speed.

NOTE 1 Rubbing of internal seals and minor localized yielding of rotor components can occur and vibration levels can increase after an overspeed event.

NOTE 2 Local temperature, material properties, loads on the wheels, blades, blade roots, shrouds, shroud attachment methods, and other rotor elements are considered by turbine vendor when determining the maximum allowable momentary rotor overshoot speed.

NOTE 3 The vendor usually determines the predicted maximum momentary rotor overshoot speed and the maximum allowable momentary rotor overshoot speed after turbine rotor design is finalized.

NOTE 4 The purchaser and the vendor can agree on values other than those in 6.6.2.1.2 based on proven operating experience with some turbine rotors.

6.6.2.2 Rotors shall be of integrally forged construction. With purchaser's approval, built-up rotors (disks shrunk on the shaft) may be applied if blade tip velocities are less than 250 m/s (825 ft/s) at maximum continuous speed or if stage inlet steam temperatures are less than 440 °C (825 °F).

6.6.2.2.1 Shafts of built-up rotors shall be machined from one-piece heat treated steel.

6.6.2.2.2 Shafts of built-up rotors with finished diameter 200 mm (8 in.) and larger shall be forged.

6.6.2.2.3 Shafts of built-up rotors with finished diameter less than 200 mm (8 in.) may be hot-rolled bar stock purchased to the same quality and heat treatment criteria as rotor forgings.

6.6.2.3 Each rotor shall be permanently marked with a unique identification number. This number shall be on the nondrive of the shaft or in another accessible area that is not prone to maintenance damage.

- **6.6.2.4** If specified, provisions shall be made for field balancing of the rotor without disassembly of the turbine. The vendor shall describe these provisions and the method of use in the proposal.

6.6.2.5 Rotors shall have steam deflector discs located between the bearing housings and outboard steam gland seal housings to prevent moisture from entering the bearing housings.

NOTE In some turbine designs, steam deflector discs are mounted inside casing end seal housings.

6.6.3 Blading

6.6.3.1 The vendor shall design each blade row analyzing potential resonances of the blades' natural frequencies or modes in the specified operating speed range with any harmonic of rotating speed, up to 15X rotating speed, and first and second upstream vane passing frequencies.

NOTE Blade natural frequencies are determined by blade shaker test, or finite element analysis method.

6.6.3.2 In the design analysis of blading, all potential sources of excitation and forces such as, but not limited to the following, shall be included:

- a) first and second passing frequencies of upstream and downstream stationary blade rows;
- b) steam passage splitters;
- c) irregularities in vane pitch at horizontal casing flanges;
- d) the first four turbine speed harmonics;
- e) casing openings (exhaust or extraction);
- f) partial arc diaphragms or nozzle plates;
- g) internal struts and structural members in the inlet and exhaust casing or horizontal joints.

6.6.3.3 The blade natural modes to be considered in the design analysis shall include at least the tangential (in-phase and out of phase), axial, and torsional modes, including, if applicable, packet (blades per banded group) modes. Blades' natural frequencies calculations shall include a correction for actual operating temperature and operating speed.

6.6.3.4 Blade design shall meet one of the following requirements.

- a) Resonance shall not occur within 10 % of the excitation frequencies mentioned in 6.6.3.1.
- b) If any resonance is possible, the relevant dynamic stresses for any specified operating condition shall be low enough to ensure continuous, trouble-free operation. This shall be assessed during the design phase according to the following methods.
 - 1) Resonance dynamic stresses calculation and comparison with allowable limits (using Goodman or Haigh or equivalent diagram) to check that the safety factor meets turbine vendor's design practices.
 - 2) Resonance is acceptable according to the standard design practices of the turbine vendor if the same type of blade and the same or scaled blade design has already been operated at the same or higher load in the same speed range.
- c) Blades shall be designed to withstand operation at all resonances with relevant excitations encountered during normal start-up.

6.6.3.5 Prior to manufacturing, the vendor shall provide the following design data for each row of blades for the purchaser's review and acceptance:

- a) steam bending stresses;
- b) Campbell or equivalent diagrams;

- c) Goodman or Haigh diagrams together with supporting computations showing total operating stress (steady state plus cyclic) of all blading for which resonant interference occurs within the normal operating speed range. The vendor shall also list the maximum allowable mean and alternating blade stresses.

6.6.3.6 All blades shall be mechanically suitable for operation (including transient conditions) over the specified speed range. The vendor shall assume that the driven equipment torque varies with the square of the speed.

6.6.3.7 Blade rows with shrouds retained by peened blade tenons shall meet the requirements of 6.6.3.7.1 through 6.6.3.7.3.

