

Gas Turbines for the Petroleum, Chemical, and Gas Industry Services

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Foreword

This standard is based on the accumulated knowledge and experience of manufacturers and users of gas turbines. The objective of this standard is to provide a purchase specification to facilitate the procurement and manufacture of gas turbines for use in petroleum, chemical, and gas industry services.

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 improving energy utilization should be thoroughly investigated and brought forth. This is especially true of new equipment proposals, since the evaluation or 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 reduced 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 such modifications, deletions, and amplifications be made by supplementing this standard, rather than by rewriting or incorporating sections thereof into another standard.

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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 extreme 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 (EPA), National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the EPA rule on labeling requirements and phased banning of asbestos products (Sections 763.160 through 763.179).

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 that 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 datasheet.

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Gas Turbines for the Petroleum, Chemical, and Gas Industry Services

1 Scope

1.1 General

This standard covers the minimum requirements for open-, simple-, and regenerative-cycle combustion gas turbine units for services of mechanical drive, generator drive, or process gas generation. All auxiliary equipment required for operating, starting, controlling, and protecting gas turbine units is either discussed directly in this standard or referred to in this standard through references to other publications. Specifically, gas turbine units that are capable of firing gas or liquid or both are covered by this standard. This standard covers both industrial and aeroderivative gas turbines.

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. The information should be indicated on the datasheets (see Annex A); otherwise, it should be stated in the quotation request or in the order.

1.2 Alternative Designs

Vendor may offer alternative designs.

1.3 Conflicts

In case of conflicts between this standard and the inquiry, the information in the inquiry shall govern. At time of order, the order shall govern.

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.

API *Manual of Petroleum Measurement Standards (MPMS) Chapter 15:2001, Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries*

API Recommended Practice 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*

API Recommended Practice 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*

API Standard 541, *Form-wound Squirrel Cage Induction Motors—375 kW (500 Horsepower) and Larger*

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

API Standard 547, *General-purpose Form-wound Squirrel Cage Induction Motors—185 kW (250 hp) through 2240 kW (3000 hp)*

API Recommended Practice 551, *Process Measurement*

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

API Standard 612, *Petroleum, Petrochemical, and Natural Gas Industries—Steam Turbines—Special-purpose Applications*

API Standard 613, *Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API Standard 614, *Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries*

API Standard 670, *Machinery Protection Systems*

API Standard 671, *Special-purpose Couplings for Petroleum, Chemical, and Gas Industry Services*

API Standard 677, *General-purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API Technical Report 684-1, *API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing*

API Recommended Practice 686, *Recommended Practice for Machinery Installation and Installation Design*

API Recommended Practice 687, *Rotor Repair*

API Recommended Practice 691, *Risk-based Machinery Management*

ABMA Standard 7 ¹, *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plan*

ABMA Standard 9, *Load Ratings and Fatigue Life for Ball Bearings*

ABMA Standard 11, *Load Ratings and Fatigue Life for Roller Bearings*

AGMA 2101-D04 ², *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

AGMA 6123-C16, *Design Manual for Enclosed Epicyclic Gear Drives*

AISI 1020 ³, *Case Hardening and General Purpose Steel*

ASME B1.1 ⁴, *Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)*

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

ASME B16.9, *Factory-Made Wrought Buttwelding Fittings*

ASME B30.2, *Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)*

ASME B30.16, *Overhead Underhung and Stationary Hoists*

ASME B30.17, *Cranes and Monorails (With Underhung Trolley or Bridge)*

ASME B31.3, *Process Piping*

ASME B36.10M, *Welded and Seamless Wrought Steel Pipe*

ASME B36.19M, *Stainless Steel Pipe*

ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*

ASME B133.8, *Gas Turbine Installation Sound Emissions*

ASME Boiler and Pressure Vessel Code (BPVC), *Section V: Nondestructive Examination*

ASME BPVC, *Section VII: Recommended Guidelines for the Care of Power Boilers*

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

ASME BPVC, *Section VIII, Division 2: Alternative Rules*

¹ American Bearing Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, <https://www.americanbearings.org>.

² American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, www.agma.org.

³ American Iron and Steel Institute, 25 Massachusetts Ave., NW, Suite 800, Washington, District of Columbia 20001, <https://www.steel.org>.

⁴ American Society of Mechanical Engineers, Two Park Avenue, New York, New York 10016, www.asme.org.

ASME BPVC, Section IX: Welding and Brazing Qualifications

ASME BTH-1, Design of Below-the-Hook Lifting Devices

ASME PTC 1, General Instructions

ASME PTC 22, Performance Test Code on Gas Turbines

ASME Y14.2M, Line Conventions and Lettering

ASTM A123/A123M ⁵, Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

ASTM A182/A182M, Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service

ASTM A193/A193M, 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 A240/A240M, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

ASTM A247, Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings

ASTM A269/A269M, Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service

ASTM A312/A312M, Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes

ASTM A320/A320M, Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service

ASTM A388/A388M:2016, Standard Practice for Ultrasonic Examination of Steel Forgings

ASTM A395/A395M:2014, Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures

ASTM A403/A403M, Standard Specification for Wrought Austenitic Stainless Steel Piping Fittings

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

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 D1655, Standard Specification for Aviation Turbine Fuels

ASTM D2880, Standard Specification for Gas Turbine Fuel Oils

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

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

ASTM E94/E94M, Standard Guide for Radiographic Examination Using Industrial Radiographic Film

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

ASTM E709, Standard Guide for Magnetic Particle Testing

⁵ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

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

ATEX Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)

AWS D1.1/D1.1M ⁶, *Structural Welding Code—Steel*

CSA C22.1-06 ⁷, *Canadian Electrical Code, Part I, Safety Standard for Electrical Installations*

EN 614-1 ⁸, *Safety of machinery—Ergonomic design principles—Part 1: Terminology and general principles*

EN 779, *Particulate air filters for general ventilation—Determination of the filtration performance*

EN 1822, *High efficiency air filters (EPA, HEPA and ULPA)—Part 1: Classification, performance testing, marking*

IEC 60079 ⁹, *Explosive atmospheres*

IEC 60034-1, *Rotating electrical machines—Part 1: Rating and performance*, 11th Edition

IEC 60204-1, *Safety of machinery—Electrical equipment of machines—Part 1: General requirements*

IEC 60529, *Degrees of protection provided by enclosures (IP code)*

IEEE 841 ¹⁰, *Standard for the Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)*

ISO 261 ¹¹, *General purpose metric screw threads—General plan*

ISO 281, *Rolling bearings—Dynamic load ratings and rating life*

ISO 2314, *Gas turbines—Acceptance tests*

ISO 3448, *Industrial liquid lubricants—ISO viscosity classification*

ISO 3744, *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 3977-3, *Gas turbines—Procurement—Part 3: Design requirements*

ISO 4386-1, *Plain bearings—Metallic multilayer plain bearings—Part 1: Non-destructive ultrasonic testing of bond of thickness greater than or equal to 0,5 mm*

ISO 6183, *Fire protection equipment—Carbon dioxide extinguishing systems for use on premises—Design and installation*

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

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

ISO 8501, *Preparation of steel substrates before application of paints and related products*

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

ISO 10380, *Pipework—Corrugated metal hoses and hose assemblies*

ISO 10474, *Steel and steel products—Inspection documents*

⁶ American Welding Society, 8669 NW 36 Street, # 130, Miami, Florida 33166, www.aws.org.

⁷ CSA Group, 178 Rexdale Blvd., Toronto, Canada M9W 1R3, <https://www.csagroup.org>.

⁸ European Committee for Standardization (CEN), Management Centre, Rue de la Science 23, B - 1040 Brussels, Belgium, <https://www.cen.eu>.

⁹ International Electrotechnical Commission, 3 Rue de Varembe, CH-1211, Geneva 20, Switzerland, www.iec.ch.

¹⁰ IEEE, 445 Hoes Lane, Piscataway, New Jersey 08854, www.ieee.org.

¹¹ International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 – 1214 Vernier, Geneva, Switzerland, www.iso.org.

ISO 10494, *Turbines and turbine sets—Measurement of emitted airborne noise—Engineering/survey method*

ISO 14123-1, *Safety of machinery—Reduction of risks to health resulting from hazardous substances emitted by machinery—Part 1: Principles and specifications for machinery manufacturers*

ISO 14520, *Gaseous fire-extinguishing systems—Physical properties and system design*

ISO 14691, *Petroleum, petrochemical and natural gas industries—Flexible couplings for mechanical power transmission—General-purpose applications*

ISO 15465, *Pipework—Stripwound metal hoses and hose assemblies*

ISO 17784, *Rubber and plastics hoses and hose assemblies—Guide for use by purchasers, assemblers, installers and operating personnel*

ISO 20816-1, *Mechanical vibration—Measurement and evaluation of machine vibration—Part 1: General guidelines*

ISO 20816-4, *Mechanical vibration—Measurement and evaluation of machine vibration—Part 4: Gas turbines in excess of 3 MW, with fluid-film bearings*

ISO 21789, *Gas turbine applications—Safety*

ISO 21940, *Mechanical vibration—Rotor balancing*

ISO 21940-12, *Mechanical vibration—Rotor balancing—Part 12: Procedures and tolerances for rotors with flexible behaviour*

MIL-S-8879 ¹², *Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification*

NACE MR0103 ¹³, *Petroleum, Petrochemical and Natural Gas Industries—Metallic Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE MR0175, *Petroleum and Natural Gas Industries—Materials for Use in H₂S-Containing Environments in Oil and Gas Production*

NEMA 250 ¹⁴, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

NFPA 12 ¹⁵, *Standard on Carbon Dioxide Extinguishing Systems*

NFPA 70, *National Electrical Code*

NFPA 72, *National Fire Alarm and Signaling Code*

NFPA 750, *Standard on Water Mist Fire Protection Systems*

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*

NFPA 2010, *Standard for Fixed Aerosol Fire-Extinguishing Systems*

OSHA 29 Code of Federal Regulations (CFR) 1910, *Occupational Safety and Health Standards*

OSHA 29 CFR 1926, *Safety and Health Regulations for Construction*

SAE B92.1 ¹⁶, *Involute Splines and Inspection*

SAE J518, *Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt Split Flange Type*

SSPC SP6 ¹⁷, *Commercial Blast Cleaning (also known as NACE No. 3)*

¹² US Department of Defense, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, Pennsylvania 19111, <https://www.defense.gov>.

¹³ NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

¹⁴ National Electrical Manufacturers Association, 1300 17th Street N 900, Arlington, Virginia 22209, www.nema.org.

¹⁵ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

¹⁶ SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096, www.sae.org.

¹⁷ The Society for Protective Coatings, 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, www.sspc.org.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. See Annex D for more information.

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. All alarm points have to be measured; however, all measured points do not have to be alarmed.

3.1.2

anchor bolts

Bolts used to attach the equipment to the support structure (concrete foundation or steel structure). (See 3.1.22 “hold-down bolts.”)

3.1.3

axially split joint

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

3.1.4

blade lock-up speed

Speed of rotation at which a part span or tip damping device (whether joining all or multiple numbers of individual blades) becomes effective.

3.1.5

blades

Rotating airfoils for both compressors and turbines unless modified by an adjective.

3.1.6

chemiluminescence

A chemical reaction that gives off light without significant amounts of heat.

3.1.7

control system

Includes both gas turbine control system and API 670 machinery protection system.

3.1.8

conventional combustor

A chamber where the fuel and air mix by turbulence and diffusion (without a premixer) and burn over a wider flammability range of fuel-to-air ratios (FARs) compared to a premixed combustor.

NOTE See 3.1.49 “premixed combustor.”

