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Petroleum and natural gas industries — General-purpose steam turbines for refinery service

*Industries du pétrole et du gaz naturel — Turbines à vapeur tous usages
pour service en raffinerie*



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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10436 was prepared by the American Petroleum Institute (API) (as STD 611, 3rd edition) and was adopted, under a special "fast-track procedure", by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*, in parallel with its approval by the ISO member bodies.

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Introduction

International Standard ISO 10436:1993 reproduces the content of API Std 611, 3rd edition, 1988. ISO, in endorsing this API document, recognizes that in certain respects the latter does not comply with all current ISO rules on the presentation and content of an International Standard. Therefore, the relevant technical body, within ISO/TC 67, will review ISO 10436:1993 and reissue it, when practicable, in a form complying with these rules.

This standard is not intended to obviate the need for sound engineering judgement as to when and where this standard should be utilized and users of this standard should be aware that additional or differing requirements may be needed to meet the needs for the particular service intended.

Standards referenced herein may be replaced by other international or national standards that can be shown to meet or exceed the requirements of the referenced standards.

Appendices A to E form an integral part of the requirements of this standard.

Petroleum and natural gas industries — General-purpose steam turbines for refinery service

1 Scope

This International Standard specifies the minimum requirements for general-purpose steam turbines for use in petroleum refinery service.

2 Requirements

Requirements are specified in:

“API Standard 611 (Std 611), Third Edition, August 1988, *General-Purpose Steam Turbines For Refinery Service*”,

which is adopted as ISO 10436.

For the purposes of international standardization, however, modifications shall apply to specific clauses and paragraphs of publication API Std 611. These modifications are outlined below.

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Information contained in **Special Notes** is relevant to the API publication only.

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Subclause 1.5.1

The referenced standards indicated hereafter are available under the following ISO references:

API Std 612 as ISO 10437

API Std 614 as ISO 10438 (at present under study).

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General-Purpose Steam Turbines For Refinery Service

API STANDARD 611
THIRD EDITION, AUGUST 1988

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005



ISO 10436:1993(E)

General-Purpose Steam Turbines For Refinery Service

Refining Department

API STANDARD 611
THIRD EDITION, AUGUST 1988

American
Petroleum
Institute



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FOREWORD

This standard is based on the accumulated knowledge and experience of manufacturers and users of steam turbines. The objective of this publication is to provide a purchase specification to facilitate the manufacture and procurement of general-purpose steam turbines for use in petroleum refinery service.

The primary purpose of API standards for mechanical equipment is to establish minimum mechanical requirements. This limitation in scope is one of charter as opposed to interest and concern. Energy conservation is of concern and has become increasingly important in all aspects of equipment design, application, and operation. Thus, innovative energy-conserving approaches should be aggressively pursued by the manufacturer and the user during these steps. Alternative approaches that may result in improved energy utilization should be thoroughly investigated and brought forth. This is especially true of new equipment proposals, since the evaluation of purchase options will be based increasingly on total life costs as opposed to acquisition cost alone. Equipment manufacturers, in particular, are encouraged to suggest alternatives to those specified when such approaches achieve improved energy effectiveness and reduce total life costs without sacrifice of safety or reliability.

This standard requires the purchaser to specify certain details and features. Although it is recognized that the purchaser may desire to modify, delete, or amplify sections of this standard, it is strongly recommended that all modifications, deletions, and amplifications be made by supplementing this standard, rather than by rewriting or incorporating sections of this standard into another complete standard.

API standards are published as an aid to procurement of standardized equipment and materials. These standards are not intended to inhibit purchasers or producers from purchasing or producing products made to specifications other than those of API.

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Suggested revisions are invited and should be submitted to the director of the Refining Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

IMPORTANT INFORMATION CONCERNING USE OF ASBESTOS OR ALTERNATIVE MATERIALS

Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of great usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 *Code of Federal Regulations* Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the proposed rule by the U.S. Environmental Protection Agency (EPA) proposing labeling requirements and phased banning of asbestos products, published at 51 *Federal Register* 3738–3759 (January 29, 1986; the most recent edition should be consulted).

There are currently in use and under development a number of substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials which can meet the specifications for, and operating requirements of, the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.

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General-Purpose Steam Turbines for Refinery Service

SECTION 1—GENERAL

1.1 Scope

1.1.1 This standard covers the minimum requirements for general-purpose steam turbines for refinery service. These requirements include basic design, materials, related lubrication systems, controls, auxiliary equipment, and accessories.

Note: A bullet (●) at the beginning of a paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the data sheets (see Appendix A); otherwise, it should be stated in the quotation request or in the order.

- **1.1.2** Steam turbines are classified as general- or special-purpose according to service requirements. The purchaser will specify the type of turbine that is best suited to his needs.

1.1.2.1 General-purpose turbines are horizontal or vertical turbines used to drive equipment that is usually spared, is relatively small in size (power), or is in noncritical service. They are generally used where steam conditions will not exceed a pressure of 700 pounds per square inch gauge (48 bar gauge) and a temperature of 750°F (400°C) or where speed will not exceed 6000 revolutions per minute.

1.1.2.2 Special-purpose turbines are horizontal turbines used to drive equipment that is usually not spared, is relatively large in size (power), or is in critical service. The use of special-purpose turbines is not limited by steam conditions or turbine speed. Requirements for special-purpose turbines are defined in API Standard 612.