6.6.3.7.1 Tenon holes in the shrouds shall be drilled or milled and finished with radii or chamfers on both ends of the holes.

6.6.3.7.2 Shrouds shall be rolled to the proper radius prior to fitting and shall be fitted to the blades and peened so that there are no gaps between the shrouds and the blades. The vendor shall state the method used for peening the tenons.

6.6.3.7.3 Prior to blade tenon peening, test peening shall be completed for each new tenon/shroud geometry and/or metallurgy. Procedure for qualifying the tenon peening process shall include the following requirements to ensure consistent results.

- a) Manufacture six "peening samples" from the same metallurgy and material properties of stock used to manufacture the blades. The samples shall have the tenon geometry machined into them, including diameter, height, fillet radius, and surface finish.
- b) Manufacture a shroud sample using the same type of material used for the final shroud, including the hole tenon with all design features such as through diameter, corner radius adjacent to the top of blade, top of tenon hole chamfer, and surface finish.
- c) Peen the tenons to the shroud using the peening process used for peening of the rotor. If an automatic peening machine is used, record all settings, including but not limited to working pressure and travel.
- d) Conduct the nondestructive examination (NDE) of the peened tenons to check for cracks.

NOTE API RP 687 includes considerations for peening of blade tenons.

6.6.3.8 The vendor shall identify to the purchaser all areas of shot peening in the blades and blade roots.

6.6.3.9 Shot peening shall conform to the requirements of 6.6.3.9.1 through 6.6.3.9.4.

6.6.3.9.1 X-ray diffraction or other approved residual stress method test results shall be available to confirm the specified intensity results in the desired compressive depth required.

6.6.3.9.2 The setup shall be purged of all shot not used for the job peening. The peening set-up shall be qualified prior to peening the blades by installing Almen strips at the same angle and distance from the nozzles as the blades. The time, intensity, and shot size shall be the same as for the blades. The test Almen strip shall indicate the same intensity as required for the blading.

6.6.3.9.3 Shot shall not be larger than 50 % of the smallest radius on the surface to be peened.

6.6.3.9.4 Peen scan shall be applied to all blade areas to be peened. Inspect all blades with a black light after peening to confirm that all peen scan has been removed and there is full coverage of the required areas. Inspect with a 10X lighted magnification all fillets and radiuses after peening.

6.6.4 Speed-sensing Element

6.6.4.1 A dedicated multi-toothed surface for speed sensing shall be provided integral with or positively attached and locked to the turbine shaft. Other speed sensors may share this surface.

6.6.4.2 The multi-toothed surface shall not be used as a gear for driving other mechanical components.

6.6.4.3 The axial width of the multi-toothed surface (the width of the surface being viewed by radial probes) shall be a minimum of one and one-half times the diameter of the probe tip.

6.7 Seals and Internal Stationary Components

6.7.1 Seals

6.7.1.1 Shaft seals or packing and inter-stage diaphragm seals shall be bronze, nickel bronze, stainless steel, or other suitable materials agreed by the purchaser and the turbine manufacturer. Gray cast iron and Ni-resist diaphragm seals are acceptable only with the purchaser's approval.

6.7.1.2 Casing end seals shall be replaceable labyrinth seals, brush seals, or a combination of both.

6.7.1.3 Interstage seals shall be replaceable labyrinths, brush seals, or a combination of both.

6.7.1.4 Labyrinth casing end seals operating at less than atmospheric pressure shall be designed for admission of dry steam to seal against air ingress.

6.7.1.4.1 Piping with pressure gauges, regulators and other necessary valves shall be provided to interconnect the end labyrinth seals. The piping shall have one common connection to the purchaser's sealing steam supply.

6.7.1.4.2 The admission and the pressure of the sealing steam shall be automatically controlled with the normal operating sealing steam supply from a positive pressure section of the turbine.

6.7.1.5 A separate gland vacuum system shall be furnished to reduce external leakage from the casing end labyrinth seals and possible contamination of the bearing oil (see 7.5).

6.7.1.6 Unless otherwise specified, the vacuum system shall be supplied loose for mounting and connection by others.

NOTE Annex F shows typical gland sealing and leak-off systems.

6.7.1.7 All piping, and components of the shaft seal and vacuum systems, shall be sized for not less than 300 % of the calculated new clearance leakage.

6.7.1.8 Sizing criteria for shaft seal and vacuum systems shall be agreed by the purchaser and turbine vendor if brush type shaft seals are used.

6.7.2 Internal Stationary Components

6.7.2.1 All control stage nozzle rings shall be replaceable. Nozzle rings welded to the outer casing are acceptable only when approved in advance by the purchaser.

