

Recommended Practice for Packaged Combustion Gas Turbines

API RECOMMENDED PRACTICE 11PGT (RP 11PGT)
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FOREWORD

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This recommended practice is based on the accumulated knowledge and experience of turbine manufacturers, turbine equipment packagers, and users. The objective is to provide a primary procurement document for the design, manufacture, and testing of a complete gas turbine package including the driven equipment. This packaged equipment is intended for use in oil and gas production service.

Historically, API Standard 616 "Gas Turbines for Refinery Service" has been the industry standard for gas turbine equipment procurement. API RP 11 PGT "Recommended Practice for Packaged Combustion Gas Turbines" allows the purchaser the option of requiring compliance with Section 2 of API 616, the turbine manufacturer's standard, or the purchaser's own specification. The purchaser must decide which option best suits the application.

1) API Standard 616 generally addresses industrial, heavy frame type gas turbines. It considers aircraft-derivative designs but not extensively. API Standard 616 was written specifically for refinery services. It should not be used with this packaging specification in its entirety.

2) Specifying a turbine manufacturer's standard design recognizes that most gas turbines are highly standardized machines. This specification provides general requirements and limitations in applying these standard turbine designs.

3) Purchasers may prefer to prepare their own specification to supplement this document.

This packaging recommended practice also accommodates options for driven equipment. The purchaser must evaluate the component specifications available and determine which is most appropriate for the service. This recommended practice is not intended to inhibit technical innovations, energy conservation, or cost reductions.

Note:

This is the first edition of this specification and was approved by Letter Ballet as Practices taken at the 1991 Standardization Conference Circ PS 1952.

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SECTION 1 GENERAL

1.1 Scope. This recommended practice is intended to cover the minimum requirements for a complete self-sufficient packaged combustion gas turbine prime mover with or without driven equipment for onshore/offshore oil and gas production services. The package shall be factory assembled to the maximum extent possible as limited by the mode of transportation. All auxiliary equipment required for operating, starting, controlling, and protecting the turbine/driven equipment is included directly or by reference in this recommended practice. Specifically intended to be covered are gas turbine packages capable of continuous service firing gas fuel, liquid fuel, or both.

NOTE: A bullet (•) in the margin indicates that a decision by the purchaser is required. These decisions should be indicated directly on the data sheets when provisions are made for them; otherwise, they should be stated in the quotation request or in the order.

1.2 Alternative Designs. The packager may offer alternative designs [5.1.1]. Equivalent metric dimensions, fasteners, and flanges may be substituted as mutually agreed upon by the purchaser and the packager.

1.3 Conflicting Requirements. In case of conflict between this recommended practice and the inquiry or order, the information included in the order shall govern. The packager and purchaser should jointly determine and quickly resolve any conflicts before placement of the order.

1.4 Definition of Terms. The terms used in this recommended practice are defined as follows:

1.4.1 Alarm point is a preset value of a parameter at which an alarm is actuated to warn of a condition requiring corrective action.

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

1.4.3 Critical speed corresponds to resonant frequencies of the system and of the forcing phenomena. If the frequency of any harmonic component of a periodic forcing phenomenon is equal to, or approximates the frequency of any mode of rotor vibration, a condition of resonance may exist; if resonance exists at a finite speed, that speed is called a critical speed.

1.4.4 Use of the word Design in any terms such as design power, design pressure, design temperature, or design speed should be avoided in the purchaser's specifications. This terminology should be used only by the equipment designer and manufacturer.

1.4.5 A Filter Stage is a section of a filter system which is designed to remove specific site contaminants at a prescribed efficiency and pressure drop. A stage may be a specific media, an inertial separator, a mist eliminator, or a self-cleaning section. Multistage filters are combinations of the various filter stages.

1.4.6 Gas generators are devices in which only that energy required to drive the compressor stages and auxiliaries is extracted from the discharging gas by its turbine stages.

1.4.7 Heat rate is the gas turbine's energy consumption per unit of output work. Heat rate is expressed in British Thermal Units (BTU) per horsepower-hour at

the output shaft for mechanical drives or in BTU per kilowatt-hour at the generator terminals for electric generator sets. Both are based on the lower heating value of the fuel.

1.4.8 Inlet cubic feet per minute (ICFM) refers to the flow rate determined at the conditions of pressure, temperature, compressibility, and gas composition, including moisture at the compressor inlet flange. Actual cubic feet per minute (ACFM) may be used to refer to flow at a number of locations and should, therefore, not be used interchangeably with inlet cubic feet per minute.

1.4.9 Local means mounted on, attached to, or adjacent to the package or equipment skids.

1.4.10 Maximum allowable speed (in revolutions per minute) is the highest speed at which the manufacturer's design will permit continuous operation.

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

1.4.12 Maximum allowable working pressure is the maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified temperature [Appendix A].