3.1.9

critical speed

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

3.1.10

design

Manufacturer’s calculated parameter. A term used by the equipment manufacturer to describe various parameters such as design power, design pressure, design temperature, or design speed. It is not intended for the purchaser to use this term.

3.1.11**diamètre nominal or nominal diameter****DN**

Alphanumeric designation of size for components of a pipework system. (See 3.1.37 “nominal pipe size.”)

EXAMPLE DN 20

NOTE 1 Adapted from ISO 6708.

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.

NOTE 4 In those standards that use the DN designation system, any relationship between DN and component dimensions should be given, e.g. DN/OD or DN/ID.

3.1.12**dry low emissions****DLE**

A combustion system using premixed combustors to minimize NO_x and CO exhaust emissions.

NOTE See 3.1.8 “conventional combustor.”

3.1.13**duty cycle**

The expected operating mode (full or part load, steady or variable, continuous or intermittent operation) of the gas turbine.

NOTE The number of thermal cycles (i.e. stops, starts, and load variations) can have a significant impact on the life of turbine components.

3.1.14**expected availability**

Expected percentage of time a gas turbine package is available for use over the service life.

NOTE Expected availability includes both unplanned and planned downtime.

3.1.15**expected reliability**

Expected percent of time a gas turbine package is available for use over the service life, excluding planned maintenance.

NOTE Expected reliability quantifies unplanned downtime.

3.1.16**fuel-to-air ratio****FAR**

Ratio of fuel to air on a mass basis, reciprocal of air-fuel-ratio.

3.1.17**filter stage**

Section of a filter system designed to remove specific site contaminants.

3.1.18**gas generator**

The portion of the gas turbine that primarily produces heated gas for the power turbine. Sometimes called “gas producer.”

3.1.19**gas turbine package**

Includes the gas turbine and all accessories supplied by the vendor except the coupling, load gears, driven equipment, and common tools.

3.1.20**gauge board**

Bracket or plate used to support and display gauges, switches, and other instruments. (See 3.1.46 "panel.") A gauge board is not a panel. A gauge board is open and not enclosed. A panel is an enclosure.

3.1.21**heat rate**

Energy consumption of a prime mover per unit of output work. For gas turbines, the heat rate is calculated on the basis of the lower heating value of the fuel.

3.1.22**hold-down bolts or mounting bolts**

Bolts holding the equipment to the mounting plate.

3.1.23**hydrodynamic bearings**

Bearings that use the principles of hydrodynamic lubrication. The bearing surfaces are oriented so that relative motion forms an oil wedge, or wedges, to support the load without shaft-to-bearing contact.

3.1.24**informative**

See 3.1.40 "normative."

NOTE An informative reference or annex provides advisory or explanatory information.

3.1.25**ISO-rated power**

New, clean, continuous power developed by the gas turbine when it is operated at design firing temperature and speed at ISO 2314 standard reference conditions with no inlet or exhaust losses.

NOTE The ISO rating provides only general sizing information and is not to be confused with site rated power.

3.1.26**local**

Position of devices on or near the equipment or console.

3.1.27**lower heating value****LHV**

The amount of heat released by combusting a defined quantity where the latent heat of vaporization of water in the reaction products is not recovered. Also known as net calorific value or net heating value.

NOTE Typically measured in kJ/kg or Btu/lbm or Btu/scf.

3.1.28**maximum allowable temperature**

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

3.1.29**maximum allowable working pressure****MAWP**

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

3.1.30**maximum continuous speed** **N_{mc}**

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

3.1.31**maximum exhaust pressure**

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

3.1.32**minimum allowable speed** **N_{ma}**

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

NOTE Minimum allowable speed can be set by many factors; these include, but are not limited to, the following: location of critical speeds (lateral and torsional), blade natural frequencies, minimum differentials that need to be developed across close clearances for lubrication, cooling, rotordynamic damping and stiffening, and minimum speed of shaft driven lubricating pumps.

3.1.33**minimum allowable temperature**

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

3.1.34**modified Wobbe index****MWI**

A relationship to describe the fuel energy density, corrected with temperature (see E.6.3). See also 3.1.77 "Wobbe index."

3.1.35**mounting plate**

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

3.1.36**natural gas liquids****NGL**

Hydrocarbons liquefied at the surface in field facilities or in gas processing plants.

NOTE Natural gas liquids include ethane, propane, butanes, and natural gasoline.

3.1.37**nominal pipe size****NPS**

Value approximately equal to the diameter in inches (see 3.1.11 "diamètre nominal").

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

NOTE 1 Refer to ASME B31.3.

NOTE 2 The letters NPS are followed by a number that is related to the physical size, in inches of the bore or outside diameter of the pipe.

3.1.38**normal operating point**

Point at which usual operation is expected and optimum efficiency is desired.

NOTE This point is usually the point at which the vendor certifies the heat rate is within the tolerances stated in this standard (see 6.1.8 and 6.1.9). Parameters used to determine the normal operating point include speed, site conditions, emissions, and fuel composition.

3.1.39**normal stop**

A nonexpedited gas turbine stop.

NOTE A normal stop can be manually initiated by an operator or an automatically scheduled stop sequence. It is not an emergency stop or trip.

3.1.40**normative**

Required. (See 3.1.24 “informative.”)

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

3.1.41**nozzles (fixed and variable)**

Turbine stationary (nonrotating) airfoils.

3.1.42**NPT**

American National Standard Pipe Taper thread form designation for pipe threads.

EXAMPLE $\frac{3}{4}$ – 14 NPT.

NOTE 1 It is comprised of a number representing nominal pipe size followed by the number of threads per inch and the letters NPT representing the thread series.

NOTE 2 Pipe size and number of threads per inch can be found in ASME B1.20.1.

3.1.43**observed**

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, i.e. not a witness point.

3.1.44**open cycle**

A process in which the working medium enters the gas turbine from the atmosphere and discharges to the atmosphere directly or indirectly through exhaust heat recovery equipment.

3.1.45**owner**

Final recipient of the equipment or their designated agent.

3.1.46**panel**

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

3.1.47**potential maximum power**

Expected power capability when the gas turbine is operated at maximum allowable firing temperature, rated speed or under other limiting conditions as defined by the manufacturer and within the range of specified site values, including the total operating envelope (see 6.14.1.2).

NOTE Potential maximum power typically occurs at the minimum air inlet temperature and lowest MWI.

3.1.48**power turbine**

Power extracting turbine stage(s) that is mechanically coupled to the load but is not mechanically connected to the shaft of the gas generator. Sometimes called a “free power turbine.”

NOTE 1 One gas turbine can have multiple turbine sections, e.g. high-pressure turbine (HPT), intermediate-pressure turbine (IPT), low-pressure turbine (LPT), and a power turbine. See Figure 1.

NOTE 2 On a single-shaft gas turbine the power turbine, gas generator, and load are all mechanically connected.

3.1.49**premixed combustor**

A chamber where fuel and air are mixed uniformly (in a premixer) and then transported to the flame zone.

NOTE This is a low NO_x combustor. See 3.1.8 “conventional combustor.”

3.1.50**pressure casing**

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

3.1.51**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.

3.1.52**radially split**

Split with the principal joint perpendicular to the shaft centerline.

3.1.53**rated speed (mechanical drive applications)**

Gas turbine output shaft speed (revolutions per minute) required to develop site rated power (see 3.1.66).

NOTE Normally, the gas turbine rated speed corresponds to the driven equipment rated speed.

3.1.54**rated speed (generator drive applications)**

Gas turbine output shaft speed (revolutions per minute) required to develop site rated power (see 3.1.66) at synchronous generator speed.

3.1.55**regenerative cycle**

A process in which the gas turbine exhaust is used to heat (by heat exchange) combustion air from the compressor.

3.1.56**relief valve set pressure**

Pressure at which a relief valve starts to lift.

3.1.57**remote**

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

3.1.58**risk assessment**

A systematic process of identifying, quantifying, and evaluating the potential risks involved in the design of the gas turbine package.

NOTE Includes failure modes and effects analysis (FMEA) and hazard and operability study (HAZOP).

3.1.59**roughness value** **R_a**

Arithmetical 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.

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

3.1.60**service life**

The duration of time that a system or component can be utilized at site rated conditions, power and duty cycle and while following the vendor defined operation and maintenance requirements. See 6.1.2.

3.1.61**shutdown**

Gas turbine package condition, as determined by the equipment user, which requires action to stop the gas turbine.

NOTE Shutdowns can be broken into several different types (e.g. manual lock-out, cooldown time), depending upon initiating event. It can be automatically implemented through the control system or manually initiated (by pressing the emergency shutdown button or normal stop button) (see 7.5.5.7.2 and 7.5.5.7.5).

3.1.62**shutdown set point**

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

3.1.63**simple-cycle**

A process in which the gas turbine exhaust is discharged to the atmosphere without exhaust gas heat recovery.

3.1.64**site rated conditions**

Conditions used to determine site rated power. See 6.1.24.

3.1.65**site rated firing temperature**

Turbine inlet total temperature, measured at a location immediately upstream of the first-stage turbine nozzles, required to meet site rated power.

3.1.66**site rated power**

Power of a new and clean gas turbine package at site rated conditions with air filters at high differential pressure alarm. See 6.1.22 through 6.1.24.

3.1.67**special tool**

Tool or fixture that is not a commercially available catalog item.

3.1.68**stator outlet temperature**

Gas path temperature exiting the first stator or vane. This is the gas temperature entering the first turbine blade.

3.1.69**superheat**

The temperature that a gas would need to be reduced, at constant pressure, to start condensation. Temperature margin of a gas above its boiling point.

3.1.70**thermal efficiency**

Ratio of the energy output at the gas turbine output shaft (or generator terminals) to the energy input (based on the lower heating value of the fuel) in the same units expressed as a percentage.

NOTE External auxiliaries directly driven are included in parasitic losses.

3.1.71**total indicator reading****total indicated runout****TIR**

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 indicated runout implies an out-of-square equal to the reading.

3.1.72**trip (also known as emergency shutdown)**

Automated shutdown to ensure personnel safety (safety critical).

3.1.73**trip speed**

Turbine speed at which the independent emergency overspeed device shuts off fuel to the gas turbine.

3.1.74**vanes (fixed and variable)**

Compressor stationary (nonrotating) airfoils.

NOTE Also known as blades.

3.1.75**vendor or supplier**

Manufacturer or manufacturer's agent that supplies the equipment.

3.1.76**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.

3.1.77**Wobbe index****WI**

A relationship to describe the fuel energy density, uncorrected for temperature (see E.6.3). See also 3.1.34 "modified Wobbe index."