6.7.2.2 All noncontrolled stage stationary blading shall be mounted in replaceable diaphragms or blade carriers.

6.7.2.2.1 Nozzles or blades shall be structurally welded (completely seal welded) to the diaphragm. Less than full perimeter welding, if proposed, shall require the purchaser's approval.

NOTE This is generally not applicable to blades in a reaction flow path.

6.7.2.2.2 Partial blading at the diaphragm split line shall be designed to prevent failure of the thin part of the blading during turbine operations.

6.7.2.3 All internal fasteners shall be positively retained or trapped to prevent them from entering the steam path.

NOTE Wire lock, slotted nuts, flanged washers, contoured threads, caulking strips and wedge lock washers are examples of devices typically used to retain fasteners inside steam turbines.

6.7.2.4 The arrangement of internal components in condensing turbine shall ensure that water cannot be trapped in the wet region (i.e. region operating at or below the onset of steam condensation).

6.7.2.4.1 The design of water drain holes in the wet region of a condensing turbine shall avoid these holes from becoming blocked by corrosion or debris.

6.7.2.4.2 In the case of drain holes in the diaphragms of an impulse type turbine, this shall be achieved by lining the drain holes with a corrosion-resistant material.

6.7.2.5 All diaphragms, blade carriers, or other inner casings shall be designed with vertical leveling and positioning lugs or shims located near the horizontal split line. Radial ground crush pins shall not be used to set the alignment.

6.7.2.5.1 The vendor shall indicate the required vertical and horizontal assembly clearances for each diaphragm or blade carrier.

6.7.2.5.2 In the condensing sections of reaction turbines, the diaphragms may be bolted to the exhaust casing.

6.7.2.6 Packing holders for shaft end seals shall be designed with vertical leveling lugs located near the split line for adjustment. If adjustable packing holders are not supplied, the vendor shall define how to align packing holders during maintenance.

6.7.2.7 Turbines operating on saturated steam shall have components in the steam path (e.g. nozzles, blading, flow path of diaphragms) made of erosion-resistant materials or have appropriate erosion-resistant coatings applied. The type of erosion-resistant coating shall be agreed by the purchaser and the turbine vendor.

6.7.2.8 Provisions shall be made to minimize water cutting of wet stages (i.e. stages operating at or below the onset of steam condensation) at the diaphragm horizontal joint and the diaphragm to casing sealing face. Options to minimize the problem include stainless steel inlay or inserted rings.

NOTE Special provisions to minimize water cutting are often unnecessary for blade carriers of wet stages in reaction turbines, due to the higher sealing surface at horizontal split joint and low moisture content upstream of the blade carrier.

6.8 Dynamics

6.8.1 General

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

6.8.1.1 In the design of rotor-bearing systems, consideration shall be given to all potential sources of excitation and force such as, but not limited to, the following:

- a) unbalance in the rotor system;
- b) fluid forces from bearings, seals, and aerodynamics;
- c) internal rubs;

- d) blade and nozzle 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;
- k) electrical line frequency.

NOTE 1 The frequency of a potential source of excitation or force 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, it is in a state of resonance.

NOTE 3 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.

6.8.1.2 Resonances of structural support systems that are within the vendor's scope and that affect the rotor vibration amplitude shall not occur within the required operating speed range or the specified separation margins (SM_r) (see 6.8.2.9). The dynamic characteristics of the structural support shall be considered in the analysis of the dynamics of the rotor-bearing-support system [see 6.8.2.3, Item e)].

6.8.1.3 The vendor with unit responsibility shall communicate the existence of any undesirable running speeds in the range from zero to trip speed. This shall be illustrated by the use of a Campbell diagram, submitted to the purchaser for review and included in the instruction manual [see Annex G for vendor drawing and data requirements (VDDR)].

NOTE Examples of undesirable running speeds are those associated with rotor lateral critical speed with amplification factors (AFs) greater than or equal to 2.5, train torsional natural frequencies, and blade modes.

6.8.1.4 Lateral analysis requirements specified in 6.8.2, 6.8.4, and 6.8.5 shall be reported per 6.8.1.4.1 through 6.8.1.4.3 and Annex H.

6.8.1.4.1 The basic rotordynamic report shall be provided for purchaser's review and approval.

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

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

6.8.1.5 Torsional analysis requirements specified in 6.8.6 shall conform to 6.8.1.5.1 through 6.8.1.5.3 and Annex I.

6.8.1.5.1 The basic torsional report for all covered machines shall be provided for purchaser's review and approval.

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

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

6.8.2 Lateral Analysis

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

6.8.2.2 The vendor 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 the stiffness range to produce free-free to rigid support modes.