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

1.4.14 Minimum allowable speed (in revolutions per minute) is the lowest speed at which the manufacturer's design will permit continuous operation.

1.4.15 Normally open and normally closed refer to "on-the-shelf" positions and designate the de-energized positions of devices such as automatically controlled electric switches and valves. It is emphasized that the position of such a device during operation of the equipment is not necessarily the same as the device's "on-the-shelf" position.

1.4.16 Normal operating point is the point at which usual operation is expected and optimum efficiency is desired. This point is usually the point at which the packager certifies that performance is within the tolerances stated in this practice. This includes power, speed, and heat rate at specified site conditions and fuel composition.

1.4.17 The packager is the vendor having responsibility for coordinating the technical aspects of the equipment, and all auxiliary systems included in the scope of the order [2.2.1, 2.2.2, 2.2.3]. Responsibility for such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation, piping, and testing of components is included.

1.4.18 Panel is an enclosure used to mount, display, and protect gages, switches, and other instruments.

1.4.19 Potential maximum power is the expected power capability when the gas turbine is operated at maximum allowable firing temperature, rated speed, or other limiting conditions as defined by the manufacturer and within the range of specified site values.

1.4.20 Power turbine is a mechanical prime mover specifically designed for recovery of energy from hot gases produced by the gas generator.

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

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

1.4.23 Rated cycle temperature at ISO conditions is the vendor's stated (calculated) turbine inlet total temperature, immediately upstream of the first stage turbine rotor blades for continuous service at ISO rated power output.

1.4.24 Rated firing temperature at ISO conditions is the vendor's stated (calculated) turbine inlet temperature, immediately upstream of the first-stage turbine nozzles, for continuous service at ISO rated power output.

1.4.25 Rated power at ISO conditions is the continuous power developed by the gas turbine when it is operated at rated firing temperature and speed under the following standard operating conditions (ISO 2314).

Inlet temperature	59 F (15 C)
Inlet (total) pressure	14.696 psia (1.0133 bar)
Inlet Relative Humidity	60%
Exhaust pressure	14.696 psia (1.0133 bar)

This power and speed is measured at the output shaft of the gas turbine ahead of any separate gears or driven equipment except in the case of electric generators where power output is measured at the generator terminals. The inlet conditions shall be measured at the gas generator inlet flange and exhaust conditions at the exhaust flange. These measuring points shall be utilized for all power and gas flow measurements. The ISO rating provides only general sizing information and should not be confused with the site rated power.

1.4.26 Rated speed (in revolutions per minute) is the speed of the gas turbine output shaft at which site rated power is developed.

1.4.27 Remote means located away from the package or equipment skids, typically in a control room or data transmission facility.

1.4.28 Site rated conditions are the specified values of the inlet air temperature, inlet air pressure, and exhaust gas pressure at which site rated power is required. Inlet and exhaust ducting and other facilities, barometric variations, and ambient temperature ranges shall be considered when specifying the site rated conditions.

1.4.29 Site rated cycle temperature is the turbine inlet total temperature immediately upstream of the first stage turbine rotor blades, required to meet site rated power.

1.4.30 Site rated firing temperature is the turbine inlet temperature, immediately upstream of the first stage turbine nozzles, required to meet site rated power.

1.4.31 Site rated power is the power developed by the gas turbine at the output shaft when it is operated at site rated firing temperature, rated speed, and rated site conditions, rated fuel composition, and with or without steam or water injection. (External auxiliaries are not included in parasitic losses.)

1.4.32 Shutdown point is a preset value of a parameter requiring automatic or manual shutdown of the system.

1.4.33 Standard cubic feet per minute (SCFM) refers to capacity at a pressure of 14.7 pounds per square inch absolute (1.01 bar) and a temperature of 60°F (15.56°C).

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

1.4.35 Thermal efficiency (η) is the ratio of the energy output at the power turbine shaft to the energy input (based on lower heating value of the fuel) expressed in the same units. (External auxiliaries are not included in parasitic losses.)

$$\eta = \frac{\text{Output BHP} \times 2545}{\text{Input BTU/HR (LHV)}} \quad (\text{Mechanical Drive})$$

$$\eta = \frac{\text{Output Kw} \times 3412}{\text{Input BTU/HR (LHV)}} \quad (\text{Generator Drive})$$

1.4.36 Trip speed (in revolutions per minute) is the speed at which the independent emergency overspeed device operates to shut down the gas turbine.

1.5 Referenced Publications.

1.5.1 The purchaser and the packager shall mutually determine the measures that must be taken to comply with any federal, state, or local codes, regulations, ordinances, or rules that are applicable to the equipment (O.S.H.A., UBC, etc.). Purchaser will be responsible for providing applicable state and local codes, regulations, ordinances, and rules.