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

AC	alternating current
AF	amplification factor
AR	(ISO) air release (lubricants)
ATEX	atmosphères explosibles
BPVC	Boiler and Pressure Vessel Code
BX	nonjacketed flexible cable
CEMS	continuous emission monitoring systems
CFD	computation fluid dynamics
CFR	(United States) Code of Federal Regulations
CPU	central processing unit
DC	direct current
DCS	distributed control system
DLE	dry low emissions
DN	diamètre nominal
dT _{DB}	temperature drop, dry bulb
EPA	(ASHRAE) efficient particulate air (filters)
FAR	fuel-to-air ratio
FAT	factory acceptance test
FEA	finite element analysis
FMEA	failure modes and effects analysis
FOD	foreign object damage
HAZOP	hazard and operability study
HEPA	(ASHRAE) high-efficiency particulate air (filter)
HMI	human machinery interface
HP	power

HPC	high-pressure compressor
HPT	high-pressure turbine
IP	ingress protection
IPC	intermediate-pressure compressor
IPT	intermediate-pressure turbine
LHV	lower heating value
LPC	low-pressure compressor
LPT	low-pressure turbine
MAWP	maximum allowable working pressure
MERV	(ASHRAE) minimum efficiency reporting value
MIL	(United States) military defense standard
MPPS	(air filtration) most penetrating particle size efficiency
MWI	modified Wobbe index
NDE	nondestructive examination
NEC	(United States) <i>National Electric Code</i>
NGL	natural gas liquids
N_{mc}	maximum continuous speed
NO _x	oxides of nitrogen
NPS	nominal pipe size
NPT	(United States) national pipe thread
PEMS	predictive emissions monitoring systems
PLC	programmable logic controller
PMI	positive material identification
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride
RMS	root mean square
RTD	resistance temperature detector
SCO	selective catalytic oxidation

SCR	selective catalytic reduction
SI	Système International (International System of Units)
SIL	safety integrity level
SM	separation margin
SNCR	selective noncatalytic reduction
SO _x	oxides of sulfur
TFE	tetrafluoroethylene
UHC	unburned hydrocarbon
ULPA	(ASHRAE) ultra-low particle air (filter)
UN	unified constant pitch (thread)
UNR	unified rounded root (thread)
UNS	(ASTM) Unified Numbering System (materials)
UPS	uninterruptible power system
USC	United States customary (units)
VDDR	vendor drawing and data requirements
VFD	variable frequency drive
VG	(ISO) viscosity grade (lubricant)
VOC	volatile organic compounds
WI	Wobbe index
WLE	wet low emissions

4 General—Unit Responsibility

Unless otherwise specified, the gas turbine vendor shall have unit responsibility and shall ensure that all subvendors comply with the requirements of this standard and all reference documents. The technical aspects to be considered by the vendor include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, and conformance to specifications and testing of components.

5 Requirements

5.1 Units of Measure

Purchaser's use of a United States customary (USC) datasheet (see A.1) indicates the USC system of measurements shall be used for all data, drawings, and maintenance dimensions. Purchaser's use of Système International (SI) datasheet (see A.2) indicates that the SI system of measurements shall be used.

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

5.2 Statutory Requirements

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

5.3 Documentation Requirements

- The hierarchy of documents shall be as specified.

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

6 Basic Design

6.1 General

6.1.1 Technology Readiness Level

- **6.1.1.1** 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.

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

6.1.1.3 In the event no such equipment or documentation is available, 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.

- **6.1.2** The gas turbine package shall be designed to meet or exceed the specified service life.

NOTE It is recognized that the package will contain components (e.g. galvanized structural steel or stainless steel inlet system) that will obtain long service life with minimal scheduled maintenance, whereas some components (e.g. gas generator, power turbine) will require multiple replacements or refurbishments to meet the service life.

6.1.3 Proposal shall include operation and maintenance requirements (with associated downtime) to achieve the gas turbine package service life (see 6.1.2). See 9.2.3.2 m).

6.1.4 Unless otherwise specified, the planned maintenance schedule of the gas turbine and control system shall not require a shutdown more frequently than once every 8760 operating hours.

NOTE 1 The 8760 hour applies to base-loaded machines using air and fuel that meets gas turbine manufacturer's specifications.

NOTE 2 Some gas turbine models have borescope inspection intervals that are shorter than 8760 hours.

NOTE 3 Operation of a gas turbine beyond the gas turbine manufacturer's inspection interval increases the likelihood of unplanned maintenance.

NOTE 4 Some applications need off-line water washing more frequently than 8760 hours to mitigate degradation and maintain power and efficiency.

- **6.1.5** If necessary, redundant components shall be installed to meet the minimum specified reliability and minimum specified availability.

- a) Proposal shall provide the expected availability of the gas turbine package based on the stated site operating conditions and duty cycle. See 9.2.3.2 m).
- b) Proposal shall provide the expected reliability of the gas turbine package based on the stated site operating conditions and duty cycle. See 9.2.3.2 m).

6.1.6 Proposal shall identify all single point failures that automatically shut down or trip the gas turbine package, including instrumentation and excluding components that cannot practically be made redundant. See 9.2.3.2 m).

NOTE Typical single point of failure issues are related to sensor failures, enclosure blowers, opening enclosure doors, but it is not practical to have all components be redundant, e.g. couplings, bearings, stator, casing, and rotors. The purchaser can review failure modes and influence the design.

- **6.1.7** The site rated power (with no negative tolerance) shall not be less than the driven equipment certified point power requirement plus the specified power margin.

NOTE For example if the driven equipment certified power requirement is 10 MW and the margin is 10 %, the site rated power needs to be at least 11 MW. The gas turbine rated point and driven equipment certified points are typically based on the same operating scenario.

- **6.1.8** The gas turbine package shall be designed for the normal operating point and all other specified operating conditions (see 3.1.38, 6.6, and Annex A).

6.1.9 The heat rate shall not exceed the guaranteed heat rate by more than 3 % at the normal operating point (see 6.1.8).

6.1.10 The gas turbine shall be one of the arrangements in Figure 1.

6.1.11 For mechanical drive applications, the gas turbine should have a free power turbine.

NOTE A free power turbine usually enables a wider speed range and the ability to start while the driven equipment is with load (e.g. compressor pressurized).

6.1.12 Proposal shall identify the gas turbine arrangement (see Figure 1). See 9.2.3.2 m).

6.1.13 Gas turbine packages shall be suitable for nonoperating periods of up to 3 weeks, under site conditions (see 6.6), without requiring any preservation procedures.

NOTE Some manufacturers need some auxiliary systems (e.g. heaters) to remain in service during nonoperating periods.

6.1.14 Proposal shall describe any necessary procedures for shutdown periods longer than 3 weeks, under site conditions (see 6.6). See 9.2.3.2 m).

- **6.1.15** The output-shaft operating speed range of gas turbines for mechanical-drive applications shall be as specified. Where only one operating speed is specified for a mechanical-drive application, the minimum speed range shall be from 70 % to 105 % of rated speed.

6.1.16 The output-shaft operating speed range of gas turbines for electrical generator drive applications shall be 95 % to 105 % of rated speed.

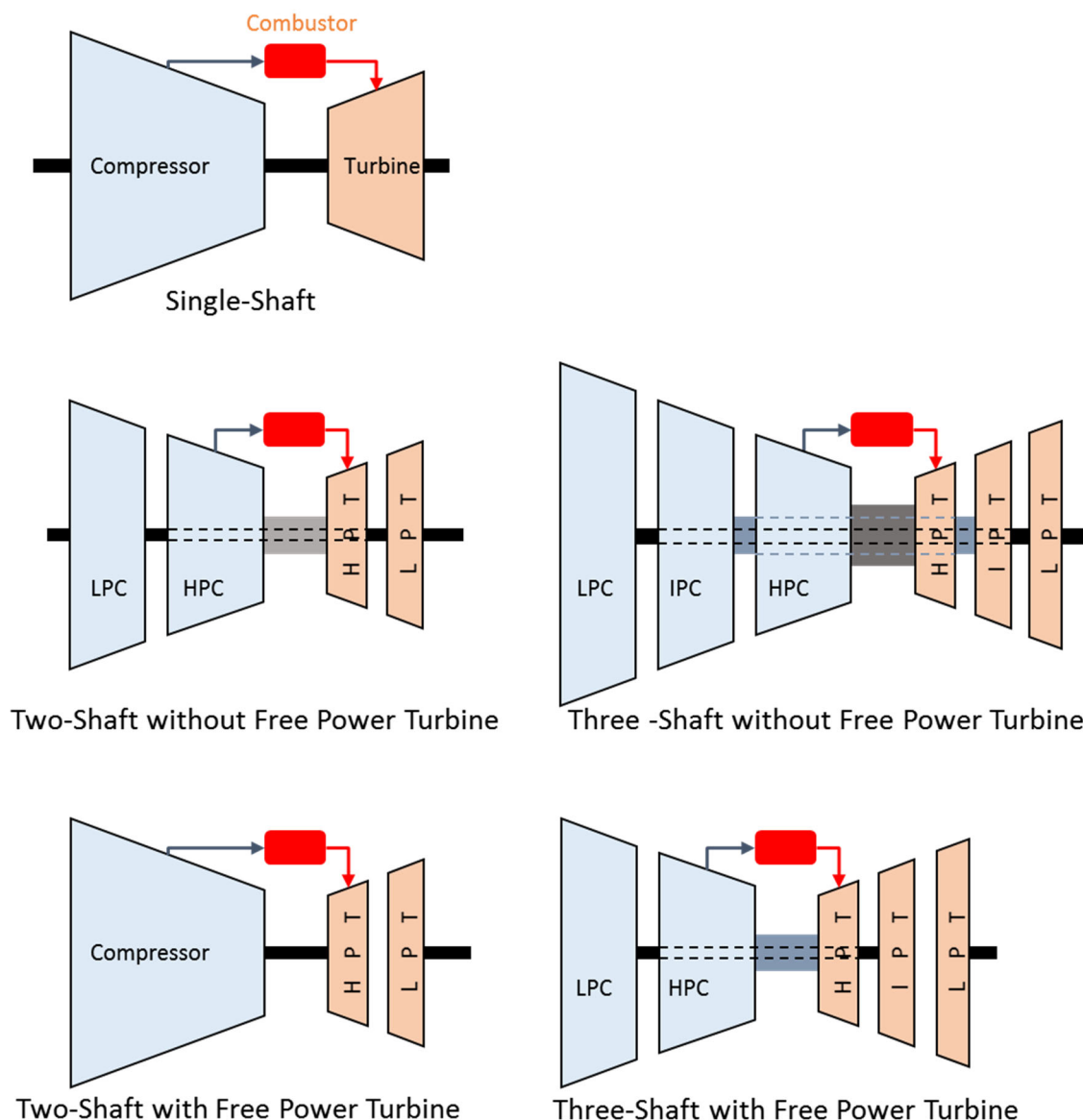


Figure 1—Gas Turbine Rotor Arrangements

6.1.17 Gas turbine package shall be designed for continuous service over the entire operating speed range (see 6.1.15 and 6.1.16) and power ranges including potential maximum power.

6.1.18 Proposal shall define the period between major overhauls while operating at potential maximum power and identify the maximum number for starts. See 9.2.3.2 m).

NOTE The period between major overhauls is based on an assumed number of starts.

6.1.19 After a normal stop, the gas turbine package shall permit immediate initiation of a normal start (no additional time added), subject to the driven equipment restrictions (see 7.1.4.1).

NOTE Transient thermal gradients following shutdown can delay restart.

6.1.20 Proposal shall define gas turbine cold start and hot restart restrictions and processes (e.g. with and without cooldown, with and without spin). See 9.2.3.2 m).

6.1.21 Equipment shall be designed to run without damage at any speed up to the highest trip speed in combination with any specific level of allowable temperature identified by the vendor.

6.1.22 For mechanical drive, site rated power and speed are referenced at the output shaft of the gas turbine ahead of any separate gear or piece of driven equipment.

NOTE For mechanical drive, site rated power excludes efficiency of all transmission and driven equipment.

- **6.1.23** For power generation, site rated power shall be referenced at the terminals of the generator and use the specified power factor.

NOTE For power generation, site rated power includes efficiency of gearbox and generator.

6.1.24 A new (less than 500 hours of operation) and clean gas turbine package shall be capable of producing site rated power, without exceeding the site rated firing temperature, at the following conditions:

- a) rated speed;
- b) specified site rated dry bulb ambient air temperature (measured upstream of all air inlet systems) (see 6.6);
- c) specified altitude (see 6.6);
- d) specified site rated relative humidity (see 6.6);
- e) specified site rated fuel composition (see 7.9.2 and 7.9.4);
- f) including losses from all inlet cooling or heating, exhaust heat recovery, and exhaust treatment systems (see 7.7.2.1.3.1, 7.7.2.1.3.2, 7.7.2.9.1.1, and 7.7.3.1.1):
 - 1) entire air inlet system installed;
 - 2) air filters at high differential pressure alarm;
 - 3) entire exhaust systems installed.