1.2 Alternative Designs

The vendor may offer alternative designs. Equivalent metric dimensions, fasteners, and flanges may be substituted as mutually agreed upon by the purchaser and the vendor.

1.3 Conflicting Requirements

In case of conflict between this standard and the inquiry or order, the information included in the order shall govern.

1.4 Definition of Terms

Terms used in this standard are defined in 1.4.1 through 1.4.26.

1.4.1 *Axially split* refers to casing joints that are parallel to the shaft centerline.

1.4.2 A *circulating oil system* withdraws oil from the housing of bearings equipped with oil rings and cools it in an external oil cooler before it is returned to the bearing housing.

1.4.3 *Hydrodynamic bearings* are bearings that use the principles of hydrodynamic lubrication. Their surfaces are oriented so that relative motion forms an oil wedge to support the load without journal-to-bearing contact.

1.4.4 *Maximum allowable speed* (in revolutions per minute) is the highest speed at which the manufacturer's design will permit continuous operation (see note to 2.1.4, Item e).

1.4.5 *Maximum allowable temperature* is the maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when operating at the maximum allowable working pressure (see note to 2.1.4, Item e).

1.4.6 *Maximum allowable working pressure* is the maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) when operating at the maximum allowable temperature (see note to 2.1.4, Item e).

1.4.7 *Maximum continuous speed* (in revolutions per minute) is the speed at least equal to 105 percent of the highest speed required by any of the specified operating conditions.

1.4.8 *Maximum exhaust pressure* is the highest exhaust steam pressure at which the turbine is required to operate continuously.

1.4.9 *Maximum exhaust casing pressure* is the highest exhaust steam pressure that the purchaser requires the casing to contain, with steam supplied at maximum inlet conditions.

1.4.10 *Maximum inlet pressure and temperature* refer to the highest inlet steam pressure and temperature conditions at which the turbine is required to operate continuously.

1.4.11 *Minimum allowable speed* (in revolutions per minute) is the lowest speed at which the manufacturer's design will permit continuous operation (see note to 2.1.4, Item e).

1.4.12 *Minimum exhaust pressure* is the lowest exhaust steam pressure at which the turbine is required to operate continuously.

1.4.13 *Minimum inlet pressure and temperature* refer to the lowest inlet steam pressure and temperature conditions at which the turbine is required to operate continuously.

1.4.14 *NEMA inlet and exhaust conditions* are equivalent to the maximum inlet and exhaust steam conditions specified on the data sheets.

1.4.15 *Normal* applies to the power, speed, and steam conditions at which the equipment will usually operate. These conditions are the ones at which the highest efficiency is desired.

1.4.16 *Oil mist lubrication* refers to lubrication systems that employ oil mist produced by atomization in a central supply unit and transported to the bearing housing by compressed air.

1.4.17 With *purge oil mist lubrication* (wet sump), the mist only purges the bearing housing. Bearing lubrication is by conventional oil bath, flinger, or oil ring.

1.4.18 With *pure oil mist lubrication* (dry sump), the mist both lubricates the bearing and purges the housing.

1.4.19 *Potential maximum power* is the approximate maximum power to which the turbine can be uprated at the specified normal speed and steam conditions when it is furnished with suitable (larger or additional) nozzles and, possibly, with a larger valve or valves.

1.4.20 The *pressure casing* is the composite of all stationary pressure-containing parts of the unit, including all nozzles and other attached parts.

1.4.21 *Radially split* refers to casing joints that are transverse to the shaft centerline.

1.4.22 *Rated* applies to the greatest turbine power specified and the corresponding speed. It includes all of the margin required by the driven-equipment specifications.

1.4.23 *Standby service* refers to a normally idle or idling piece of equipment that is capable of immediate automatic or manual start-up and continuous operation.

1.4.24 *Total indicated runout (TIR)*, also known as total indicator reading, is the runout of a diameter or face determined by measurement with a dial indicator. The indicator reading implies an out-of-squareness equal to the reading or an eccentricity equal to half the reading.

1.4.25 *Trip speed* (in revolutions per minute) is the speed at which the independent emergency overspeed device operates to shut down the turbine. The trip-speed setting will vary with the class of governor (see 3.4.2.7).

1.4.26 *Unit responsibility* refers to the technical responsibility for coordinating the general arrangement of the driver and driven equipment, as well as power requirements, speed, direction of rotation, and so forth; for designing and laying out lubrication and sealing systems; for analyzing vibration and noise data; and for supervising and coordinating all required tests and material reports for all equipment within the scope of this standard.

1.4.27 The use of the word *design* in any term (such as design power, design pressure, design temperature, or design speed) should be avoided in the purchaser's specifications. This terminology should be used only by the equipment designer and the manufacturer.

1.5 Referenced Publications

1.5.1 The following standards, codes, and specifications are cited in this standard:

AFBMA¹

- 7 *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plans*
- 9 *Load Ratings and Fatigue Life for Ball Bearings*
- 20 *Metric Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plans*

AGMA²

- 514 *Load Classification and Service Factors for Flexible Couplings*
- 515 *Balance Classification for Flexible Couplings*
- 9002-A86 *Bores and Keyways for Flexible Couplings (Inch Series)*

¹Anti-Friction Bearing Manufacturers Association, 1235 Jefferson Davis Highway, Arlington, Virginia 22202.

²American Gear Manufacturers Association, 1901 North Fort Myer Drive, Arlington, Virginia 22209.