1.5.2 The current editions of the following standards, codes, and specifications shall, to the extent specified herein, form a part of this recommended practice. The applicability of changes in standards, codes, and specifications that occur after the inquiry shall be mutually agreed upon by the purchaser and the packager:

AGMA¹

Std 420 Practice for Helical and Herringbone Gear Speed Reducers and Increaseers

Std 421 Practice for High Speed Helical and Herringbone Gear Units

AISC² — Manual of Steel Construction

AISI³ — Standard Type 300 Stainless Steel

— Standard Type 1020 Plain Carbon Steel

ANSI⁴

- B16.11 Forged Steel Fittings, Socket-Welding and Threaded
- B16.5 Steel Pipe Flanges and Flanged Valves and Fittings
- B31.3 Chemical Plant and Petroleum Refinery Piping
- C50.10 General Requirements for Synchronous Machines
- C50.12 Requirements for Salient-Pole Synchronous Generators
- C50.13 Requirements for Cylindrical-Rotor Synchronous Generators
- C50.14 Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators
- S5.1 Test Code for the Measurement of Sound from Pneumatic Equipment
- Y14.2M Line Conventions and Lettering

API⁵

- RP-541 Form Wound Squirrel-Cage Induction Motors, 250HP and Larger
- RP-546 Form Wound Brushless Synchronous Motors - 500 hp and larger
- RP-550 Manual on Installation of Refinery Instruments and Control Systems
- Std 610 Centrifugal Pumps for General Refinery Services
- Std 611 General Purpose Steam Turbines for Refinery Services
- Std 613 Special Purpose Gear Units for Refinery Services
- Std 614 Lubrication, Shaft-Sealing, and Control Oil Systems for Special Purpose Applications
- Std 616 Gas Turbines for Refinery Services
- Std 617 Centrifugal Compressors for General Refinery Services
- Std 618 Reciprocating Compressors for General Refinery Services
- Std 660 Shell and Tube Heat Exchangers for General Refinery Services
- Std 661 Air Cooled Heat Exchangers for General Refinery Services
- Std 670 Vibration, Axial-Position, and Bearing-Temperature Monitoring Systems
- Std 671 Special Purpose Couplings for Refinery Services
- Std 678 Accelerometer-Based Vibration Monitoring System

ASME⁶

Boiler and Pressure Vessel Code:
 Section V, Nondestructive Examinations
 Section VIII, Unfired Pressure Vessels
 Section IX, Welding and Brazing Qualifications

B1.20.1, General Purpose (inch) Pipe Threads
 B31.3, Chemical Plant and Petroleum Refinery Piping

Power Test Code:
 PTC-1, General Instructions.
 PTC-22, Gas Turbine Power Plants.

ASTM⁷

- A36 Structural Steel
- A53 Zinc-Coated Welded and Seamless Black and Hot-Dipped Steel Pipe
- A105 Carbon Steel Forgings for Piping Components
- A106 Seamless Carbon Steel Pipe for High-Temperature Service
- A120 Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Use
- A123 Zinc (Hot Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plated, Bars, and Strip
- A153 Zinc Coating (Hot Dipped) on Iron and Steel Hardware
- A193 Alloy Steel and Stainless Steel Bolting Materials for High Temperature
- A194 Carbon and Alloy Steel Nuts for Bolts for High Pressure and High Temperature Service
- A197 Cupola Malleable Iron
- A202 Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Manganese-Silicon
- A269 Seamless and Welded Austenitic Stainless Steel Tubing for General Service
- A307 Carbon Steel Externally Threaded Standard Fasteners
- A312 Seamless and Welded Austenitic Stainless Steel Pipe
- A338 Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine, and other Heavy Duty Service at Temperatures up to 650F (345C)
- A358 Electric Fusion Welded Austenitic Cr-Ni Alloy Steels Pipes for High Temperature Service
- A500 Cold Formed Welded and Seamless Carbon Steel Structural Tubing on Rounds and Shapes
- A515 Pressure Vessel Plates, Carbon Steel, for Intermediate and Higher Temperature Service
- A524 Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures
- A525 General Requirements for Steel Sheet, Zinc Coated (Galvanized) by the Hot Dip Process