6.8.2.3 The lateral analysis shall include, but not be limited to, the following:

- rotor stiffness, mass, and polar and transverse moments of inertia, including coupling halves, and rotor stiffness changes due to shrunk on components and temperature variation along the rotor;
- material properties as a function of operating temperature variation along the turbine shaft;
- bearing lubricant-film stiffness and damping values, including changes due to speed, load, minimum to maximum preload, range of oil inlet temperature and pressure, maximum to minimum clearances resulting from accumulated assembly tolerances, and the effect of asymmetric loading that may be caused by partial arc steam admission, bearing support effects, thermal effects on the bearings, and eccentric clearances;

NOTE Minimum and maximum bearing clearance for a tilt pad bearing occurs at the maximum and minimum preload conditions respectively. These can be calculated using the following formulas.

For minimum clearance at maximum preload:

$$\text{Preload}_{\max} = 1 - \frac{\text{Bearing radius}_{\min} - \text{Shaft radius}_{\max}}{\text{Pad bore}_{\max} - \text{Shaft radius}_{\max}}$$

$$\text{Bearing clearance}_{\min} = \text{Bearing radius}_{\min} - \text{Shaft radius}_{\max}$$

For maximum clearance at minimum preload:

$$\text{Preload}_{\min} = 1 - \frac{\text{Bearing radius}_{\max} - \text{Shaft radius}_{\min}}{\text{Pad bore}_{\min} - \text{Shaft radius}_{\min}}$$

$$\text{Bearing clearance}_{\max} = \text{Bearing radius}_{\max} - \text{Shaft radius}_{\min}$$

- for tilt-pad bearings, the pad pivot stiffness and pad inertia;
- support structure stiffness, mass, and damping characteristics, including effects of excitation frequency over the required analysis range; for machines whose dynamic support stiffness values are less than or equal to 3.5 times the maximum bearing stiffness values at N_{mc} , the support characteristics shall be incorporated as an adequate dynamic system model, calculated frequency dependent support stiffness and damping values (impedances), or support stiffness and damping values (impedances) derived from modal or other testing; the vendor 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);
- 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;
- the influence over the operating range of the casing end gland seals; minimum and maximum stiffness shall be considered taking into account the tolerance on the component clearance;

- h) the location and orientation of the radial vibration probes which shall be the same in the analysis as in the machine;
- i) the effective stiffness diameter at the turbine wheel stages;
- j) for tilt-pad squeeze film damper bearings, damper mass, stiffness and damping values considering the component clearance and centering tolerance, oil inlet temperature range, and operating eccentricity.

NOTE Details and product of the analysis are covered in 6.8.2.7 and 6.8.2.8.

- **6.8.2.4** If specified, the vendor with unit responsibility shall provide a train lateral analysis for machinery trains with flexible couplings.

6.8.2.5 The vendor with unit responsibility shall provide a train lateral analysis for machinery trains with rigid couplings.

6.8.2.6 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 and shall meet the requirements of 6.8.2.6.1 through 6.8.2.6.3.

6.8.2.6.1 For the translatory (symmetric) modes, the unbalance shall be based on the sum of the journal static loads.

6.8.2.6.2 For conical (asymmetric) modes, unbalances shall be 180° out of phase and of a magnitude based on the static load on the adjacent bearing.

6.8.2.6.3 For overhung modes, the unbalances shall be based on the overhung mass.

6.8.2.7 Figure 1 shows the typical mode shapes and indicate the location and definition of U_a for each of the shapes. The magnitude of the unbalances shall be two times the value of U_r as calculated by Equation (1).

In SI units:

$$U_r = 6350 \frac{W}{N_{mc}} \text{ (for } N_{mc} < 25,000 \text{ rpm)} \quad (1a)$$

$$U_r = \frac{W}{3.937} \text{ (for } N_{mc} \geq 25,000 \text{ rpm)}$$

In USC units:

$$U_r = 4 \frac{W}{N_{mc}} \text{ (for } N_{mc} < 25,000 \text{ rpm)} \quad (1b)$$

$$U_r = \frac{W}{6250} \text{ (for } N_{mc} \geq 25,000 \text{ rpm)}$$

where

U_a	$= 2 \times U_r$ = input unbalance for the unbalance response analysis, g-mm (oz-in.);
U_r	is the maximum allowable residual unbalance, g-mm (oz-in.);
N_{mc}	is the maximum continuous operating speed, rpm;
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 1).

NOTE Above 25,000 rpm, 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 is invoked for small rotors running at high speeds.