ANSI³

- B1.1 *Unified Inch Screw Threads (UN and UNR Thread Forms)*
- B16.1 *Cast Iron Pipe Flanges and Flanged Fittings, Class 25, 125, 250, and 800*
- B16.5 *Pipe Flanges and Flanged Fittings, Steel Nickel Alloy and Other Special Alloys*
- B16.11 *Forged Steel Fittings, Socket-Welding and Threaded*
- B16.42 *Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300*
- B17.1 *Keys and Keyseats*
- Y14.2M *Line Conventions and Lettering*

API

- Spec 5L *Specification for Line Pipe*
- RP 550 *Manual on Installation of Refinery Instruments and Control Systems*
- Std 612 *Special-Purpose Steam Turbines for Refinery Services*
- Std 614 *Lubrication, Shaft-Sealing, and Control-Oil Systems for Special-Purpose Applications*
- Std 615 *Sound Control of Mechanical Equipment for Refinery Services*
- Std 670 *Vibration, Axial-Position, and Bearing-Temperature Monitoring Systems*
- Std 677 *General-Purpose Gear Units for Refinery Services*
- Std 678 *Accelerometer-Based Vibration Monitoring System*

ASME⁴

- B1.20.1 *Pipe Threads, General Purpose*
- B31.3 *Chemical Plant and Petroleum Refinery Piping*
- PTC 6 *Performance Test Code—Steam Turbines*
- Boiler and Pressure Vessel Code, Section V, "Non-destructive Examination," Section VIII, "Pressure Vessels," and Section IX, "Welding and Brazing Qualifications"*

ASTM⁵

- A 53 *Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless*
- A 105 *Forgings, Carbon Steel, for Piping Components*
- A 106 *Seamless Carbon Steel Pipe for High-Temperature Service*

- A 120 *Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless, for Ordinary Uses*
- A 153 *Zinc Coating (Hot-Dip) on Iron and Steel Hardware*
- A 181 *Forgings, Carbon Steel for General Purpose Piping*
- A 193 *Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
- A 194 *Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service*
- A 197 *Cupola Malleable Iron*
- A 269 *Seamless and Welded Austenitic Stainless Steel Tubing for General Service*
- A 278 *Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (345°C)*
- A 307 *Carbon Steel Externally Threaded Standard Fasteners*
- A 312 *Seamless and Welded Austenitic Stainless Steel Pipe*
- A 325 *High-Strength Bolts for Structural Steel Joints*
- A 338 *Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine, and Other Heavy Duty Service at Temperatures Up to 650°F (345°C)*
- A 388 *Ultrasonic Examination of Heavy Steel Forgings*
- A 395 *Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*
- A 515 *Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*
- A 536 *Ductile Iron Castings*
- E 94 *Guides for Radiographic Testing*
- E 125 *Reference Photographs for Magnetic Particle Indications on Ferrous Castings*
- E 142 *Method for Controlling Quality of Radiographic Testing*
- E 709 *Magnetic Particle Examination*

AWS⁶

- D1.1 *Structural Welding Code—Steel*

MSS⁷

- SP 55 *Quality Standard for Steel Castings—Visual Method*

³American National Standards Institute, 1430 Broadway, New York, New York 10018.

⁴American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

⁵American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

⁶American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33135.

⁷Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, Virginia 22180.

NEMA⁸

- MG 1 *Motors and Generators*
 SM 23 *Steam Turbines for Mechanical Drive Service*

NFPA⁹

- 70 *National Electrical Code, Chapter 5, Article 500, "Hazardous (Classified) Locations," and Article 501, "Class I Locations"*

OSHA¹⁰

Occupational Safety and Health Standards of the
 U.S. Department of Labor

1.5.2 The purchaser and the vendor shall mutually determine the measures that must be taken to comply with any federal, state, or local codes, regulations, ordinances, or rules that are applicable to the equipment.

SECTION 2—BASIC DESIGN

2.1 General

2.1.1 The equipment (including auxiliaries) covered by this standard shall be designed and constructed for a minimum service life of 20 years and at least 3 years of uninterrupted operation. It is recognized that this is a design criterion.

2.1.2 The vendor shall assume responsibility for the engineering coordination of the equipment and all auxiliary systems included in the scope of the order.

2.1.3 The equipment's normal operating point will be specified on the data sheets.

2.1.4 Turbines shall be capable of the following:

- a. Operating at normal power and speed under normal steam conditions. The manufacturer's certified steam rate shall be at these conditions.
- b. Delivering rated power at its corresponding speed with coincident minimum inlet and maximum exhaust conditions as specified on the data sheets. To prevent oversizing or to obtain higher operating efficiency, the purchaser may desire to limit maximum turbine capability by specifying normal or a selected percentage of rated power instead of rated power.

Note: Rated power may be achieved by using a hand valve or valves under normal steam conditions and an additional hand valve or valves under minimum inlet and maximum exhaust steam conditions. (See 3.4.1.4 for information about using hand valves at other operating conditions.)

c. Continuously operating at maximum continuous speed and at any speed within the range specified.

d. Continuously operating at rated power and speed under maximum inlet steam conditions and maximum or minimum exhaust steam conditions.

e. Operating with variations from rated steam conditions in accordance with NEMA SM 23.

Note: Regardless of the design limit of any turbine component, the turbine should not be operated or rerated outside the nameplate limits without consultation with the manufacturer.