- A569 Steel, Carbon (0.15 max), Hot Rolled Sheet and Strip, Commercial Quality
- A591 Steel Sheet, Cold Rolled, Electrolytic Zinc Coated
- A606 Steel Sheet and Strip, Hot Rolled and Cold Rolled, High Strength, Low Alloy, with Improved Atmospheric, Corrosion Resistance
- A662 Specification for Pressure Vessel Plates, Carbon, Manganese for Moderate and Lower Temperature Service.
- E94 Guides for Radiographic Testing
- E125 Reference Photographs for Magnetic Particle Indications on Ferrous Castings
- E142 Method for Controlling Quality of Radiographic Testing
- E709 Practice for Magnetic Particle Examination
- AWS⁸
- D1.1 Structural Welding Code - Steel
- IEEE⁹
- 45 Recommended Practice for Electrical Installation on Shipboards
- 115 Test Procedures for Synchronous Machines
- 522 Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for AC Rotating Electric Machines, 1977 Edition (Reaffirmed 1981)
- ISO¹⁰
- ISO-2314 — Gas Turbines - Acceptance Tests
- ISO-3448 — Standard Industrial Liquid Lubricants — ISO Viscosity Classification
- MIL¹¹
- Mil-E-5007 Engines, Aircraft, Turbojet, and Turbofan, General Specifications for
- Mil-STD-1534 Engines, Aircraft, Gas Turbines Technical Design Requirements
- NACE¹²
- MR-01 Sulfide Stress Corrosion Cracking Resistant Metallic Material for Oilfield Equipment
- NEMA¹³
- MG1-20 Motors and Generators (Induction Motors)
- MG1-21 Motors and Generators (Synchronous Motors)
- MG1-22 Motors and Generators (Synchronous Generators)
- SM-23 Steam Turbines for Mechanical Drive Services
- NFPA¹⁴
- 37 Stationary Combustion Engines and Gas Turbines
- 70 National Electrical Code
- 500 Laboratory Classified Locations
- 501 Class I Locations
- 502 Class II Locations

72E Automatic Fire Detectors

OSHA¹⁵

Code of Federal Regulations (CFR) 29 CFR 1910 — Occupational Safety and Health Standards

SAE¹⁶

TEMA¹⁷ Standards, Codes, and Specification

UBC¹⁸ Uniform Building Code

Reference standards may be obtained from the following organizations.

¹American Gear Manufacturer's Association, 1901 Fort Myer Dr., Arlington, VA 22209

²American Institute of Steel Construction, Inc. 400 North Michigan Avenue, Chicago, IL 60611

³American Iron and Steel Institute, 1000 16th Street, N.W., Washington, DC 20036

⁴American National Standards Institute, 1430 Broadway, New York, NY 10018

⁵American Petroleum Institute, 1220 L Street North West, Washington, D.C. 20005

⁶American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017

⁷American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103

⁸American Welding Society, 550 NW LeJeune Rd., Miami, FL 33135

⁹Institute of Electrical and Electronic Engineers, 345 East 47th Street, New York, NY 10017-2394

¹⁰International Organization for Standardization. ISO publications are available from ANSI (4)

¹¹Department of Defense - obtain from: Commanding Officer, Naval Publications Forms Center, ATTN: NPFC 105, 5801 Tabor Ave., Philadelphia, PA 19120

¹²National Association of Corrosion Engineers, P.O. Box 218340, Houston, TX 77218

¹³National Electrical Manufacturer's Association, 2101L Street, NW, Washington, DC 20037

¹⁴National Fire Protection Association, Batterymarch Park, Quincy, MA 02269

¹⁵Occupational Safety and Health Administration, U.S. Department of Labor. The Code of Federal Regulations is available from the U.S. Government Printing Office, Washington, DC 20402

¹⁶Society of Automotive Engineers, Inc., Aerospace Materials Division, 400 Commonwealth Drive, Warrendale, PA 15096

¹⁷Tubular Exchanger Manufacturer's Association, 25 North Broadway, Terrytown, NY 10591

¹⁸International Conference of Building Officials (UBC), 5360 South Workman Mill Road, Whitter, CA 90601.

SECTION 2 BASIC PACKAGE DESIGN

2.1 Site Specific Requirements.

2.1.1 Service Life. The complete package covered by this recommended practice shall be designed and constructed for a minimum service life of 20 years and minimum uninterrupted continuous service interval of 3 years. The hot gas path inspection interval shall be a minimum of 8000 hours. It is recognized that these are design criteria. It is recognized that applications with marginal fuels and/or water or steam injection may require a more frequent inspection interval. It is the purchaser's responsibility to provide the packager pertinent site information. It is the packager's responsibility to identify in his proposal any special equipment and maintenance procedures necessary to achieve the aforesaid life and service intervals.

2.1.2 Unit Responsibility. The packager shall be responsible for complete train performance and the mechanical integrity of the entire package to meet specified performance.

- **2.1.3 Site Rating Condition.** The purchaser will specify the package site specific operating point(s) on the data sheets [Appendix A]. Unless otherwise specified, the gas turbine shall be designed to provide site rated power with no negative tolerance at the heat rate quoted.

- **2.1.4 Starting Requirements.** The purchaser will define any operating requirements which impact start cycle sequence or duration [2.2.9].

- **2.1.5 Transient Requirements.** Operational stability under load transients shall meet the requirement as specified by the purchaser. These requirements should be clearly defined by a relationship of load, speed, and time parameters.