For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall be 2 times the maximum of the following assembly check balance values, calculated by Equation (2) and Equation (3).

$$U_{ac1} = \frac{K_1 \times W}{N_{mc}} \quad (2)$$

$$U_{ac2} = K_2 \times W \quad (3)$$

where

K_1 63,500 (40);

K_2 12.7 (0.008);

U_{ac} is the coupling unbalance used in the response analysis, g-mm (oz-in.);

N_{mc} is the maximum continuous operating speed, rpm;

W is the half coupling mass, kg (lbm) (see Figure 1).

6.8.2.8 Additional analyses shall be made for use with the verification test specified in 6.8.3. The location of the unbalance shall be determined by the vendor.

6.8.2.8.1 The unbalance shall not be less than 2 times or greater than 8 times the value from Equation (1) or as specified in 6.8.2.8.2. Any test stand parameters that influence the results of the analysis shall be included.

6.8.2.8.2 For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall not be less than 2 times or greater than 8 times the maximum value of Equations (2) and (3).

NOTE For most machines, there is only one plane readily accessible for the placement of an unbalance, for example, the coupling flange on a single ended drive machine. However, some turbomachinery (steam turbines) can provide additional externally accessible balance planes.

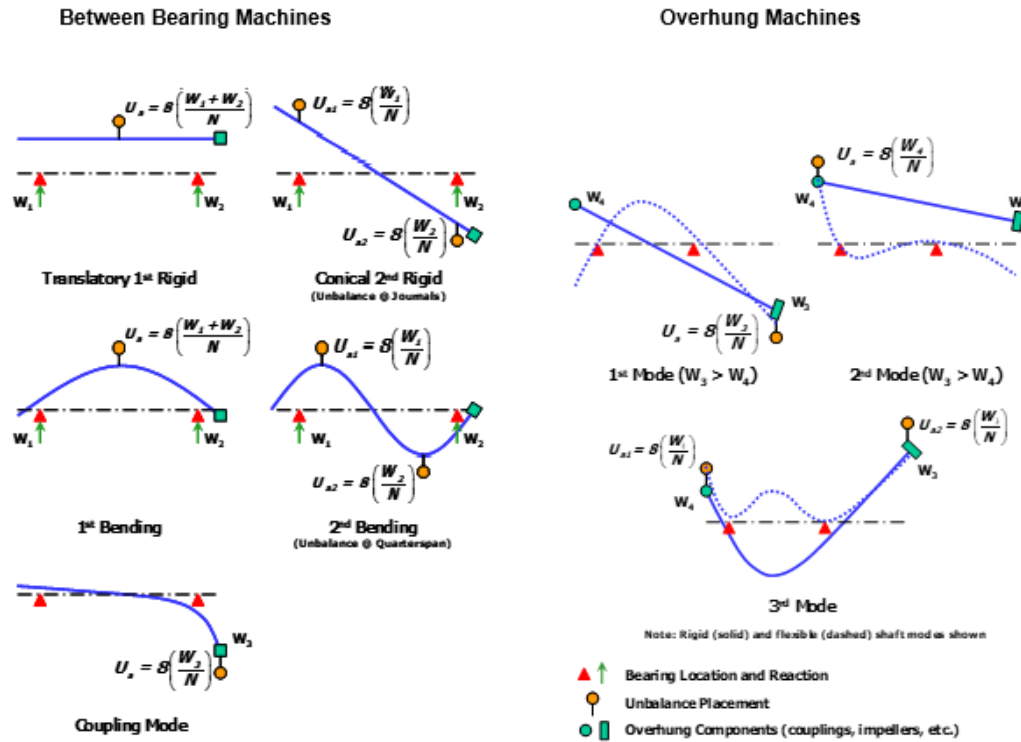


Figure 1—Unbalance Placement

6.8.2.9 The damped unbalance response analysis shall indicate that the machine meets the requirement given by Equation (4).

$$SM_a = SM_r \quad (4)$$

where

SM_r is the required separation margin, %;

SM_a is defined in Figure 2.