2.1.5 Equipment shall be designed to run without damage up to the trip speed and relief valve settings.

2.1.6 Single-stage turbines shall be suitable for immediate start-up to full load without a preliminary warmup period. The purchaser will allow for proper drainage of the inlet piping, turbine casing, steam chest, and packing glands.

Note: Consultation with the manufacturer is recommended, since additional considerations may be required when single-stage turbines are to be applied for immediate automatic unattended start-up.

2.1.7 The turbine wheel or wheels for single-stage and multistage units shall be located between the bearings. Other arrangements require specific purchaser approval.

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

2.1.9 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as casing components and bearing housings shall be designed (shouldered or cylindrically doweled) and manufactured to ensure accurate alignment on reassembly.

⁸National Electrical Manufacturers Association, 2101 L Street, N.W., Washington, D.C. 20037.

⁹National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269.

¹⁰Occupational Safety and Health Administration, U.S. Department of Labor, Washington, D.C. 20210.

2.1.10 The turbine and other equipment within the scope of the order shall perform on the test stand and on the permanent foundation within the specified acceptance criteria. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor.

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

Velocity over heat exchanger surfaces	5–8 ft/s	1.5–2.5 m/s
Maximum allowable working pressure	≥75 psig	≥5.2 bar (ga)
Test pressure	≥115 psig	≥7.9 bar (ga)
Maximum pressure drop	15 psi	1 bar
Maximum inlet temperature	90°F	32°C
Maximum outlet temperature	120°F	49°C
Maximum temperature rise	30°F	17°C
Fouling factor on water side	0.002 hr-ft ² ·°F/Btu	0.35 m ² ·K/kW
Shell corrosion allowance	0.125 in.	3.2 mm

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

Note: To avoid condensation, the minimum inlet water temperature to the bearing housings should preferably be above the ambient air temperature.

- **2.1.12** Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor. Unless otherwise specified, the equipment furnished by the vendor shall conform to the requirements of API Standard 615 and the maximum allowable sound pressure level specified.
- **2.1.13** Motors, electrical components, and electrical installations shall be suitable for the area classification (class, group, and division) specified by the purchaser on the data sheets and shall meet the requirements of NFPA 70, Articles 500 and 501, as well as local codes specified and furnished by the purchaser (see 3.4.5.4).
- **2.1.14** The purchaser will specify whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), as well as the weather and environmental conditions in which the equipment must operate (including maximum and minimum temperatures and unusual humidity or dust problems). The unit and its auxiliaries shall be suitable for operation under these specified conditions.

2.1.15 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance.

- **2.1.16** When specified, the equipment feet shall be equipped with vertical jackscrews.

2.1.17 Equipment feet shall be drilled with pilot holes for use in final doweling.

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

2.2 Pressure Casings

2.2.1 All pressure parts shall be at least suitable for operation at the most severe coincident conditions of pressure and temperature expected for the specified steam conditions.

2.2.2 The hoop-stress values used in the design of the casing shall not exceed the maximum allowable stress values in tension specified in Section VIII, Division 1, of the ASME Code at the maximum operating temperature of the material used.

2.2.3 Axially split casings shall use a metal-to-metal joint (with a suitable joint compound) that is tightly maintained by suitable bolting. Gaskets (including string type) shall not be used on the axial joint. When gasketed joints are used on radially split casings, they shall be securely maintained by confining the gaskets.

2.2.4 Axially split horizontal turbines shall be designed to permit inspection and removal of the rotor and wearing parts without removing the casing from its foundation or disconnecting inlet or exhaust steam piping (except when up-exhaust is specified). Axially split multistage turbine casings may also be split radially between high- and low-pressure portions.

2.2.5 Radially split horizontal turbines shall be designed to permit inspection and replacement of the bearings and outer glands without removing the casing from its foundation or disconnecting inlet or exhaust steam piping.

Note: Radially split horizontal turbines may require removal from their foundations to permit removal of rotors.

2.2.6 Casings and supports shall be designed to have sufficient strength and rigidity to limit any change of shaft alignment at the coupling flange (caused by the worst combination of allowable pressure, torque, and piping forces and moments) to 0.002 inch (50 micrometers). Supports and alignment bolts shall be rigid enough to permit the machine to be moved by the use of lateral and axial jackscrews. Axially split horizontal turbines shall have centerline supports to maintain proper alignment with connected equipment. The lower horizontal mounting surface of each turbine support shall be machined parallel within 0.002 inch per foot (1:6000). Corresponding surfaces shall be coplanar

within 0.002 inch per foot of distance between surfaces (0.17 millimeter per meter).

2.2.7 Drain connections shall be provided for the steam chest, casing, packing glands, and cooling jackets.

2.2.8 Gauge connections shall be provided for the steam-ring chamber on single-valve turbines and for the first stage of multistage turbines.

2.2.9 Jackscrews, guide rods (for multistage turbines), and casing alignment dowels shall be provided to facilitate disassembly and reassembly. When jackscrews are used to part 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. Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly. Lifting lugs or eyebolts shall be provided for lifting only the top half of the casing. Methods of lifting the assembled machine shall be specified by the vendor.

2.2.10 The use of tapped holes in pressure parts shall be minimized. To prevent leakage in pressure sections of casings, metal equal in thickness to at least half the nominal bolt diameter, in addition to the allowance for corrosion, shall be left around and below the bottom of drilled and tapped holes.