- **2.1.6 Instrumentation/Communication.** Minimum controls requirements are defined by 2.2.15. The purchaser will specify any additional requirements for instrumentation, data acquisition, data transmission, and system interface with total facility.

2.1.7 Maintenance/Inspection. Recommended inspections, normal maintenance, and major overhaul intervals shall be stated in the packager's proposal. The package shall be designed for ease in servicing and to provide adequate clearances necessary to perform all normal maintenance, and changeout of components on the package. Special tools and procedures shall be stated in the packager's proposal. All tool lists, parts list, and maintenance procedures shall be included in the packager's maintenance manual.

2.1.8 Spare Parts.

2.1.8.1 The packager shall consider the specific site conditions and include in his proposal a list of spares needed to complete package commissioning and field acceptance of initial operations. A second list of spares for three years operation shall also be included.

2.1.8.2 Spare parts for the package components shall be identical to originally installed parts.

2.1.9 Site Condition/Environment.

- **2.1.9.1** The purchaser will furnish accurate site conditions to the packager that include but are not

limited to: location, climatic conditions (temperature, humidity, wind, barometer, precipitation), airborne atmospheric conditions (any unusual dust or corrosive environment, airborne pollutants, agricultural chemicals, etc.), site elevation, geological and seismic conditions.

- **2.1.9.2** The purchaser will advise the packager of the area classification(s) requirements.

- **2.1.9.3** The purchaser will specify whether the installation is indoors (heated or unheated) or outdoors (with or without a roof) in which the equipment must operate.

- **2.1.9.4** Purchaser will state the degree of operator attendance.

2.1.9.5 The package and auxiliaries shall be suitable for operation under the specified conditions. For the purchaser's guidance, the packager shall define in the proposal any special protection that the purchaser is required to supply.

- **2.1.10 Sound Level.** Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the packager. The equipment furnished by the packager shall conform to the maximum allowable sound pressure level specified by the purchaser.

- **2.1.11 Emission.** Control of exhaust emission levels of the package shall be a joint effort of the purchaser and the packager. The purchaser will specify the maximum allowable emission levels at the package boundaries. The packager shall state in his proposal expected emission levels consistent with purchaser's specified fuel properties and site operating conditions. The packager shall supply the turbine combustion emission suppression system to meet the specified levels of NO_x, CO, and unburned hydrocarbons in the turbine's exhaust gas.

- **2.1.12 Fuels.** The fuel system shall be operable with the normal fuel or any alternate or starting fuel specified. Purchaser will provide the composition, range of heating values, temperatures, dew point temperature, pressure, contaminants, and other properties of the fuel supply. The packager shall advise the purchaser of the effects of the fuel(s) on turbine package operation and equipment life. When specified, the packager shall provide any fuel treatment equipment required [3.8].

2.2 Package Design.

2.2.1 Packaged Equipment. The packager shall provide, as a minimum, the equipment listed below (referred to herein as a "package") packaged to meet the specified operating conditions. This equipment shall be assembled (packaged) to the maximum extent possible.

- a. Baseplate(s).
- b. Combustion gas generator.
- c. Controls and instrumentation.
- d. Couplings and guards.
- e. Exhaust collector.
- f. Fuel system(s).

- g. Lube oil system(s).
- h. Power turbine (if separate from gas generator).
- i. Starting system.
- j. Gas Turbine washing or cleaning system.
- k. Vibration monitoring system.

2.2.2 Shipped Loose Equipment. The packager shall provide the accessory equipment listed below to meet the specified operating conditions. This equipment shall be either packaged or shipped loose.

- a. Control panel.
- b. Inlet ducting.
- c. Inlet filtration system.
- d. Inlet silencer.

- **2.2.3 Other Equipment.** Any other equipment required will be specified by the purchaser and shall be included in the packager's proposal. Such equipment may include:

- a. Combustion emission control system.
- b. Driven equipment in accordance with applicable specifications.
- c. Enclosure(s) for acoustical, weather, and/or fire protection.
- d. Exhaust system (including expansion joints, silencers, structures).
- e. Fuel conditioning.
- f. Inlet evaporative air cooler.
- g. Inlet anti-icing system.
- h. Lifting equipment for maintenance.
- i. Lifting equipment for shipping and handling.
- j. Motor control center.
- k. Recuperator or regenerator for turbine performance enhancement.
- l. Starting system auxiliaries.
- m. Steam or water injection fluid conditioning system.
- n. Turbine load train condition monitoring equipment.
- o. Uninterrupted power supply for controls, instrumentation, and operation.
- p. Waste heat recovery systems.

2.2.4 Preliminary Review. Many factors (such as piping and ducting loads, alignment at operating conditions, supporting structure, and assembly at the site) may adversely affect site performance. To minimize the influence of these factors, the packager shall review and comment on the purchaser's piping, ducting, and foundation drawings.