NOTE Purchaser to consider barometric variations and ambient temperature ranges when specifying the site rated conditions. The inlet air temperature specified for site rated conditions is not normally the highest or lowest recorded air temperature and humidity; this would result in extra equipment that would be rarely needed.

6.1.25 Proposal shall identify the fuel pressure and temperature limits necessary to generate site rated power (see 7.9.2.1). See 9.2.3.2 m).

6.1.26 N_{mc} shall not be less than 105 % of rated speed.

6.2 Air Emissions

- **6.2.1** Air emissions levels shall not be greater than the specified maximums with the specified fuel (see 7.9.2 and 7.9.4).

NOTE 1 Air emission maximums can include limits on NO_x , SO_x , CO, CO_2 , hydrocarbons [unburned hydrocarbons (UHC), etc. SO_x and CO_2 are more influenced by fuel composition rather than gas turbine performance.

NOTE 2 Air emissions include gas turbine exhaust and package vents.

6.2.2 Unless otherwise specified, site background air emissions are assumed to be zero.

NOTE Gas turbine air emissions are additive to background air emissions levels.

6.2.3 Unless otherwise specified, all air emission abatement systems necessary to comply with 6.2.1 shall be supplied.

NOTE The complete abatement solution can be a joint effort of the vendor and the purchaser (e.g. fuel processing).

6.2.4 Proposal shall list any restrictions on gas turbine speed or load range related to air emissions abatement. See 9.2.3.2 m).

6.2.5 Vendor shall provide air emissions data necessary for the purchaser to obtain permits.

6.2.6 Proposal shall state expected air emission levels with the fuel composition (see 7.9.2 or 7.9.4) and site operating conditions (see 6.6). See 9.2.3.2 m).

- **6.2.7** If specified, the gas turbine may utilize steam or water injection to reduce exhaust emissions.

6.2.8 Proposal shall describe the effects (e.g. maintenance recommendations and parts replacement) of steam or water injection. See 9.2.3.2 m).

6.2.9 Proposal shall describe the required quantity and quality of steam or injection water. See 9.2.3.2 m).

6.3 Noise Emissions

- **6.3.1** Sound power levels shall not be greater than the specified maximums.
- **6.3.2** Sound pressure levels shall not be greater than the specified maximums.

NOTE There can be multiple sound pressure level requirements (e.g. different levels at different locations, near field, far field).

6.3.3 Unless otherwise specified, site background noise levels are assumed to zero.

NOTE Gas turbine noise is additive to background noise levels.

6.3.4 Unless otherwise specified, all noise attenuation systems shall be supplied.

6.3.5 Proposal shall list the predicted maximum attenuated sound pressure level and sound power level data per octave band for each principal noise source within the vendor scope (e.g. gas turbine enclosure, inlet, exhaust). See 9.2.3.2 m).

6.4 Cooling Water Systems

6.4.1 Unless otherwise specified, the water side of cooling water system(s) shall be in accordance with API 614.

6.4.2 If the criteria for minimum temperature rise and velocity over heat exchange surfaces result in a conflict, the purchaser will approve the final selection.

NOTE 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.

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

6.5 Package Design

6.5.1 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor during the proposal phase. Pre-engineered packages with prearranged piping and equipment may be offered.

6.5.2 The arrangement of enclosure piping and conduits shall provide adequate clearance areas and safe access for operation and maintenance and shall not cause a maintenance obstruction.

6.5.3 Unless otherwise specified, all electrical installations shall conform to NFPA 70 [*National Electrical Code (NEC)*], or:

- a) if specified, all electrical installations shall conform to IEC 60079; or
 - b) if specified, all electrical installations shall conform to ATEX 2014/34/EU; or
 - c) if specified, all electrical installations shall conform to CSA C22-1-06.
- **6.5.4** Motors, electrical components, electrical installations, controls, and instrumentation shall be suitable for the specified area classification (class, division/zone, group).

NOTE Electrical devices on aeroderivative gas turbines are typically designed in accordance with aircraft explosion-proof requirements of MIL-E-5007.

6.5.5 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 (particulates), and other foreign matter during periods of operation and idleness.

6.5.6 All equipment shall be designed to facilitate maintenance in the specified environmental conditions (see 6.6).

- a) Major parts such as casing components and bearing housings shall be designed (shouldered or cylindrically doweled) and manufactured to ensure that vendor's alignment specifications are met on reassembly.
- b) Vanes and nozzles, seals, and rotating elements shall be replaceable on-site.

NOTE For small and aeroderivative gas turbines, it is not unusual to remove the entire gas turbine or a major component such as the gas generator or power turbine and perform all disassembly work in a shop.

- c) The package design shall incorporate lifting devices for all normal maintenance activities.
- d) Proposal shall describe the special tooling, including lifting and support devices, needed for on-site repair or replacement of parts. See 9.2.3.2 m).
- e) If the design requires field disassembly, the vendor drawing and data requirements (VDDR) [see Annex B, item 42 f)] shall include procedures for the disassembly required for such repair or replacement of parts.
- f) Proposal shall state the duration of the maintenance activities and the number of people required to perform the work at site. See 9.2.3.2 m) and 9.2.3.2 u).

6.5.7 The uncoupled gas turbine vibration levels, on the permanent foundation, shall not exceed the uncoupled test stand acceptance criteria.

6.5.8 The coupled gas turbine vibration levels, on the permanent foundation, shall not exceed the criteria in 6.16.6.3.

6.5.9 Vendor shall provide the maximum acceptable forces and moments at each interface point (e.g. piping, ducting, supporting structure, lifting points, including during transportation, handling, and assembly at the site).

NOTE Piping misalignment, when major flanges of the equipment are unfastened, can indicate excessive forces or moments.

6.5.10 If specified, the vendor's representative shall:

- a) review and comment on the purchaser's ducting layout, piping systems, and foundations drawings;
- b) observe a check of the major field piping connections by parting the flanges;
- c) check field shaft alignment at the operating temperature;
- d) witness the initial field shaft alignment check.

6.5.11 Spare parts for the gas turbine package and all furnished auxiliaries shall meet all the criteria of this standard.

6.5.12 Proposal shall describe utility air requirements for normal operation and off design conditions (e.g. pre-start and post-shutdown). See 9.2.3.2 m).

- **6.5.13** The gas turbine package, including all auxiliaries, shall be in accordance with the specified building code (e.g. national and local).
- **6.5.14** The gas turbine package, including all auxiliaries, shall be designed for the specified transportation loads.

6.5.15 The gas turbine package when correctly aligned shall not have detrimental forces (nozzle loads or shaft displacement) when cold.

6.5.16 Mounting surfaces on machinery shall meet the following criteria.

6.5.16.1 Equipment mounting surfaces between the equipment and mounting plate shall comply with 7.3.

6.5.16.2 The upper machined or spot faced surface shall be parallel to the mounting surface.

6.5.16.3 Hold-down bolt holes shall be drilled perpendicular to the mounting surface or surfaces.

6.5.16.4 Holes shall be spot faced to a diameter suitable for a washer positioned eccentrically around the bolt.

6.5.16.5 Holes shall not be slotted.

6.5.16.6 Holes shall be 13 mm ($1/2$ in.) larger in diameter than the hold-down bolt.

6.6 Environmental Conditions

- **6.6.1** The gas turbine package, including all auxiliaries, shall be suitable for installation and operation under the operating environmental scenarios specified.

NOTE 1 Be careful not to specify ranges of conditions (e.g. load, temperature and humidity) that cannot happen simultaneously.

NOTE 2 The site history of environmental conditions can be used to select environmental scenarios (e.g. winter, summer, rainy season operation).

- **6.6.2** The gas turbine package, including all auxiliaries, shall be suitable for shipment and storage under the shipment environmental scenarios specified.
- **6.6.3** The gas turbine package, including all auxiliaries, shall be suitable for operation at the seismic conditions and codes specified.

- **6.6.4** The gas turbine package, including all auxiliaries, shall be suitable for operation at the wind conditions specified.
- **6.6.5** The gas turbine package, including all auxiliaries, shall be designed to maintain the mechanical integrity at the specified extreme wind conditions (e.g. cyclone, tornados) while not operating.
- **6.6.6** The gas turbine package, including all auxiliaries, shall be suitable for operation at the specified site meteorological data.
- **6.6.7** The gas turbine package, including all auxiliaries, shall be suitable for operation with the specified chemical contaminants in the air.
- **6.6.8** The gas turbine package, including all auxiliaries, shall be suitable for operation with the specified particulate contaminants in the air.
- **6.6.9** The gas turbine package, including all auxiliaries, shall not be damaged by exposure to the specified extreme minimum temperature or extreme maximum temperature. The gas turbine may need to be offline when outside the operating environmental scenarios (see 6.6.1).

NOTE Often, it is not practical to design the gas turbine to operate for all historical extreme weather conditions; therefore, compromises can be necessary.

6.7 Pressure Casings

6.7.1 For industrial gas turbines, the hoop-stress values used in the design of the casing shall not exceed the maximum allowable stress values (in tension and at the maximum operating temperature) in Section VIII, Division 2 of the ASME *BPVC*.

NOTE Aeroderivative gas turbine casings are manufactured to recognized codes of the aircraft industry, which does not necessarily conform to ASME requirements.

6.7.2 All pressure parts shall be suitable for operation at the most severe coincident condition of pressure and temperature.

6.7.3 Casing joints may be radially or axially split.

6.7.4 VDDR [see Annex B, item 42 f)] shall describe casing disassembly requirements for site maintenance.

6.7.5 All casing joints, except inlet and exhaust flange connections, shall be metal fits without gaskets.

6.7.6 All casing joints shall be tight at operating pressure and temperature with minimum perceptible leakage. Minimum perceptible leakage shall be such that it poses no health issues to personnel adjacent to the joint, no impact to the site rated power and site rated heat rate of the gas turbine, no damage to the instrumentation near the joint, nor influence the heat detection system associated with fire protection inside the gas turbine enclosure.

NOTE Using the above criteria, it can take some time for damage to appear and to identify the leakage rate as above minimal perceptible leakage.

6.7.7 Casings, supports, and baseplates shall be designed to prevent any harmful distortion that could be caused by the worst combination of allowable temperature, pressure, torque, and external forces and moments.

6.7.8 Casings shall be designed or guarded to contain all blade-off (blade-out or blade liberation) events and the subsequent collateral damage.

NOTE Disk burst and overhung shaft failures are extremely rare high-energy events and very hard and possibly impractical to contain.

6.7.9 Supports and alignment bolts shall be rigid enough to permit the machine to be moved by the use of its lateral and axial jackscrews.

NOTE Many aeroderivative gas turbines are mounted by adjustable links.

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

NOTE Not all gas turbine casings are axially split.

6.7.11 If required for casing disassembly and reassembly, jackscrews, guide rods, and casing-alignment dowels shall be provided.

NOTE Not all gas turbines need jackscrews, guide rods, or casing-alignment dowels.

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

6.7.13 Lifting provision per 7.4.3 shall be provided for lifting the top half of each horizontally split casing.

6.7.14 If jackscrews are used, as a means of parting contacting faces, one of the faces shall be relieved (counter-bored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

6.7.15 Casing openings for inspection instruments, such as borescopes, shall be provided to permit complete inspection of all gas generator blades, turbine blades, hot gas-path components, and balance weights without pressure casing disassembly.