2.2.11 Bolting shall be furnished as specified in 2.2.11.1 through 2.2.11.6.

2.2.11.1 The details of threading shall conform to ANSI B1.1.

2.2.11.2 Studs are preferred to cap screws.

2.2.11.3 Studded connections shall be furnished with studs and nuts installed. Blind stud holes should be drilled only deep enough to allow a preferred tap depth of $1\frac{1}{2}$ times the major diameter of the stud; the first $1\frac{1}{2}$ threads at both ends of each stud shall be removed.

2.2.11.4 The minimum material quality of bolting for pressure joints shall be carbon steel (ASTM A 307, Grade B) for cast iron parts and a high-temperature alloy steel (ASTM A 193, Grade B-7) for steel and alloy parts. Carbon steel (ASTM A 325) may be used for parts where the temperature is below 500°F (260°C). Nuts shall conform to ASTM A 194, Grade 2H (or, where space is limited, to ASTM A 307, Grade B, case-hardened).

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

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

2.2.12 The machined finish of the mounting surface shall be 125–250 microinches (3.2–6.4 micrometers) arithmetic average roughness (R_a). Hold-down or foundation bolt holes shall be drilled perpendicular to the mounting surface or surfaces and spot faced to a diameter three times that of the hole.

2.3 Casing Appurtenances

All nozzles or nozzle blocks shall be replaceable. All other stationary blading shall be mounted in replaceable diaphragms or segments.

2.4 Casing Connections

- 2.4.1** Inlet and outlet connections shall be flanged or machined and studded, oriented as specified on the data sheets, and suitable for the maximum inlet and maximum exhaust steam conditions as specified and defined in 1.4.8 and 1.4.9.

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

2.4.3 Casing openings for piping connections shall be at least $\frac{3}{4}$ inch nominal pipe size. Threaded openings are permissible in sizes $\frac{3}{4}$ inch, 1 inch, and $1\frac{1}{2}$ inches nominal pipe size. Openings shall be installed as specified in 2.4.3.1 through 2.4.3.7.

2.4.3.1 A pipe nipple, preferably not more than 6 inches (150 millimeters) long, shall be connected to the opening.

2.4.3.2 Pipe nipples shall be a minimum of Schedule 160 seamless for sizes 1 inch and smaller and a minimum of Schedule 80 seamless for a size of $1\frac{1}{2}$ inches.

2.4.3.3 Pipe nipples shall be provided with welding-neck or socket-weld flanges for steam pressures of 180 pounds per square inch gauge (12.4 bar gauge) or higher.

2.4.3.4 Threaded connections shall be seal welded; however, seal welding is not permitted on cast iron equipment, for instrument connections, or where disassembly is required for maintenance. Seal-welded joints shall be in accordance with ASME B31.3.

2.4.3.5 Tapped openings and bosses for pipe threads shall conform to ANSI B16.5.

2.4.3.6 Pipe threads shall be taper threads that conform to ASME B1.20.1.

2.4.3.7 Openings for socket-welded connections shall conform to ANSI B16.11.

2.4.4 Openings for nominal pipe sizes of 1¼, 2½, 3½, 5, 7, and 9 inches shall not be used.

2.4.5 Tapped openings not connected to piping shall be plugged with solid round-head steel plugs furnished in accordance with ANSI B16.11. As a minimum, these plugs shall meet the material requirements of the casing. Plugs that may later require removal shall be of corrosion-resistant material. Threads shall be lubricated. Plastic plugs are not permitted.

2.4.6 Flanges shall conform to ANSI B16.1 or B16.5, or B16.42 as applicable, except as specified in 2.4.6.1 through 2.4.6.5.

2.4.6.1 Cast iron flanges shall be flat faced and shall have a minimum thickness of Class 250 in accordance with ANSI B16.1 for sizes 8 inches and smaller. Exhaust flanges 10 inches and larger may be Class 125.

2.4.6.2 Flat-faced flanges are acceptable on all exhaust connections. Flat-faced flanges shall have full raised-face thickness.

2.4.6.3 Flanges that are thicker or have a larger outside diameter than that required by ANSI B16.1, B16.5, or B16.42, as applicable, are acceptable.

2.4.6.4 The concentricity between the bolt circle and the bore of all casing flanges shall be such that the surface area for the seating of the machined gasket is adequate to accommodate a complete standard gasket that does not protrude into the fluid flow.

• **2.4.6.5** For the purpose of manufacturing mating parts, the vendor shall supply equipment flange details to the purchaser when connections larger than those covered by ANSI B16.5 or B16.42 are supplied. When specified, the mating parts shall be furnished by the vendor.

2.4.7 The finish of the contact faces of flanges and nozzles shall conform to the flange-finish roughness requirements in Table 1. Milled flanged surfaces are acceptable with the purchaser's approval.

2.4.8 All of the purchaser's connections shall be accessible for disassembly without moving the machine.

• **2.4.9** Mounting flanges for vertical turbines shall be made of cast iron or steel and shall be adequately bolted and ribbed for rigidity. Mounting flanges shall

Table 1—Arithmetic Average Roughness Height (R_a)

Type	Service	Contact Surface Roughness (R_a)
Flat and raised face	Vacuum	63–125
	Above atmospheric	125–500
Ring joint	All	<63

be of rabbeted design, flat-faced with a provision for accurate centering and doweling conforming to NEMA MG 1, or as specified.

2.5 External Forces and Moments

Turbines shall be designed to withstand the external forces and moments calculated in accordance with NEMA SM 23.