- **2.2.5 Motors and Electrical Components.** Motors, electrical components, and electrical installations shall be suitable for the area classification(s) (class, group, and division) specified by the purchaser on the data sheets and shall meet the requirements of NFPA 70, Articles 500 and 501, as well as local, state, and federal codes specified and furnished by the purchaser.
- **2.2.6 Operating Speed Range.** The output shaft operating speed range of gas-turbine units for me-

chanical drive applications shall be suitable to meet all operating conditions specified by the purchaser on the data sheets. Where only one operating condition is specified for an application, the minimum speed range for single shaft machines shall be 25 percent (from 80 to 105 percent of rated speed) and the minimum speed range for two or more shaft machines shall be 55 percent (from 50 to 105 percent of rated speed). The turbine shall have satisfactory mechanical performance at all operating conditions specified on the data sheets and within the range among those conditions. The unit shall be capable of operation, without damage, to the trip speed setting at all operating conditions.

2.2.7 Rating Condition. The gas turbine package shall be mechanically designed and satisfactory for continuous service at potential maximum power [1.4.19].

2.2.8 Operating Criteria.

2.2.8.1 The package shall operate on the test stand and on its permanent foundation within the specified acceptance criteria [4.3]. After installation, the acceptance of mechanical and operating performance of the package shall be the joint responsibility of the purchaser and the packager.

2.2.8.2 The purchaser will specify the available utility supplies on the data sheets; the packager shall provide the required utility loads on the data sheets (Appendix A).

2.2.9 Starting Requirements. The package design shall permit immediate starting from any nonrotating condition. Any restrictions shall be defined in the proposal.

2.2.10 Temperature/Speed Limits. Equipment shall be designed to run without damage at any speed up to the highest trip speed in combination with any of the packager's allowable temperatures.

2.2.11 Package Arrangement. The arrangement of the package, including piping, coolers, pumps, and controls shall provide adequate clearance areas and safe access for operation and maintenance.

2.2.12 Maintenance Requirements.

2.2.12.1 All major equipment shall be designed to permit rapid and economical maintenance. Parts such as casing components and bearing housings shall be designed (shouldered or cylindrically doweled) and manufactured to ensure accurate alignment during reassembly. Stationary vanes, nozzles, seals, bearings, diaphragms, gas turbine modules, and the rotating elements shall be replaceable at site. The packager's proposal shall describe the special tooling needed for the above purposes. If the equipment designs do not permit such replacement, the packager shall state in his proposal the procedures required for such repairs.

2.2.12.2 All equipment shall be suitable for periods of idleness up to 3 weeks, under specified site conditions, without requiring any special maintenance procedures.

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

- **2.2.14 Steam or Water Injection.** When specified, the gas turbine shall be designed to permit steam or water injection for either increasing the power capability of the unit or for emission control. The packager shall specify the required quality and quantity of the injection fluid [3.8.5].

2.2.15 Control Requirements. The package control system shall provide for sequenced startup, stable operation, warning of abnormal conditions, monitoring of operation, and shutdowns of the package in the event of impending damage to the unit [3.9].

2.2.16 Special Tools and Fixtures.

- **2.2.16.1** When special tools and fixtures are required to disassemble, assemble, or maintain the package, they shall be included in the quotation and, when specified, furnished as part of the initial supply of the package. For multiple unit installations, the requirements for quantities of special tools and fixtures shall be mutually agreed upon by the purchaser and the packager. These or similar special tools shall be used during shop assembly and post-test disassembly of the equipment.

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

- **2.2.17 Compartment Enclosure(s).** When specified, suitable enclosure(s) shall be provided to meet purchaser's acoustical, weatherproofing, and/or fire protection requirements. Enclosure(s) shall be designed to ensure the package can meet the maintenance, operation, and service life requirements [3.3].

2.3 Combustion Gas Turbine Drive Train Mechanical Equipment Components.

2.3.1 Combustion Gas Turbine Drivers.

2.3.1.1 The combustion gas turbine driver shall be a current production model suitable for installations in production facilities.

- **2.3.1.2** The Purchaser will specify whether the packager shall supply a combustion gas turbine driver in accordance with API Standard 616 Section 2 or the Manufacturer's Standard. When conflict between API Standard 616 Section 2 and this specification exists, this practice shall apply.

2.3.1.3 The data sheets from Appendix A shall be completed and become a part of the package data sheets.

2.3.2 Couplings and Guards.

2.3.2.1 The packager shall furnish all couplings and guards, including adaptor plates, between the turbine, starting driver, auxiliary gears, and if applicable, load gear and the load equipment.