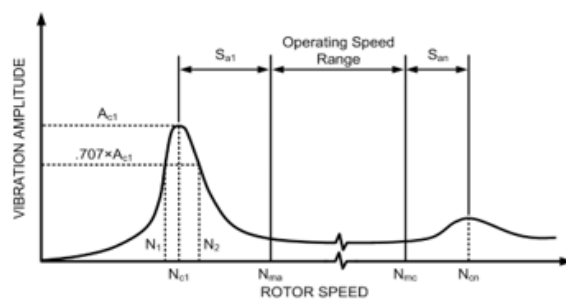
- If the AF at a particular critical speed is less than 2.5, the response is considered critically damped and separation margin is not required ($SM_r = 0$).
- If the AF at a particular critical speed is greater than or equal to 2.5 and that critical speed is below the minimum allowable speed N_{ma} , the SM_r is given by Equation (5).

$$SM_r = 17 \left(1 - \frac{1}{AF - 1.5} \right) \quad (5)$$

- 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 N_{mc} , the SM_r is given by Equation (6).

$$SM_r = 10 + 17 \left(1 - \frac{1}{AF - 1.5} \right) \quad (6)$$

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



N_{c1} = Rotor first critical speed
 N_{cn} = n^{th} 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 n^{th} critical speed (%)
 $= 100 \times S_{an} / N_{mc}$

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

Figure 2—Rotor Response Plot

6.8.2.10 The calculated unbalanced peak-to-peak response at each vibration probe, for each unbalance amount and case as specified in 6.8.2.7, shall not exceed the mechanical test vibration limit, A_{vl} , of [25.4 μm (1.0 mil) or Equation (7), whichever is less] over the range of N_{ma} to N_{mc} as shown in Figure 3.

In SI units:

$$A_{vl} = 25.4 \sqrt{\frac{12,000}{N_{mc}}} \quad (7a)$$

In USC units:

$$A_{vl} = \sqrt{\frac{12,000}{N_{mc}}} \quad (7b)$$

where

A_{vl} is the mechanical test vibration limit, μm (mil);
 N_{mc} is the maximum continuous speed, rpm.

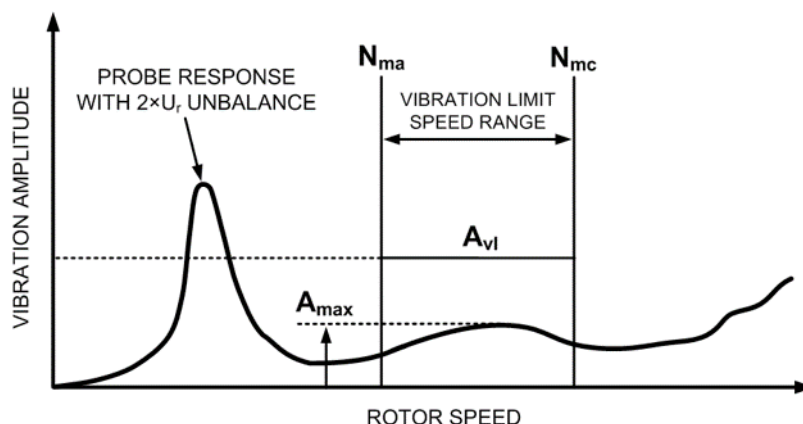


Figure 3—Plot of Applicable Speed Range of Vibration Limit

6.8.2.11 For each unbalance amount and case as specified in 6.8.2.7, the calculated major-axis, peak-to-peak response amplitudes at each close clearance location shall be multiplied by a scale factor defined by Equation (8).

$$S_{cc} = A_{vl}/A_{max} \text{ or } 6, \text{ whichever is less} \quad (8)$$

where

- S_{cc} is the scale factor for close clearance check;
- A_{vl} is the mechanical test vibration limit defined in 6.8.2.10;
- 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 The scale factor will be greater than or equal to one, to meet the requirements of 6.8.2.10.

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

- a) centrifugal/thermal growth;
- b) bearing lift;
- c) rotor sag;
- d) nonconcentricity (of stator to the bearings).

NOTE Running clearances can be different than the assembled clearances with the machine shutdown.

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

- a) the required separation margins, or
- b) the requirements of 6.8.2.10 or 6.8.2.11,

and the purchaser and vendor have agreed that all practical design efforts have been exhausted, then acceptable amplitudes, separation margins, and AFs shall be agreed by the purchaser and the vendor.

6.8.3 Unbalanced Rotor Response Verification Test

6.8.3.1 An unbalanced rotor response test shall be performed as part of the mechanical running test (see Section 8), 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 shall be

6.8.2.8 shall be used for determining the validity of the damped unbalanced response analysis. To accomplish this, the requirements of 6.8.3.1.1 through 6.8.3.1.6 shall be followed.

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

6.8.3.1.1 During the mechanical running test, the amplitudes and phase angle of the shaft vibration from trip to slow roll speed shall be recorded before and after the 4-hour run. The recording instrumentation resolution shall be at least 1.25 μm (0.05 mils).

NOTE This set of readings is normally taken during a coastdown, with convenient increments of speed; typically, 50 rpm. Any vibration amplitude and phase detected is usually the result of residual unbalance and mechanical and electrical runout.