6.7.16 All casing inspection ports shall be stamped or tagged for identification purposes.

6.7.17 Proposal shall describe the extent of casing disassembly necessary for combustor system maintenance. See 9.2.3.2 m).

6.8 Casing Bolts

6.8.1 VDDR [see Annex B, item 42 g)] shall describe the standard used for the pressure casing bolting.

NOTE ISO 261 (metric) or ASME B1.1 (inch series) are typical for industrial gas turbine, and aeroderivative gas turbines typically use MIL-S-8879.

6.8.2 Clearance shall be provided at bolting locations to permit the use of commercially available socket or box wrenches (not special tools; see 3.1.67).

6.8.3 Internal socket-type, slotted-nut, or spanner-type bolting shall not be used unless approved by the purchaser. For limited space locations, integrally flanged fasteners may be used.

NOTE Dirt and water can accumulate in the internal cavities in bolts and nuts, leading to corrosion.

6.8.4 Studs, $\frac{3}{8}$ in. (10 mm) in diameter and larger, and bolts, $\frac{1}{4}$ in. (6 mm) in diameter and larger, shall have the material grade and manufacturer's identification symbols applied to one end. If space is inadequate, the grade symbol may be marked on one end and the manufacturer's identification symbol marked on the other end.

6.8.5 Studs shall be marked on the exposed end.

6.8.6 Set screws and washers may not have grade symbol or manufacturer's identification symbol.

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

6.9 Casing Design for Field Balancing

6.9.1 The ducting, rotor, and casing design shall permit field balancing in the end planes of the rotors without requiring the removal of major components.

6.9.2 Rotors shall not be balanced by adding weights to coupling bolting.

6.9.3 VDDR [see Annex B, item 42 l)] shall provide procedures for field balancing.

NOTE Some multi-shaft gas turbines might not have all rotors accessible without major component removal.

6.10 Combustors

6.10.1 All combustor systems shall be provided with dual ignition. Combustor systems without cross-ignition tubes shall be provided with two igniters in each combustor.

6.10.2 For multi-fuel systems, the system shall operate on each fuel without the need for periodic fuel source switching.

6.10.3 Ports shall be included for inspection of the combustion system components, either borescope or direct visual observation.

6.10.4 VDDR [see Annex B, item 42 f)] shall include all procedures and special equipment required for combustion system inspection and maintenance.

6.11 Combustion Temperature Measurement

6.11.1 VDDR [see Annex B, item 42)] shall state the maximum permissible temperature variation in the plane of measurement, define the plane, and identify the location of the temperature sensors.

6.11.2 Each combustor shall have at least one combustion temperature sensor.

NOTE Most gas turbine combustion temperature sensors are not located in the combustor. The sensors are normally located downstream of the gas generator in the inlet to the turbine or the gas turbine exhaust diffuser outlet.

6.11.3 Each gas turbine shall have at least six combustion temperature sensors.

6.12 Fuel Injectors

6.12.1 Fuel injectors shall be removable without dismantling of the combustors.

NOTE 1 "Fuel injectors" are also known as "fuel nozzles."

NOTE 2 Removal of the combustor or burner, in some dry low emissions (DLE) gas turbines, is needed to access and service the fuel injectors.

6.12.2 For liquid fuels, fuel injectors shall be designed to operate without erosion, plugging, and carbonization that would require service attention between scheduled maintenance intervals.

6.12.3 When multi-fuel injectors are used, proposal shall list any requirements for continuous purging and cooling of the idle nozzles. See 9.2.3.2 m).

6.12.4 Combustors and fuel injectors shall be designed and calibrated to permit random exchange of new nozzles without the need for field calibration and adjustment of flow or pressure drop.

6.13 Casing Connections

6.13.1 All piping except the gas generator and turbine casing connections shall be in accordance with 7.6.

NOTE Gas generators and turbines are standard products, as such the casing connections are defined by the gas turbine manufacturer.

6.13.2 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 (see 6.24). All welding of connections shall be completed before the casing is hydrostatically tested.

6.13.3 Purchaser casing connections shall be at least DN 20 [nominal pipe size (NPS) $\frac{3}{4}$] and shall be either:

- a) flanged;
- b) machined and studded.

NOTE See 7.6 for purchaser connection details.

6.13.4 Connections and tubing on the gas generator and turbine may be gas turbine manufacturer standard.

6.13.5 Tapped openings, in ferrous casings not connected to piping, shall be plugged with solid, steel plugs.

6.13.5.1 As a minimum, these plugs shall meet the material compatibility and strength requirements of the casing.

6.13.5.2 The corrosion resistance of all plugs shall be equal or better than the casing.

6.13.5.3 Lubricant and anti-seize compound of the proper temperature specification shall be used on all threaded connections.

- a) Lubricants shall not react or degrade to form hazardous compounds.
- b) Calcium-based lubricants or anti-seize compounds shall not be used where temperatures can exceed 300 °C.

NOTE Compounds can react at high temperatures with alloys to form hazardous compounds (e.g. hexavalent chromium residue).

6.13.5.4 Thread tape shall not be used.

6.13.6 Mating flanges, studs, and nuts for nonstandard connections shall be supplied.

6.14 Rotating Elements

6.14.1 Shafts

6.14.1.1 Shafts shall be designed and manufactured with the capability to transmit the maximum torque that can be developed at any steady-state or transient condition in the total operating envelope.

NOTE Maximum torque typically occurs at the lowest ambient temperature.

6.14.1.2 The total operating envelope is defined by the manufacturer for the range of site operating conditions (see 6.6) and fuel compositions (see 7.9.2 and 7.9.4).

6.14.1.3 For generator drives, the vendor shall also provide the transient torque due to short circuit overloads.

6.14.1.4 For generator applications, the vendor shall provide the power limit, identify the weakest shaft element, and, if necessary, provide overload protection.

6.14.1.5 Rotor shaft design shall be one of the following:

- a) stacked disks or tiebolt(s);
- b) welded drum construction;
- c) combination of a) and b);
- d) single-piece construction.

6.14.1.6 Rotor shafts that have a finished diameter larger than 200 mm (8 in.) shall be forged steel.

6.14.1.7 Rotor shafts that have a finished diameter of 200 mm (8 in.) or less shall be forged steel or, with the purchaser's approval, hot rolled bar-stock, provided such bar-stock meets all quality and heat treatment criteria established for shaft forgings.

6.14.1.8 Rotor shaft material shall be heat-treated steel or high-strength nickel-based alloys.

6.14.1.9 Proposal shall describe the rotor shaft design. See 9.2.3.2 m).

6.14.1.10 Shaft End Design

6.14.1.10.1 For removable coupling hubs, gas turbine load shaft ends shall conform to API 671.

6.14.1.10.2 Shafts with splined shaft ends shall conform to SAE B92.1.

6.14.1.10.3 Shaft end integral hubs may be used.

6.14.1.10.4 If radial vibration and/or axial-position probes are furnished, the rotor shaft sensing areas to be observed by the probes shall conform to API 670.

6.14.1.10.4.1 The surface areas to be observed by the probes shall not be metallized, sleeved, or plated. The final surface finish shall be a maximum of 0.8 μm (32 $\mu\text{in.}$) RMS, preferably obtained by honing or burnishing.

6.14.1.10.4.2 Electrical and mechanical runout shall be determined by rotating the rotor through the full 360° supported in V-blocks or rollers at the journals while continuously recording the combined runout with a noncontacting vibration probe and measuring the mechanical runout with a dial indicator at the centerline of each probe location and one probe-tip diameter to either side.

NOTE 1 V-blocks with soft facing material are not appropriate for some rotors with high bearing unit loading.

NOTE 2 The rotor runout determined above generally cannot be reproduced when the rotor is installed in a machine with hydrodynamic bearings. This is due to pad orientation on tilt pad bearings and effect of lubrication in all journal bearings. The rotor will assume a unique position in the bearings based on the slow roll speed and rotor weight.

6.14.1.10.4.3 The shaft radial vibration sensing areas shall be properly demagnetized to the levels specified in API 670 or otherwise treated so that the combined total electrical and mechanical runout, relative to the journals, does not exceed 6 μm (0.25 mil) peak-to-peak or 25 % of the permissible vibration according to 6.16.6.2.1 to 6.16.6.2.3, whichever is less.

6.14.1.10.4.4 For areas to be observed by axial-position probes, the shaft combined total electrical and mechanical runout shall not exceed 15 μm (0.6 mil) peak-to-peak or 25 % of the permissible axial displacement, whichever is less.

NOTE See 6.14.1.10.4.2 for measurement, and see 6.16.6.2.7 and 6.16.6.2.8 for recording of mechanical and electrical runout.

6.14.1.10.4.5 If all reasonable efforts fail to achieve the limits noted in 6.14.1.10.4.4, the vendor and the purchaser shall mutually agree on alternate acceptance criteria.

6.14.2 Rotors

6.14.2.1 Gas generator rotors and rotors of single-shaft gas turbines shall be mechanically designed to safely withstand momentary speeds up to 110 % of the gas turbine trip speed settings throughout the vendor-defined firing temperature range. The proposal shall describe any inspections that would be required, before restart, after such momentary overspeed conditions have occurred. See 9.2.3.2 m).

6.14.2.2 In the event of an instantaneous loss of 100 % of site rated load and the driven inertia, gas turbine rotors shall be capable of safe operation without the blades, disks, or shafts fracturing or separating as a result of the ensuing overspeed. The proposal shall state any inspections or maintenance required before restart when overspeed excursions exceed the normal overspeed trip limits. See 9.2.3.2 m).

6.14.2.3 Each rotor shall be clearly marked with a unique identification number. This number shall be in an area that is not prone to operation or maintenance damage.

NOTE This requirement is not always possible to achieve for aeroderivative gas turbines because of their compact design.

6.14.3 Disk and Blading

6.14.3.1 The tips of rotating blades and the labyrinths of shrouded rotating blades shall be designed to allow the unit to start up at any time in accordance with the vendor's requirements.

6.14.3.2 When the design permits rubbing during normal startup, the component shall be designed to be rub tolerant and the proposal shall state if rubbing is expected. See 9.2.3.2 m).

6.14.3.3 Proposal shall describe restrictions on restarting. See 9.2.3.2 o).

6.14.3.4 Blade Natural Frequencies

6.14.3.4.1 The blade natural frequencies shall not coincide with any source of excitation from 10 % below N_{ma} to 10 % above N_{mc} .

6.14.3.4.2 Blade stress levels developed at all operating conditions (see 6.1.8) shall be low enough to allow unrestricted operation for the service life (see 6.1.2).

6.14.3.4.3 Blades shall withstand operation at resonant frequencies during normal transients (e.g. warm-up, cooldown).

6.14.3.4.4 Proposal shall list all speeds, below the N_{mc} , corresponding to blade resonances. See 9.2.3.2 m).

NOTE Excitation sources include fundamental and first harmonic passing frequencies of rotating and stationary blades upstream and downstream of each blade row, gas passage splitters, irregularities in vane and nozzle pitch at horizontal casing flanges, the first ten rotor speed harmonics, meshing frequencies in gear units, and periodic impulses caused by the combustor arrangement.

6.14.3.4.5 Gas turbine blade and disk designs (e.g. materials, cooling pattern, root design, airfoil, thermal barrier coating) shall have twice demonstrated at least 24k hour intervals of documented, continuous, trouble-free operation at similar operating conditions. The intervals may be demonstrated with either one or two different gas turbines.

- **6.14.3.4.6** If specified, the vendor shall present Campbell and Goodman diagrams for the blading, backed by demonstrated experience in the application of identical blades operating with the same source or frequency of excitation that is present in the proposed unit. The vendor shall indicate on the Goodman diagrams the standard acceptance margins.