- **2.3.2.2** When specified, main load couplings, coupling mountings, and guards shall conform to API Standard 671. The coupling make, type, and mounting arrangement shall be agreed upon by the packager and by the purchaser. A spacer coupling shall be used, unless otherwise specified.
- **2.3.2.3** When specified, the packager shall supply a special, equivalent moment type, idling adapter as required for the mechanical running test [4.3.4].

2.3.2.4 Couplings shall be sized for maximum continuous torque based on the potential maximum power capability that can be delivered to a specific coupling.

2.3.2.5 For power generation service, the generator load coupling shall be sized to withstand the worst case of generator fault conditions unless a shear type coupling is provided.

2.3.2.6 Couplings shall be dynamically balanced on an individual component basis and then assembled into a completed coupling which is also dynamically balanced as an assembly as per API Standard 671, paragraph 2.5.3.1, procedure 3.

2.3.2.7 Coupling-to-shaft connections shall be designed and manufactured to be capable of transmitting power at least equal to the maximum continuous torque rating of the coupling.

2.3.2.8 Coupling spacer length shall allow removal and replacement of bearings and seals without disturbing main equipment casings.

2.3.3 Auxiliary Gears.

2.3.3.1 The gas turbine driver may utilize auxiliary gears for starting functions, lubrication drive, liquid fuel pumps, and bearing sump scavenging pumps. Main load gears may utilize auxiliary gearing for main load train lubrication pump drives and starting functions.

2.3.3.2 Auxiliary gears shall comply with AGMA 420 or 421 as applicable, and shall be rated for at least 110 percent of the power transmitted. Tooth surface finish shall be to AGMA quality level 10 or better.

2.3.4 Load Gears.

- **2.3.4.1** Unless otherwise specified, load gears design, testing, and application shall comply with API Standard 613 and the purchaser's specifications. Pertinent design/gear loading data shall be designated by the purchaser on the applicable data sheets shown in Appendix A. Epicyclic/planetary type gear designs and applications shall comply with the applicable paragraphs of API Standard 613, AGMA 420, and AGMA 421.

2.3.4.2 The minimum horsepower ratings of load gears shall be at least equal to the maximum potential power output of the gas turbine per purchaser's stated ambient temperature range. If this results in an excessively large gear/horsepower ratings, packager and purchaser may mutually agree on a lesser size gear/actual gear rating.

- **2.3.4.3** The minimum generator load must also be considered in the design of load gear for turbine-generator sets. The purchaser will specify the minimum generator load.

2.3.5 Driven Equipment.

2.3.5.1 Packager supplied packaged combustion gas turbine driven equipment load-trains typically will be turbo-machinery type with driven equipment such as centrifugal compressors, centrifugal pumps, AC power generators, or combinations thereof.

2.3.5.2 Centrifugal Compressors.

2.3.5.2.1 Unless otherwise specified, centrifugal compressor design, testing, and installation shall be in accordance with API Standard 617 and the purchaser's specifications.

- **2.3.5.2.2 Compressor equipment** shall include seal oil or seal gas arrangements. Where seal oil systems are utilized, a combined seal oil/lubrication oil system shall be utilized only with purchaser's approval.

The purchaser will specify on the data sheets whether the seal-oil and lube-oil systems are to be separate or combined. If separate systems are specified, the means of preventing interchange of oil between the two systems shall be described in the vendor's proposal.

- **2.3.5.2.3 Compressor performance requirements** in including gas flow rates, operating pressure, temperature ranges, and gas composition will be provided by purchaser on the applicable data sheets.

2.3.5.3 Centrifugal Pumps.

2.3.5.3.1 Unless otherwise specified, centrifugal pump design, testing, and installation shall be in accordance with API Standard 610 and the purchaser's specifications.

- **2.3.5.3.2 Centrifugal pump performance requirements** in regard to liquid flow rates, operating pressure and temperature ranges, and liquid fluid properties will be provided by purchaser on the applicable data sheet shown in Appendix A.

2.3.5.4 Generators.

2.3.5.4.1 Generators shall be designed and installed per the purchaser's requirements and specifications. Unless otherwise specified, generators shall be a two-bearing, air cooled, AC synchronous design.

- **2.3.5.4.2 Generator rating and electrical hardware and instrumentation requirements** to be provided by packager will be specified by purchaser on the applicable data sheet shown in Appendix A.

2.3.5.4.3 Generators shall be designed to meet the applicable requirements of NEMA MG1-22 and ANSI C50.10, C50.12, C50.13, and C50.14 Standards. The generator mechanical design qualities shall be equivalent to those required in API RP 546. Generator rotor dynamics design, assembly, and testing shall be in accordance with this specification's section 2.5 and the Dynamics Section 2.4.7 of API RP 546.

- **2.3.5.4.4** As specified in Appendix A, the packager shall provide equipment as indicated on The Generator Power System one line diagram. The purchaser and packager will agree on the scope of supply and location of the required equipment.