2.6 Rotating Elements

2.6.1 ROTORS

2.6.1.1 Rotors shall be capable of operating without damage at momentary speeds up to 110 percent of trip speed.

2.6.1.2 Rotors (other than integrally forged shafts and disks) shall be assembled to prevent movement of the disk relative to the shaft when operating at any specified start-up or operating condition and any speed up to 110 percent of trip speed. The wheels shall be keyed to the shaft and assembled with a shrink fit.

2.6.1.3 The purchaser's specific approval is required for built-up rotors when blade tip velocities at maximum continuous speed exceed 825 feet per second (250 meters per second) or when stage inlet steam temperatures exceed 825°F (441°C).

2.6.2 SHAFTS

2.6.2.1 Shafts shall be accurately finished throughout their entire length and shall be ground to a finish of 32 microinches (0.8 micrometer) R_a or better at the coupling and bearing locations and sealing areas for carbon ring packing.

2.6.2.2 When noncontacting vibration or axial position probes are furnished or specified, the rotor shaft sensing areas to be observed by radial vibration probes shall be concentric with the bearing journals. All shaft sensing areas (both radial vibration and axial position) shall be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway. These areas shall not be metallized, sleeved, or plated. The final surface finish shall be 16–32 microinches (0.4–0.8 micrometer) R_a , preferably obtained by honing or burnishing. These areas shall be properly demagnetized or otherwise treated so that

the combined total of electrical and mechanical runout does not exceed 25 percent of the maximum allowed peak-to-peak vibration amplitude or the following value, whichever is greater:

- a. For areas to be observed by radial vibration probes, 0.25 mil (6 micrometers).
- b. For areas to be observed by axial position probes, 0.5 mil (13 micrometers).

2.6.2.3 Shafts shall be protected by corrosion-resistant material under carbon ring packing for casing end glands. The manufacturer's application method, the coating material used, and the finished coating thickness shall be stated on the data sheets.

2.6.2.4 Keyways shall have fillet radii that conform to ANSI B17.1.

2.6.3 BLADING

2.6.3.1 Combined stress levels (steady state plus cyclic) developed in rotating blades at any equipment operating condition shall be low enough to ensure trouble-free operation even if resonant vibration occurs.

2.6.3.2 All blades shall be mechanically suitable for operation (including transient conditions) over the specified speed range and momentarily up to 110 percent of trip speed.

2.7 Seals

2.7.1 Outer glands shall be sealed at the shaft by carbon-ring or replaceable labyrinth packing or both.

2.7.2 Carbon-ring packing shall be used only when the rubbing speed at the shaft sealing surface is less than 160 feet per second (49 meters per second). The number of carbon rings shall be determined by the service and venting requirements, with 35 pounds per square inch (2.41 bar) being the maximum allowable average differential pressure per active sealing ring. Springs for carbon packing shall be made of nickel-chromium-iron alloy (heat treated after cold coiling) or equal material. Variations in operating steam temperature shall be considered when the required cold clearances for packing rings are established.

2.7.3 Gland cases shall be furnished with a full complement of carbon rings.

- **2.7.4** When specified, a separate vacuum device shall be furnished for connection to the glands to reduce external steam leakage. Unless otherwise specified, the device shall be mounted and connected by the vendor who mounts the turbine on the baseplate.

- **2.7.5** Glands that operate at less than atmospheric pressure shall be designed to admit steam that will seal against air leakage. Piping with relief valves, pressure gauges, regulators, and other necessary valves shall be provided to interconnect the end glands. Piping shall have one common connection to the purchaser's sealing-steam supply. When specified, the admission of sealing steam shall be automatically controlled throughout the load range. The normal operating sealing-steam supply shall preferably come from a positive-pressure section of the turbine.

2.7.6 All piping and components of shaft seal and vacuum systems shall be sized for 300 percent of the calculated new clearance leakage.

2.7.7 Sealing of interstage diaphragms on multistage turbines shall be by replaceable labyrinth packing.

2.7.8 The gland casing leak-off connections shall comply with 2.4.2.

2.8 Dynamics

2.8.1 CRITICAL SPEEDS

2.8.1.1 When the frequency of a periodic forcing phenomenon (exciting frequency) applied to a rotor-bearing support system corresponds to a natural frequency of that system, the system may be in a state of resonance.

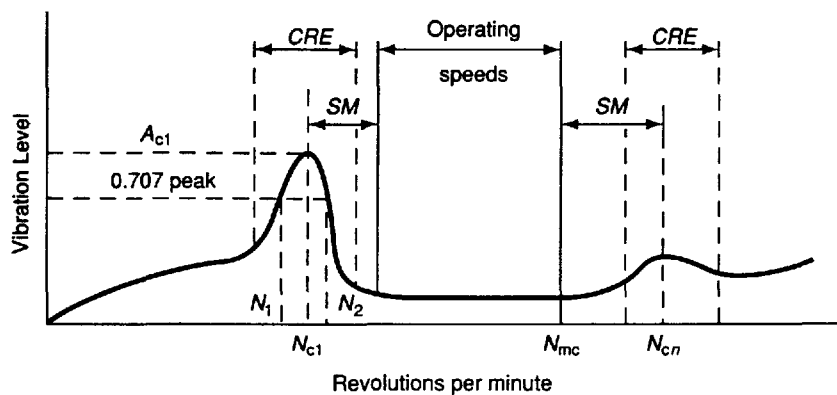
2.8.1.2 A rotor-bearing support system in resonance will have its normal vibration displacement amplified. The magnitude of amplification and the rate of phase-angle change are related to the amount of damping in the system and to the mode shape taken by the rotor.