NOTE Gas turbine manufacturers can consider Campbell diagram proprietary and show them without providing copies.

6.14.3.4.7 All Campbell diagrams shall show the blade frequencies corrected to reflect actual operating conditions. Where applicable, the diagrams for shrouded blades shall show frequencies above and below the blade lock-up speed and identify the speed at which blade lock-up occurs.

6.14.3.4.8 Proposal and VDDR [see Annex B, item 42 l)] shall describe restrictions and measures necessary to avoid windmilling or slow roll damage. See 9.2.3.2 m).

6.15 Seals

6.15.1 Replaceable or repairable sealing components (such as labyrinths, honeycombs, brush seals, or abradable surfaces) shall be provided at all gas turbine internal close-clearance points between the rotating and stationary parts to minimize the leakage of air, gas combustion products, and prevent the leakage of oil from the bearing housings.

6.15.2 The seals shall be designed so that wear occurs predominantly on the replaceable or repairable components.

6.15.3 At all external points where shafts pass through the casings, seals shall be replaceable.

6.16 Dynamics

6.16.1 General

6.16.1.1 The gas turbine manufacturer shall conduct the following rotordynamic analysis and testing, as required, during the gas turbine development or rotor system modification and submit the data or reports as requested by the purchaser. The following paragraphs, 6.16.1 through 6.16.4, are a guide to the analytical development and testing report submittals (see API TR 684-1).

NOTE Typically, gas turbine engines are designed and developed as standard products and applied to well-developed gas turbine packaged drive systems.

6.16.1.2 Rotor-bearing systems shall be designed for all potential sources of periodic forcing phenomena (excitation) including, but not limited to:

- a) unbalance in the rotor system;
- b) oil-film instabilities (whirl);
- c) internal rubs;
- d) blade, vane, nozzle, and diffuser passing frequencies;
- e) gear-tooth meshing and side bands;
- f) coupling misalignment;
- g) loose rotor-system components;
- h) hysteretic and friction whirl;
- i) boundary-layer flow separation;
- j) acoustic and aerodynamic cross-coupling forces;
- k) asynchronous whirl;
- l) ball and race frequencies of rolling element bearings; and
- m) electrical line frequency.

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

NOTE 2 When the frequency of a periodic forcing phenomenon (excitation) applied to a rotor-bearing support system coincides with a natural frequency of that system, the system will be in a state of resonance. A rotor-bearing support system in resonance may 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.

6.16.1.3 Resonances of structural support systems (that are within the vendor's scope of supply and that affect the rotor vibration amplitude) shall not occur within the operating speed range (see 6.1.14 and 6.1.15) or the separation margins (SMs) (see 6.16.2.14). The effective stiffness of the structural support shall be included in the analysis of the dynamics of the rotor-bearing support system [see 6.16.2.6 e)].

6.16.1.4 If structural resonances within the operating speed range or within the SMs are predicted or known (see 6.16.1.3), the vendor shall provide the operational history for the subject design. The acceptability of the subject design for the proposed service shall be contingent on purchaser approval.

NOTE Aeroderivative gas turbines often exhibit structural resonances in their operating speed range and yet operate reliably.

6.16.1.5 The vendor with unit responsibility (see Section 4) shall communicate the existence of any undesirable running speeds in the range from zero to trip speed. A list of all undesirable speeds from zero to trip shall be submitted to the purchaser for review and included in the instruction manual (see Annex B).

NOTE Examples of undesirable speeds are those caused by the rotor lateral critical speeds, system torsional critical speeds as well as blade and vane resonant modes.

6.16.2 Lateral Analysis

6.16.2.1 Critical speeds and their associated amplification factors (AFs) shall be determined by means of a damped unbalanced rotor response analysis.

6.16.2.2 The location of all critical speeds below the trip speed shall be confirmed on the test stand as required per 8.3.4.3.4. For a gas turbine with a modified bearing or rotor configuration or a gas turbine prototype, the accuracy of the analytical model shall be demonstrated as required per 6.16.2.21.

6.16.2.3 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 as a minimum the stiffness range to produce free-free to rigid support rotor modes. For machinery with widely varying bearing loads and/or load direction, such as overhung style machines, the vendor may substitute mode shape plots for the undamped critical speed map and list the undamped critical speed for each of the identified modes.

6.16.2.4 The results of the undamped analysis shall be furnished.

6.16.2.5 The presentation of the results shall include the following.

- a) Mode shape plots (relative amplitude vs. axial position on the rotor).
- b) Critical speed-support stiffness map (frequency vs. support stiffness). Superimposed on this map shall be the calculated system support stiffness, horizontal (k_x) and vertical (k_y) (see Figure 2).

NOTE The first undamped critical speed on rigid bearings is the value of the first mode at the extreme right of the critical speed-support stiffness map.

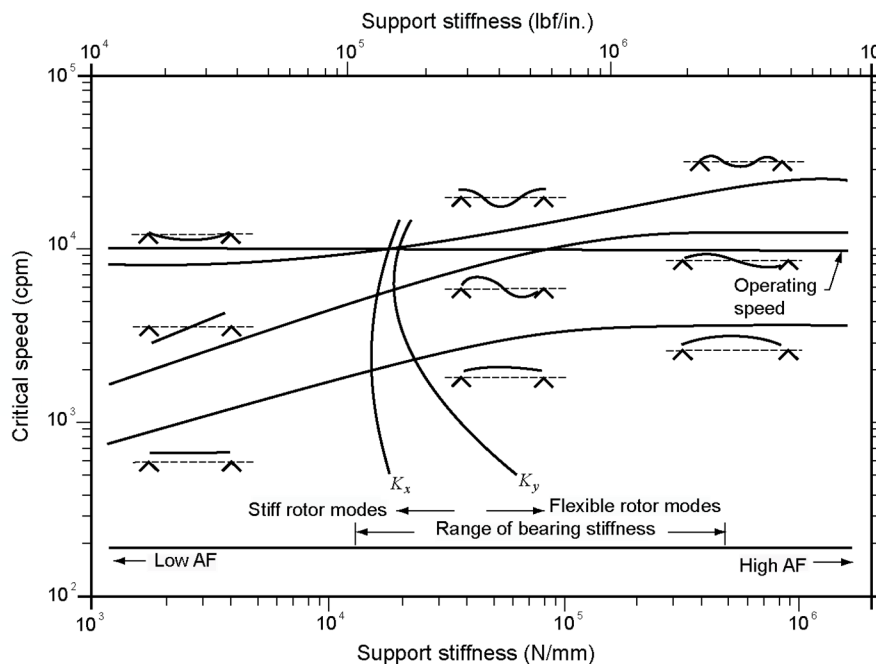


Figure 2—Undamped Critical Speed Map

6.16.2.6 The damped unbalanced response analysis shall include, but shall not be limited to, the following:

- rotor masses and polar and transverse moments of inertia, including coupling halves, and rotor stiffness changes due to shrunk on components;
- material properties as a function of operating temperature variation along the shaft;
- bearing lubricant-film stiffness and damping values including changes due to speed, load, preload, range of oil inlet temperature, maximum to minimum clearances resulting from accumulated assembly tolerances, and the effect of asymmetrical loading that may be caused by gear forces (including the changes over the range of maximum to minimum torque), etc.;
- for tilt-pad bearings, the pad pivot stiffness;
- structure stiffness, mass, and damping characteristics, including effects of excitation frequency over the required analysis range; for machines whose dynamic structural stiffness values are less than or equal to 33.5 times the bearing stiffness values in the range from 0 % to 150 % of N_{mc} , the structure characteristics shall be incorporated as an adequate dynamic system model, calculated frequency dependent structure stiffness and damping values (impedances), or structure stiffness and damping values (impedances) derived from modal or other testing; the vendor shall state the structure characteristics values used in the analysis and the basis for these values (e.g. 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 upon test conditions if different), trip speed, and coast down conditions;
- the location and orientation of the radial vibration probes, which shall be the same in the analysis as in the machine;
- squeeze film damper mass, stiffness and damping values considering the component clearance and centering tolerance, oil inlet temperature range, and operating eccentricity;
- for machines equipped with rolling element bearings, the vendor shall state the bearing stiffness and damping values used for the analysis; the basis for these values or the assumptions made in calculating the values shall be presented.

NOTE The above list does not address the details and product of the analysis that is covered in 6.16.2.9 and 6.16.2.12.

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

NOTE Lateral behavior of both bodies connected by a rigid coupling need to be considered together when performing any lateral rotordynamic analysis (unbalance response, undamped critical speeds, or stability).

- **6.16.2.8** If specified, a train lateral analysis shall be provided by the supplier with unit responsibility.

6.16.2.9 A separate damped unbalanced response analysis shall be conducted for each critical speed within the speed range of 0 % to 150 % of N_{mc} .

6.16.2.9.1 Unbalance shall analytically be placed at the locations that have been determined by the undamped analysis to affect the particular mode most adversely.

- For the translatory (symmetric) modes, the unbalance shall be based on the sum of the journal static loads ($W_1 + W_2$ as shown in Figure 3) and shall be applied at the location of maximum displacement.
- For conical (asymmetric) modes, an unbalance shall be applied at the location of maximum displacement nearest to each journal bearing. These unbalances shall be 180° out of phase and of a magnitude based on the static load on the adjacent bearing.
- For overhung modes, the unbalances shall be based on the overhung mass.

NOTE Figure 3 shows the typical mode shapes and indicates the location and definition of U for each of the shapes.

6.16.2.9.2 The magnitude of the unbalances, U_a , shall be two times the value of U as calculated by Equation (1a) and Equation (1b).

Between Bearing Machines

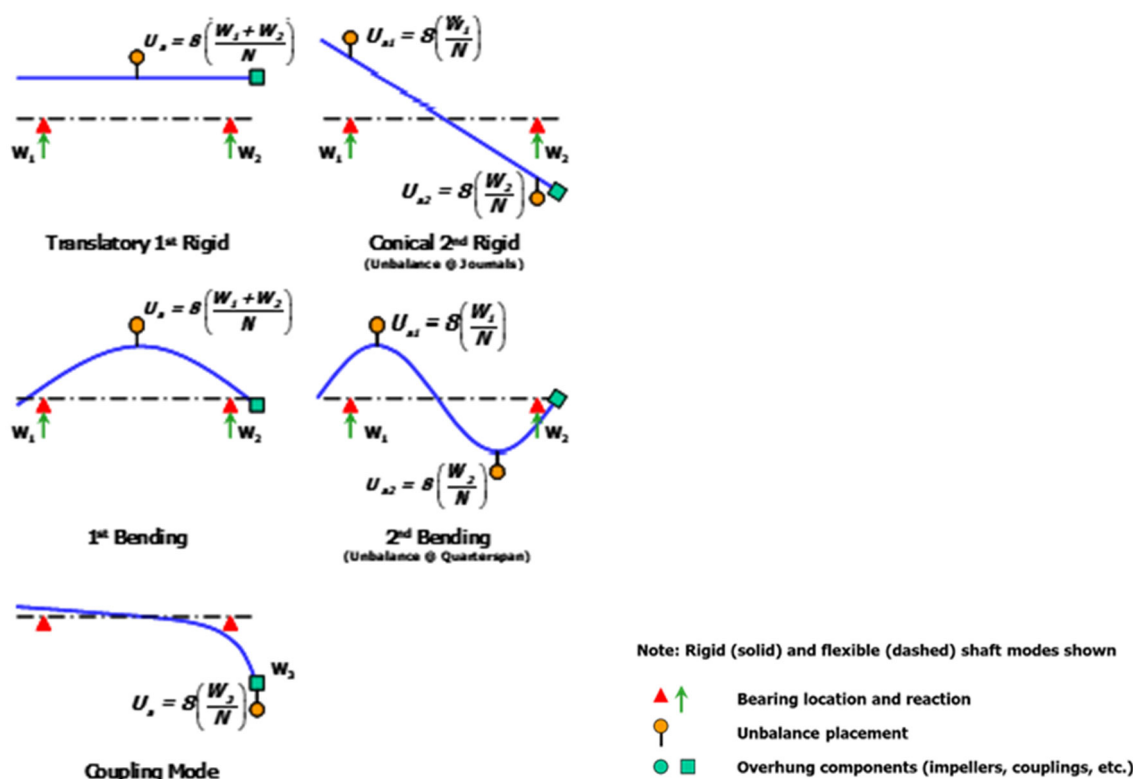


Figure 3—Typical Mode Shapes for Between Bearing Machines

In SI units:

$$U = 6350 \, W/N \text{ for } N < 25\text{k rpm} \quad (1a-1)$$

$$U = W/3.937 \text{ for } N \geq 25\text{k rpm} \quad (1a-2)$$

In USC units:

$$U = 4 \, W/N \text{ for } N < 25\text{k rpm} \quad (1b-1)$$

$$U = W/6250 \text{ for } N \geq 25\text{k rpm} \quad (1b-2)$$

where

U is the input unbalance for the rotordynamic response analysis, g-mm (oz-in.);