6.8.3.1.2 The unbalance that was used in the analysis performed in 6.8.2.8 shall be added to the rotor in the location used in the analysis.

6.8.3.1.3 The machine shall then be brought up to trip speed after being held at maximum continuous speed until bearing temperatures and radial vibrations have stabilized, and the indicated vibration amplitudes and phase shall be recorded during the coastdown using the same procedure as 6.8.3.1.1.

NOTE Temperature and vibration stabilization can be assumed if respective changes are less than 1 °C (2 °F) and $\pm 20\%$ of vibration limit over 15 minutes at constant oil inlet conditions.

6.8.3.1.4 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 vectorially subtracted from the 1X Bode plots to accurately define the location of the critical speeds.

6.8.3.1.5 The corresponding indicated vibration data taken in accordance with 6.8.3.1.1 and 6.8.3.1.4 shall be vectorially subtracted. Slow roll runout shall be checked prior to subtraction.

NOTE Slow roll runout data taken prior to subtraction is expected to be nearly identical for both runs.

6.8.3.1.6 The results of the mechanical run including the unbalance response verification test shall be compared with those from the analytical model specified at 6.8.2.8. The probe orientation used in the analysis shall be the same as on the machine for the comparison to be valid.

- **6.8.3.2** If specified, the unbalance verification test shall be performed in an operation speed balance bunker. Placement of the unbalance weight and vibration readings shall be agreed.

6.8.3.3 Using the unbalance response test results, the vendor 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 $\pm 5\%$.
- b) At N_{mc} , the probe responses from the results of 6.8.3.1.5 shall not exceed the predicted range.

6.8.3.4 The vendor 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.

6.8.3.5 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.

6.8.3.6 After correcting the model, if required, the response shall be checked against the limits specified in 6.8.2.9 through 6.8.2.11. The vendor shall explain how the model was corrected.

6.8.4 Stability Analysis

6.8.4.1 A stability analysis shall be performed on all turbine rotors whose N_{mc} is greater than the first undamped critical speed on rigid supports (FCSR) in accordance with 6.8.2.3. The stability analysis shall be performed at API defined N_{mc} .

6.8.4.2 The model used in the stability analysis shall include the items listed in 6.8.2.3 to produce the minimum log decrement.

6.8.4.3 If tilt pad journal bearings are used, the analysis shall be performed with synchronous tilt pad coefficients.

6.8.4.4 For turbine rotors that have quantifiable external radial loading (including partial admission steam forces), the stability analysis shall also include the external loads associated with the dimensional and operating conditions defined in 6.8.4.5. For some rotors, the unloaded (or minimal load condition) may represent the worst stability case and shall be considered.

6.8.4.5 The anticipated cross coupling, QA, present in the rotor is defined by Equation (9).

For axial flow turbine rotors:

$$q_a = \frac{(HP)B_t C}{D_t H_t N_r} \quad (9)$$

where

HP is the rated power per turbine stage, Nm/s (HP);

B_t is 1.5;

C is 9.55 (63);

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

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

N_r is the normal operating speed for calculation of aerodynamic excitation, rpm;

q_a is the cross coupling of stage.

Equation (9) is calculated for each stage of the rotor. QA is equal to the sum of q_a for all stages.

6.8.4.6 All potential sources of excitation shall be included in the stability analysis. These shall include, but not be limited to, the following:

- a) labyrinth seals;
- b) blade flow aerodynamic effects;
- c) internal friction.

The vendor 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 above.

6.8.4.7 The stability analysis shall be calculated at N_{mc} .

6.8.4.8 The steam conditions defined for the normal operating point shall be extrapolated to N_{mc} within the operating map if the steam conditions at N_{mc} are different from that at the normal operating point.

6.8.4.9 The dynamic coefficients of the labyrinth seals shall be calculated at the minimum and maximum expected seal operating clearance.

6.8.4.10 The frequency and log decrement of the first forward damped mode shall be calculated progressively for the following configurations:

- a) rotor and support system only;
- b) each source from 6.8.4.6 used in the analysis;
- c) complete model including all sources (final log decrement, δ_f).

6.8.4.11 A sensitivity analysis shall be performed with a varying amount of cross coupling introduced at the rotor mid-span.

6.8.4.11.1 The applied cross coupling shall extend from zero to that required to produce a zero log decrement.

6.8.4.11.2 The anticipated cross coupling QA shall be plotted.

6.8.5 Stability Acceptance Criteria

6.8.5.1 The stability analysis shall indicate that the machine, as calculated in 6.8.4.1 through 6.8.4.11, shall have a final log decrement, δ_f , greater than 0.1.