Note: The mode shapes are commonly referred to as the first rigid (translatory or bouncing) mode, the second rigid (conical or rocking) mode, and the (first, second, third, . . . , n th) bending mode.

2.8.1.3 When the rotor amplification factor (see Figure 1), as measured at the vibration probe, is greater than or equal to 2.5, that frequency is called critical, and the corresponding shaft rotational frequency is called a *critical speed*. For the purposes of this standard, a critically damped system is one in which the amplification factor is less than 2.5.

2.8.1.4 An exciting frequency may be less than, equal to, or greater than the rotational speed of the rotor. Potential exciting frequencies that are considered in system design shall include but are not limited to the following sources:

- a. Unbalance in the rotor system.
- b. Oil-film instabilities (whirl).
- c. Internal rubs.



- N_{c1} = Rotor first critical, center frequency, cycles per minute.
 N_{cn} = Critical speed, n th.
 N_{mc} = Maximum continuous speed, 105 percent.
 N_1 = Initial (lesser) speed at $0.707 \times$ peak amplitude (critical).
 N_2 = Final (greater) speed at $0.707 \times$ peak amplitude (critical).
 $N_2 - N_1$ = Peak width at the half-power point.
 AF = Amplification factor

$$= \frac{N_{c1}}{N_2 - N_1}$$
 SM = Separation margin.
 CRE = Critical response envelope.
 A_{c1} = Amplitude at N_{c1} .
 A_{cn} = Amplitude at N_{cn} .

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

Figure 1—Rotor Response Plot

- d. Blade, vane, nozzle, and diffuser passing frequencies.
- e. Gear-tooth meshing and side bands.
- f. Coupling misalignment.
- g. Loose rotor-system components.
- h. Hysteretic and friction whirl.
- i. Boundary-layer flow separation.
- j. Acoustic and aerodynamic cross-coupling forces.
- k. Asynchronous whirl.

2.8.1.5 Resonances of support systems within the vendor's scope of supply shall not occur within the specified operating speed range or the specified separation margins unless the resonances are critically damped.

2.8.1.6 The vendor who is specified to have unit responsibility shall determine that the drive-train critical speeds (rotor lateral, system torsional, blading modes, and the like) are compatible with the critical speeds of the machinery being supplied and that the combination is suitable for the specified operating speed range, including any starting-speed detent (hold-point) requirements of the train. A list of all undesirable speeds from zero to trip shall be submitted to the purchaser for his review and included in the instruction manual for his guidance (see 5.2.5.2).

- **2.8.1.7** When specified, the turbine vendor shall supply all necessary information for lateral and torsional analyses to the vendor who has unit responsibility.

2.8.1.8 The first rigid mode of single-stage turbines shall be at least 120 percent of maximum continuous speed.

2.8.2 LATERAL ANALYSIS

2.8.2.1 The vendor's standard critical speed values that have previously been analytically derived and test proven for prior manufactured turbines of the same frame size and rotor/bearing configuration are acceptable and shall be submitted to the purchaser as part of the proposal. For new turbine designs and rotor/bearing configurations, the vendor shall perform a lateral critical analysis in accordance with the guidelines outlined in Appendix B.

- **2.8.2.2** When specified, the vendor shall provide calculations and/or available supporting test data for separation margins in accordance with 2.8.1.8 and B.1.4.

2.8.3 TORSIONAL ANALYSIS

2.8.3.1 Excitations of torsional resonances may come from many sources that should be considered in the analysis. These sources may include but are not limited to the following:

- a. Gear problems such as unbalance and pitch line runout.
- b. Start-up conditions such as speed detents (under inertial impedances) and other torsional oscillations.
- c. Hydraulic-governor control-loop resonances.

2.8.3.2 The vendor who has unit responsibility shall ensure that the torsional resonances of the complete train are at least 10 percent above or 10 percent below any possible excitation frequency within the specified operating speed range (from minimum to maximum continuous speed).

2.8.3.3 Torsional criticals at two or more times running speed shall preferably be avoided or, in systems in which corresponding excitation frequencies occur, shall be shown to have no adverse effect. In addition to multiples of running speeds, torsional excitations that are not a function of operating speeds or that are nonsynchronous in nature shall be considered in the torsional analysis, when applicable. The purchaser and the vendor shall be mutually responsible for identifying these frequencies.

2.8.3.4 When torsional resonances are calculated to fall within the margin specified in 2.8.3.2, 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 stress analysis shall be performed to demonstrate that the resonances have no adverse effect on the complete train.

- **2.8.3.5** When specified, the vendor shall perform a torsional vibration analysis of the complete coupled train and shall be responsible for directing the modifications necessary to meet the requirements of 2.8.3.1 through 2.8.3.4.

2.8.4 VIBRATION AND BALANCING

2.8.4.1 Each disk or thrust collar shall be given a single-plane balance before it is assembled on its own shaft. Other major parts shall be given an individual dynamic balance before they are assembled on the shaft.