N is the maximum continuous operating speed, rpm;

W is W_1 , W_2 , W_3 , or $(W_1 + W_2)$, depending on unbalance case (see Figure 3);

W_1 and W_2 are journal static weight load (including effects of overhung mass), kg (lbm);

W_3 is the overhung mass (for bending modes where the maximum deflection occurs at the shaft ends), kg (lbm).

NOTE The limits on mass displacement are in general agreement with the capabilities of conventional balance machines and are necessary to invoke for small rotors running at speeds running above 25k rpm.

6.16.2.10 For rotors with disk(s) cantilevered beyond the journal bearings, unbalance shall be sized and placed according to Figure 4.

6.16.2.11 For rotors with disk(s) cantilevered beyond the journal bearings, each mode that is less than 150 % of maximum continuous speed shall be analyzed.

NOTE Figure 4 shows the typical mode shapes and indicates the location and definition of U for each of the shapes.

Overhung Machines

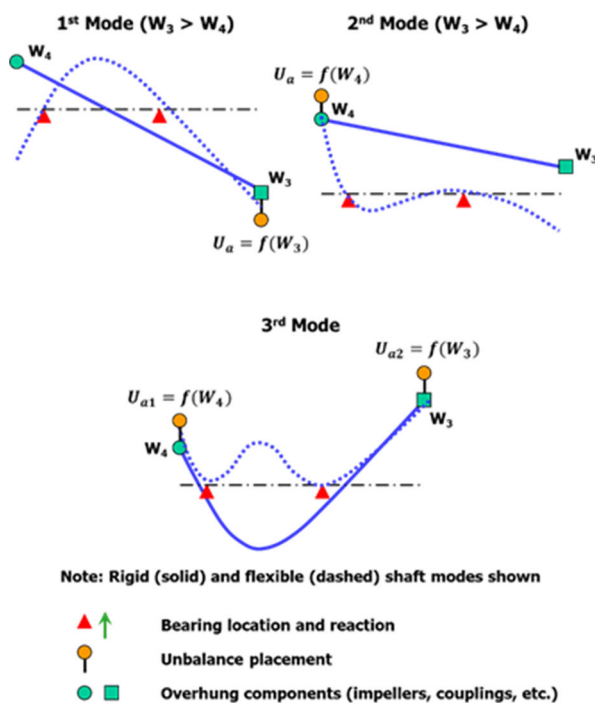


Figure 4—Typical Mode Shapes for Overhung Machines

6.16.2.12 As a minimum, the damped unbalanced response analysis shall produce the following:

- a) identification of the frequency of each critical speed, regardless of the amplification factor (AF), in the range from 0 % to 150 % of N_{mc} ;
- b) frequency, phase, and response amplitude data (Bode plots) at the vibration probe locations from 0 % to 150 % of N_{mc} for each unbalance case considered in 6.16.2.9;
- c) the plot of deflected rotor shape for each critical speed resulting from the unbalances (see 6.16.2.9), showing the major-axis amplitude at each coupling plane of flexure, the centerlines of each bearing, the locations of each radial probe, and at each seal throughout the machine as appropriate; the minimum design diametral running clearance of the seals shall also be indicated;
- d) additional Bode plots that compare absolute shaft motion with shaft motion relative to the bearing housing for machines where the support stiffness is less than three and a half times the oil-film stiffness.

6.16.2.13 Additional analyses shall be made for use with the verification test (see 6.16.2.21).

6.16.2.13.1 The location of the unbalance shall be determined by the vendor.

6.16.2.13.2 Any test stand parameters that influence the results of the analysis shall be included.

NOTE For some rotors, there will only be one plane readily accessible for the placement of an unbalance, e.g. the coupling flange on a single-shaft gas turbine. However, if multiple planes are available, it is possible to excite other critical speeds and multiple analyses could be necessary to avoid any detrimental effect of the unbalanced operation.

6.16.2.13.3 For coupling unbalance placement (unbalance based on the coupling half weight), the unbalance shall not be less than 16 times the value of Equation (1a) or Equation (1b), where W is the coupling half-weight and N is N_{mc} .

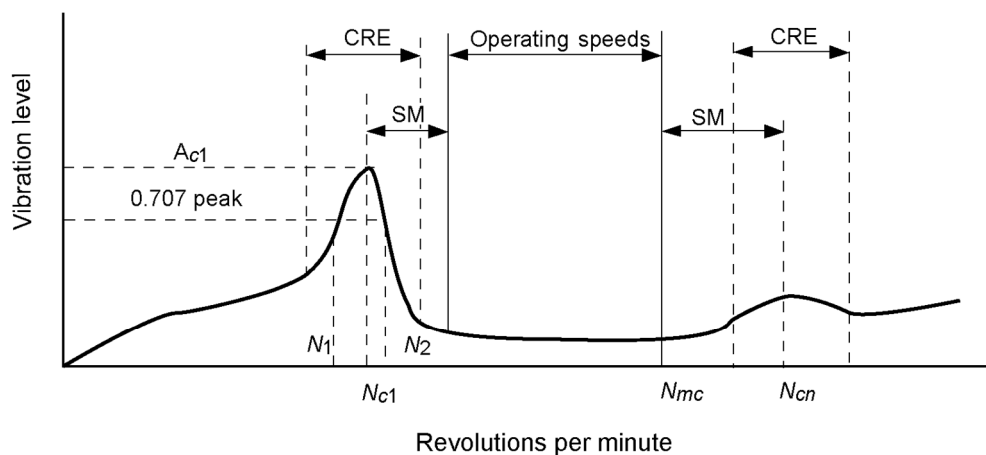
6.16.2.14 The damped unbalanced response analysis shall indicate that the machine will meet the following SM (see Figure 5):

- a) if the AF at a particular critical speed is less than 2.5, the response is considered critically damped and no SM is required;
- b) if the AF at a particular critical speed is equal to 2.5 or greater and that critical speed is below the N_{ma} , the SM (as a percentage of the N_{ma}) shall not be less than the value from Equation (2):

$$SM = 17 \left(1 - \frac{1}{AF - 1.5} \right) \quad (2)$$

- c) if the AF at a particular critical speed is equal to 2.5 or greater and that critical speed is above the N_{mc} , the SM (as a percentage of the N_{mc}) shall not be less than the value from Equation (3):

$$SM = 10 + 17 \left(1 - \frac{1}{AF - 1.5} \right) \quad (3)$$



- N_{c1} = Rotor first critical, center frequency, cycles per minute.
 N_{cn} = Critical speed, n th.
 N_{mc} = Maximum continuous speed, 105%.
 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 5—Rotor Response Plot

6.16.2.15 The calculated unbalanced peak-to-peak response at each vibration probe, for each unbalance amount and case as specified in 6.16.2.9, shall not exceed the mechanical test vibration limit, $A_{SS(p-p)}$, in 6.16.6.2.2 a). See Figure 6.

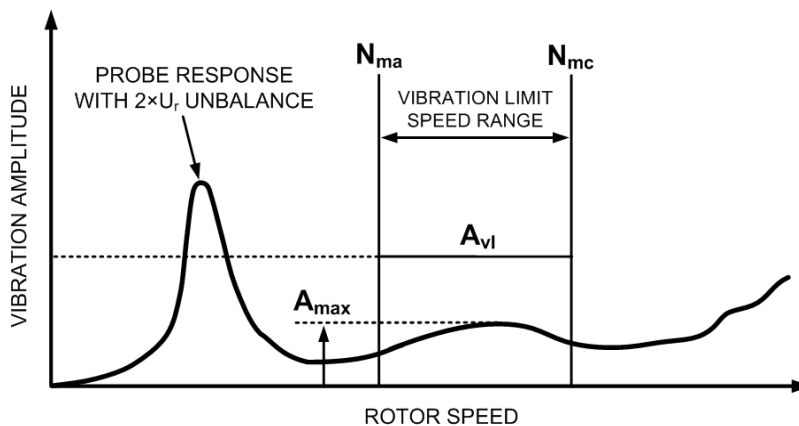


Figure 6—Plot of Applicable Speed Range of Vibration Limit

6.16.2.16 For each unbalance amount and case as specified in 6.16.2.9, the calculated major-axis, peak-to-peak response amplitudes at each close clearance location shall be multiplied by a scale factor, defined by Equation (4). The correction factor shall be between 1.0 and 6.0, inclusive.

$$S_{cc} = A_{SS(p-p)} / A_{max} \text{ or } 6, \text{ whichever is less} \quad (4)$$

where

- S_{cc} is scale factor for close clearance check;
- $A_{SS(p-p)}$ is mechanical test vibration limit defined in 6.16.6.2.2;
- A_{max} is 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.

6.16.2.17 The calculated major-axis, peak-to-peak, unbalanced rotor response amplitudes, corrected in accordance with 6.16.2.15 at any speed from zero to trip speed shall not exceed 75 % of the minimum design diametral running clearances throughout the machine (with the exception of floating-ring seal locations). For machines with abradable seals, the response amplitude to the running clearance shall be mutually agreed. Running clearances may be different than the assembled clearances with the machine shutdown.

6.16.2.18 If the analyses indicates that either of the following requirements cannot be met:

- a) the required SMs;
- b) the requirements of 6.16.2.15 and 6.16.2.16;

and the purchaser and vendor have agreed that all practical design efforts have been exhausted, then acceptable amplitudes SMs and amplification factors shall be agreed.

6.16.2.19 For the unbalanced sensitivity test, the unbalance weight(s) shall be applied to most adversely excite the response peak(s) in question.

- a) The magnitude of the weight(s), defined in Figure 3 or Figure 4, and the resulting measured vectorial change shall not exceed the vibration acceptance limits defined in 6.16.6.2.2 a) and the clearance check of 6.16.2.17.
- b) In case it is not possible to place the unbalance weight(s) in accordance with the mode shape of the particular resonance (see 6.16.2.10), scaling shall be performed to verify that the requirements are fulfilled. The magnitude of the unbalance weight(s) shall be scaled for the mode(s) in question by the ratio between 1) the maximum modal amplitude, and 2) the modal amplitude at the balance plane where the weight is applied.