- **6.8.5.2** If after all practical design efforts have been exhausted to achieve the requirements of 6.8.4.9, acceptable levels of the log decrement, δ_f , shall be agreed, or if specified, a stability test to measure damping ratio and to determine the corresponding log decrement, shall be performed as specified by the purchaser.

6.8.6 Torsional Analysis

6.8.6.1 For trains including gears, the vendor having unit responsibility shall ensure that a torsional vibration analysis of the complete coupled train is performed and shall be responsible for directing any modifications necessary to meet the requirements of 6.8.6.3 through 6.8.6.7.

- **6.8.6.2** If specified, for direct driven steam turbine trains, the turbine vendor 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 6.8.6.3 through 6.8.6.7.

A simplified torsional model (lumped rotor inertia and stiffness) is sufficient for direct driven steam turbine trains.

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

6.8.6.3 The torsional analysis shall include, but not be limited to, the following:

- a) torsional stiffness and inertia of built-up shafts;
- b) effects of operating temperature on material properties;
- c) calculation and distribution of polar mass moment of inertia;
- d) nonlinear effects from sources such as elastomeric or torque limiting couplings;
- e) coupling torsional stiffness boundary;
- f) electromechanical stiffness and damping in generator air gap;

g) penetration factor effects on torsional stiffness due to:

- 1) shaft diameter changes;
- 2) keyways;
- 3) shrink fits;
- 4) bolted assemblies;

h) damping from the following sources:

- 1) material and frictional damping within assemblies;
- 2) fluid/viscous devices (if applicable).

6.8.6.4 Excitation of torsional natural frequencies shall be considered in the analysis. These sources shall include, but are not limited to, the following:

- a) torsional excitation resulting from electric generators;
- b) one and two times electrical line frequency (applicable to electric generator drive);
- c) one and two times operating speed(s).

6.8.6.5 The primary (coupling) modes shall be at least 10 % above or 10 % below the 1X electrical excitation frequency.

6.8.6.6 The intersection of the primary (coupling) modes with the 1X mechanical excitation shall be at least 10 % above or 10 % below the specified operating speed range from minimum to N_{mc} .

6.8.6.7 The intersection of all other torsional natural frequencies with any possible excitation frequency shall be at least 10 % above or 10 % below the specified operating speed range from minimum to N_{mc} .

6.8.6.7.1 If torsional resonances are calculated to fall within the margin specified in 6.8.6.7 (and the purchaser and the vendor 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.

6.8.6.7.2 The analysis shall show that all shaft sections and couplings have infinite life using an agreed criterion.

- **6.8.6.8** If specified, for turbine trains including an electrical generator, a transient short circuit fault analysis shall be performed in accordance with 6.8.6.8.1 and 6.8.6.8.2.

6.8.6.8.1 The following faults shall be considered, but not be 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.

6.8.6.8.2 For these fault conditions, generated stresses in the shafting shall not exceed the low cycle fatigue limit and in couplings, the torque shall not exceed the coupling vendor's peak torque rating.

NOTE The analysis for these fault conditions assumes a onetime event. It is possible that some components identified by the analysis need replacement following the fault event.

- **6.8.6.9** 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.

6.8.7 Vibration and Balancing

6.8.7.1 Major parts of the rotating element such as shaft, discs, and balance drum (if provided) shall be individually dynamically balanced before assembly, to Equation (1) or better.

6.8.7.1.1 If 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.

6.8.7.1.2 Keyways 180° apart, but not in the same transverse plane, shall also be filled.

6.8.7.1.3 The initial balance correction to the bare shaft shall be recorded.

6.8.7.1.4 The components mounted on the shaft shall also be balanced in accordance with the "half-key-convention," as described in ISO 8821.

6.8.7.2 The rotating element shall be sequentially multiplane dynamically balanced during assembly unless an operating speed balance is to be performed. 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. The maximum allowable residual unbalance per plane (journal) shall be calculated as per Equation (1) as applicable.

6.8.7.2.1 In the sequential balancing process, any half keys used in the balancing of the bare shaft (see 6.8.7.1) 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.

6.8.7.2.2 The weight of all half-keys used during final balancing of the assembled element shall be recorded on the Residual Unbalance Worksheet (see Annex J for sample filled-in worksheets).

- **6.8.7.3** If specified, completely assembled rotating elements shall be subject to operating speed balancing.

6.8.7.4 High-speed Balancing Procedure

6.8.7.4.1 The following information shall be provided, prior to high-speed balancing:

- a) the contract rotor dynamic 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.