- **2.8.4.2** The rotating element shall be multiplane dynamically balanced during assembly. This shall be accomplished after adding no more than two major components. Balancing correction shall be applied only to the elements that are added. Other components may

require minor corrections during the final trim balancing of the completely assembled element. On rotors that have single keyways, the keyway shall be filled with a fully crowned half-key. When specified, the weight of all half-keys used during the final balancing of the assembled element shall be recorded on the residual unbalance work sheet (see Appendix C). The maximum allowable residual unbalance per plane (journal) shall be calculated as follows:

$$U_{\max} = 4W/N$$

In SI units,

$$U_{\max} = 6350W/N$$

Where:

$U_{\max}$ = residual unbalance, in ounce-inches (gram-millimeters).

W = journal static weight load, in pounds (kilograms).

N = maximum continuous speed, in revolutions per minute.

When spare rotors are supplied, they shall be dynamically balanced to the same tolerances as the main rotor.

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

2.8.4.4 High-speed balancing (balancing in a high-speed balancing machine at the operating speed) shall be done only with the purchaser's specific approval. The acceptance criteria for this balancing shall be mutually agreed upon by the purchaser and the vendor.

2.8.4.5 During the shop test of the machine, assembled with the balanced rotor, operating at its maximum continuous speed or at any other speed within the specified operating speed range, the peak-to-peak amplitude of unfiltered vibration in any plane, measured on the shaft adjacent and relative to each radial bearing, shall not exceed the following value or 2.0 mils (50 micrometers), whichever is less:

$$A = \sqrt{\frac{12,000}{N}} \quad (1)$$

In SI units,

$$A = 25.4 \sqrt{\frac{12,000}{N}}$$

Where:

- A = amplitude of unfiltered vibration, in mils (micrometers) peak to peak.
 N = maximum continuous speed, in revolutions per minute.

At any speed greater than the maximum continuous speed, up to and including the trip speed of the driver, the vibration shall not exceed 150 percent of the maximum value recorded at the maximum continuous speed.

Note: These limits are not to be confused with the limits specified in Appendix B for shop verification of unbalanced response.

- **2.8.4.6** When specified, electrical and mechanical runout shall be determined and recorded by rolling the rotor in V blocks while measuring runout with a noncontacting vibration probe and a dial indicator at the same shaft location.

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

2.8.4.8 If the vendor can demonstrate that electrical or mechanical runout is present, a maximum of 25 percent of the test level calculated from Equation 1 or 0.25 mil (6 micrometers), whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory test.

2.8.4.9 When noncontacting vibration probes are not provided or when vibration cannot be measured on the shaft, the peak vibration velocity measured on the bearing housing while it operates at speeds described in 2.8.4.5 shall not exceed 0.15 inch (3.8 millimeters) per second (unfiltered) and 0.10 inch (2.5 millimeters) per second at running speed frequency (filtered).

2.9 Bearings and Bearing Housings

2.9.1 Hydrodynamic radial bearings shall be required under the following conditions:

- Where antifriction-bearing dN factors are 300,000 or more. [A dN factor is the product of bearing size (bore) in millimeters and rated speed in revolutions per minute.]
- When standard antifriction bearings fail to meet an L_{10} rating life (see AFBMA Standard 9) of either 50,000 hours with continuous operation at rated conditions or 32,000 hours at maximum axial and radial loads and rated speed. (The rating life is the number of hours at the rated bearing load and speed that 90 percent of a group of identical bearings will complete or exceed before the first evidence of failure.)

- **2.9.2** Horizontal turbines shall be equipped with thrust bearings designed to handle axial loads in either direction. Multistage turbines shall have hydrodynamic thrust bearings when specified or where antifriction bearings fail to meet the minimum L_{10} rating life (see 2.9.1, Item a).

- **2.9.3** Vertical turbines may have oil- or grease-lubricated ball- or roller-type radial and thrust bearings. Thrust bearings shall be designed for 200 percent of the driven-equipment thrust (up or down) specified on the data sheets. Antifriction bearings shall be protected against overgreasing.

2.9.4 Antifriction bearings shall be retained on the shaft and fitted into housings in accordance with the requirements of AFBMA Standard 7; however, the device used to lock ball thrust bearings to the shaft shall be restricted to a nut with a tongue-type lock-washer, such as Series W.

2.9.5 Except for the angular contact type, antifriction bearings shall have a loose internal clearance fit equivalent to AFBMA Symbol 3, as defined in AFBMA Standard 20. Single- or double-row bearings shall be of the Conrad type (no filling slots).

2.9.6 Hydrodynamic radial bearings shall be split for ease of assembly, precision bored, and of the sleeve or pad type, with steel-backed, babbitted replaceable liners, pads, or shells. These bearings shall be equipped with antirotation pins and shall be positively secured in the axial direction. The bearing design shall suppress hydrodynamic instabilities and provide sufficient damping over the entire range of allowable bearing clearances to limit rotor vibration to the maximum specified amplitudes (see 2.8.4.5) while the equipment is operating loaded or unloaded at specified operating speeds, including operation at any critical frequency. The liners, pads, or shells shall be in horizontally split housings and shall be replaceable without removing the top half of the casing of an axially split machine or the head of a radially split unit and without removing the coupling hub.

2.9.7 Hydrodynamic thrust bearings shall be in accordance with 2.9.7.1 through 2.9.7.3.

2.9.7.1 Hydrodynamic thrust bearings shall be of the steel-backed, babbitted multiple-segment type, designed for equal thrust capacity in both directions and arranged for continuous pressurized lubrication to each side. Both sides shall be of the tilting-pad type, incorporating a self-leveling feature that assures that each pad carries an equal share of the thrust load with minor variation in pad thickness.