- **6.16.2.20** If specified, in addition to the other requirements of 6.16.2, the lateral analysis report shall include the following model data:

- a) dimensional data of the bearing design in sufficient detail to enable calculations of stiffness and damping coefficients;
- b) the weight, polar and transverse moments of inertia and center of gravity of the impellers/disk(s), blades, balance piston, shaft end seals and coupling(s) with sufficient detail to conduct an independent analysis of the rotor;
- c) the mass elastic model used for the vendor's analysis;
- d) the support stiffness used in the analysis and its basis;
- e) for machines equipped with rolling element bearings, the vendor shall state the bearing stiffness and damping values used for the analysis and either the basis for these values or the assumptions made in calculating the values.

6.16.2.21 For a gas turbine with a modified bearing or rotor configuration or a gas turbine prototype, an unbalanced rotor response verification test shall be performed.

6.16.2.21.1 Unbalanced rotor response test results (see 8.3.4.3.7) 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 (see 6.16.2.13) shall be the criterion for determining the validity of the damped unbalanced response analysis. To accomplish this, the requirements of 6.16.2.21 through 6.16.2.21.4 shall be followed.

- a) During the mechanical running test, the 1x operating speed amplitude and phase angle of the shaft vibration, from zero to trip speed shall be recorded.

NOTE This set of readings is normally taken during a coast down, with convenient decrements of speed such as 50 rpm.

- b) The location of critical speeds below the trip speed shall be established.
- c) The unbalance that was used in the analysis performed in 6.16.2.13, multiplied by the appropriate correction factor, shall be added to the rotor in the location used in the analysis. The unbalance shall not exceed eight times the value from Equation (1a) or Equation (1b).
- d) The machine shall then be brought up to the trip speed and the indicated vibration amplitudes and phase shall be recorded using the same procedure used for 6.16.2.21.1 a).
- e) The corresponding indicated vibration data taken in accordance with 6.16.2.21.1 a) shall be vectorially subtracted from the results of this test.

NOTE It is practical to store the residual unbalance (see Annex C) vibration measurements recorded in the step at 6.16.2.21.1 a) and by use of computer code perform the vectorial subtraction called for in this paragraph at each appropriate speed. This makes the comparison of the test results with the computer analysis of 6.16.2.13 quite practical. It is necessary for probe orientation be the same for the analysis and the machine for the vectorial subtraction to be valid.

- f) The results of the mechanical running test, including the unbalance response verification test, shall be compared with those from the analytical model (see 6.16.2.13).

6.16.2.21.2 The vendor shall correct the model if it fails to meet either of the following criteria.

- a) The actual critical speeds determined on test shall not deviate from the corresponding critical speeds predicted by analysis by more than 5 %. Where the analysis predicts more than one critical speed in a particular mode (due, for example, to the bearing characteristics being significantly different horizontally and vertically or between the two ends of the machine), the test value shall not be lower than 5 % below the lowest predicted value nor higher than 5 % above the highest predicted value.
- b) If an operating speed falls between two different predicted critical speeds, these two critical speeds shall be treated separately, as if they resulted from separate modes.

NOTE It is possible the vertical and horizontal stiffnesses are significantly different and the analysis can predict two differing critical speeds.

- c) The actual major axis amplitude of peak responses from test, including those critically damped, shall not exceed the predicted values. The predicted peak response amplitude range shall be determined from the computer model based on the four radial probe locations.

6.16.2.21.3 If the support stiffness is less than two times the bearing oil film stiffness, the absolute vibration of the bearing housing shall be measured and vectorially added to the relative shaft vibration, in both the balanced [see 6.16.2.21.1 a)] and in the unbalanced [see 6.16.2.21.1 c)] condition before proceeding with 6.16.2.21.1 f). In such a case, the measured response shall be compared with the predicted absolute shaft movement.

6.16.2.21.4 After correcting the model, the requirements of 6.16.2.15 shall be confirmed.

6.16.3 Stability Analysis

6.16.3.1 For gas turbines with rotors whose N_{mc} is greater than the first undamped critical speed on rigid supports, a stability analysis shall be performed in accordance with 6.16.2.3 to 6.16.2.5. The stability analysis shall be calculated at the N_{mc} . The machine inlet and discharge conditions shall be at either the rated condition or another operating point unless the vendor and purchaser agree upon another operating point.

NOTE The Level I stability analysis (see API TR 684-1) was developed to fulfill two purposes. First, it provides an initial screening to identify rotors that do not require a more detailed study. The approach as developed is conservative. Second, the Level I analysis specifies a standardized procedure that is applied to all manufacturers similar to the lateral analysis found in 6.16.2. (Refer to API TR 684-1 for a detailed explanation of a Level I stability analysis.)

6.16.3.2 The model used in the Level I stability analysis shall include the items listed in 6.16.2.6.

6.16.3.3 All bearings shall be analyzed using the extreme values of oil inlet temperature and operating limits for clearance to produce the minimum log decrement.

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

6.16.3.5 The anticipated cross-coupling, Q_A , present in the rotor is defined by the following procedures.

$$q_a = \frac{(HP)B_t C}{D_t H_t N_r} \quad (5)$$

Equation (5) is calculated for each stage of the rotor. Q_A is equal to the sum of q_a for all stages.

Where:

B_t is stage efficiency per displacement, 1.5;

C is units conversion constant, 9.55 (63);

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

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

HP is potential maximum power per stage or impeller, W (hp);

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

q_a is cross-coupling defined in Equation (5) for each stage, kN/mm (klbf/in.);

Q_A is anticipated cross-coupling for the rotor, kN/mm (klbf/in.); see Equation (6);

$$Q_A = \sum_{i=1}^S q_{ai} \quad (6)$$

S is the number of stages or impellers.

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

6.16.3.7 The applied cross-coupling shall extend from zero to the minimum of the following:

- a) a level equal to 10 times the anticipated cross-coupling, Q_A ;
- b) the amount of the applied cross-coupling required to produce a zero log decrement, Q_0 ; this value can be reached by extrapolation or linear interpolation between two adjacent points on the curve; Q_0 is the minimum cross-coupling needed to achieve a log decrement equal to zero for either minimum or maximum bearing clearance, kN/mm (klbf/in.).

6.16.3.8 A plot of the calculated log decrement, for the first forward mode shall be prepared for the minimum and maximum bearing clearances. A typical plot is presented in API TR 684-1. Q_0 and Q_A are identified as the minimum values from either bearing clearance curves.

- a) Each curve shall contain a minimum of five calculated stability points.
- b) The ordinate (y-axis) shall be the log decrement.
- c) The abscissa (x-axis) shall be the applied cross-coupling with the range defined in 6.16.3.6.
- d) For double overhung rotors, the applied cross-coupling will be the sum of the cross-coupling applied to each impeller or stage.
- e) Acceptable stability exists if both of the following criteria are met, specifically:
 - 1) $Q_0/Q_A > 2.0$;
 - 2) $\delta_A > 0.1$;

where

ξ is the damping ratio;

δ is the logarithmic decrement; see Equation (7);

$$\delta = 2\pi\xi(1-\xi^2)^{0.5} \quad (7)$$

δ_A is the minimum log decrement at the anticipated cross-coupling for either minimum or maximum bearing clearance.

6.16.3.9 If after all practical design efforts have been exhausted to achieve the requirements of 6.16.3.8, acceptable levels of the log decrement, δ_A , shall be mutually agreed upon by the purchaser and vendor.

6.16.4 Torsional Analysis

6.16.4.1 For trains including motors, generators, positive displacement units or gears, the vendor having unit responsibility shall ensure that a torsional vibration analysis of the complete coupled train is carried out and shall be responsible for directing any modifications necessary to meet the requirements of 6.16.4.6 through 6.16.4.11.

- **6.16.4.2** If specified, the supplier with unit responsibility shall perform a train torsional vibration analysis. All modifications necessary to meet the requirements of 6.16.4.6 through 6.16.4.11 shall be completed.

6.16.4.3 For packages covered in 6.16.4.1, a torsional analysis employing a simplified model (lumped rotor inertia and stiffness) and 1x excitation is sufficient.

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

6.16.4.4 The torsional analyses shall include all significant excitation sources, including, but not limited to:

- a) gear characteristics such as unbalance, pitch line runout, and cumulative pitch error;
- b) torsional pulsations due to gear radial vibrations;
- c) cyclic process impulses;
- d) electrical system harmonics of mechanically connected helper motor/generator; purchaser will describe electrical system harmonics (especially for systems that include electric motors driving positive displacement machines);
- e) one and two times electrical line frequency (if applicable);
- f) one and two times operating speed(s).

NOTE Torsional natural frequencies can be excited from many sources.

6.16.4.5 Interferences of the primary (coupling) modes and 1x excitation frequency (mechanical or electrical) shall be at least 10 % above or 10 % below the entire operating speed range (from N_{ma} to N_{mc} ; see 6.1.15 and 6.1.16).

6.16.4.6 All other interferences with torsional natural frequencies and any possible excitation frequency shall be at least 10 % above or 10 % below the entire operating speed range (from N_{ma} to N_{mc} ; see 6.1.15 and 6.1.16).

6.16.4.7 When torsional resonances are calculated to fall within the margin in 6.16.4.6 (and the purchaser and 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.

- **6.16.4.8** The torsional analysis shall support that the life of all shaft sections, couplings, and gear mesh exceeds the service life (see 6.1.2) by a specified service factor.

6.16.4.9 For trains with variable frequency drive (VFD) driven helper motors, vendor shall extend the analysis defined in 6.16.4.5 to 6.16.4.8 to include the following 6.16.4.9.1 to 6.16.4.9.4.

6.16.4.9.1 In addition to the excitations of 6.16.4.4, the following shall also be considered, but is not limited to:

- a) integer orders of the drive output frequency;
- b) sidebands of the pulse width modulation.

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

6.16.4.9.2 A steady-state response analysis shall be performed from 0 to N_{mc} to quantify the effects of the VFD excitation of 6.16.4.9.1.

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

6.16.4.9.4 For interferences occurring within the operating speed range (see 6.1.15 and 6.1.16), the criteria set forth in 6.16.4.8 shall be used.

6.16.4.10 For packages with an electrical generator or helper motor, a transient short circuit fault analysis shall be performed.

6.16.4.10.1 The following fault conditions shall be considered, but are not limited to:

- a) short circuits:
 - 1) line-to-line;
 - 2) two-phase;
 - 3) three-phase;
 - 4) line-to-ground;
 - 5) line-to-line-to-ground;
- b) synchronization (generators):
 - 1) single-phase;
 - 2) three-phase.

6.16.4.10.2 For all fault conditions, the stresses in the shafting and couplings shall not exceed the low cycle fatigue limit.

NOTE Due to the timing of the torsional analysis, the vendor and purchaser need to discuss the impact of any design changes to meet the specification. The analysis for these fault conditions assumes a one-time event. Some components, as identified by the analysis, need to be replaced following the fault event.

6.16.4.11 For generators, the torsional analysis shall show that alternating torques produced by breaker reclosure have no negative impact on the service life (see 6.1.2).

6.16.5 Balancing

6.16.5.1 General

6.16.5.1.1 Rotors shall be balanced in accordance with the following procedures.

- a) Rotors with rigid behavior shall be balanced at low speed in two planes per ISO 21940-11. If the first undamped critical speed on rigid supports exceeds the maximum operating speed by at least 50 %, then the rotor can normally be considered rigid for balancing purposes.
- b) Rotors with flexible behavior require multiplane balancing at high-speed or low-speed balancing in stages during assembly (see ISO 21940-12). Rotors that do not satisfy the rigid rotor definition can be considered flexible for balancing purposes.
- c) When a rotor with a keyway is balanced, the keyway shall be filled with a fully crowned half key, in accordance with ISO 21940-32.