- **2.3.5.4.5** When specified, inspection and testing shall be in accordance with Appendix E

2.3.5.5 Reciprocating Compressors. Gas turbine driven reciprocating compressor packages are not addressed by this specification. The purchaser and packager shall mutually agree upon the unique design issues of torsional pulsation and specific packaging provisions associated with reciprocating compressors.

2.3.6 Vibration and Balance.

2.3.6.1 When shaft displacement type vibration monitoring is used, the following applies: During the shop test of the machine, assembled with the balanced

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

$$\Delta = [12,000/N]^{0.5} \quad \text{Equation 1}$$

In SI units, this converts to:

$$\Delta = 25.4[12,000/N]^{0.5}$$

Where:

Δ = amplitude of unfiltered vibration, in mils (micrometers) peak to peak

N = maximum continuous speed, in revolutions per minute

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

Note: These limits are not to be confused with the limits specified in 2.3.6.6 for shop verification of unbalanced response.

2.3.6.2 Electrical and mechanical runout shall be determined and recorded by rolling the rotor in V blocks while measuring runout with a noncontacting vibration probe and a dial indicator at the same shaft location.

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

2.3.6.4 If the vendor can demonstrate that electrical or mechanical runout is present, a maximum of 25 percent of the test level calculated from Equation 1 or 0.25 mil (6.4 micrometers), whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory test.

2.3.6.5a Where case mounted (Seismic) vibration systems are standard on packaged equipment, the manufacturer(s) shall provide purchaser with the criteria used to define the manufacturer's acceptable vibration limits. These criteria shall include, but not be limited to, the following:

- Locations and types of transducers
- Filtration and signal conditioning
- Operational conditions
- Quoted limits
- Shop/field experience factors from previous/similar units.

2.3.6.5b During the factory test of the assembled aircraft-derivative gas generator/gas turbine, at any steady state speed within the specified operating range, the amplitude of vibration (measured at the manufacturer's standard sensor locations) shall not exceed 50 percent of the manufacturer's published alarm set point value. This limit may be based on filtered or unfiltered data as published by the manu-

facturer and shall be verified during the factory test. Summary data from previously tested units shall be included to document vibration levels.

2.3.6.6 The rotating element shall be multiplane dynamically balanced during assembly. This shall be accomplished after the addition of no more than two major components. Balancing correction shall only be applied to the elements added. Minor correction of other components may be required during the final trim balancing of the completely assembled element. On rotors with single keyways, the keyway shall be filled with a fully crowned half-key. The weight of all half-keys used during final balancing of the assembled element shall be recorded on the residual unbalance work sheet [Appendix C]. The maximum allowable residual unbalance per plane (journal) shall be calculated as follows:

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

In SI units, this converts to:

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

Where:

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

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

N = maximum continuous speed, in revolutions per minute

2.3.6.7 The method of balancing a stacked rotor assembly where the rotor is progressively assembled and cannot be removed as a unit, and when paragraph 2.3.6.6 cannot be followed because of rotor design, the following shall apply:

- a. All rotating parts shall be component balanced.
- b. The assembled rotor shall be check balanced to the limits specified in 2.3.6.6. No correction to the assembled rotor is permitted. If correction is required, the entire rotating element shall be disassembled and the dynamic balancing of the individual components repeated to achieve the allowable residual unbalance limits.

2.3.6.8 Generator rotor balance shall be done with all rotor armature pieces in place, including the exciter assembly.

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

2.3.6.10 Final residual unbalance levels (inch-ounces/gram-millimeters) shall be recorded with the rotational speed of balance noted and unbalance angle locations indicated for each rotor assembly.

2.3.6.11 Residual magnetism shall not exceed 3 gauss in the rotating and stationary interface areas such as the shaft journals or the bearing sleeve. Residual magnetism in the shaft extension and coupling areas shall not exceed 3 to 5 gauss. Magnetic fields exceeding these values will require demagnetizing to within acceptable levels prior to shipment.

2.4 Critical Lateral and Torsional Speeds Considerations/Responsibilities.

2.4.1 General.

2.4.1.1 This section is concerned with the rotor dynamics of the combustion gas turbine driver as well as the associated driven load-train equipment. Each load-train equipment component manufacturer should be responsible for the acceptable rotor dynamics design of the equipment as an isolated, singular component in accordance with this Section 2.4 and Section 2.5 as well as the requirements of the applicable component standards.

2.4.1.2 When all combustion gas turbine driven equipment components are assembled as a load-train of equipment, individual equipment component rotor dynamic response characteristics can be expected to change from that of the isolated, singular component signature basis. A total load-train rotor dynamics analysis shall be performed to ensure that these changes will not be detrimental to the satisfactory long-term operation of any equipment component.

2.4.2 Packager Responsibility.

2.4.2.1 The packager shall be responsible to insure that the drive-train critical speeds (rotor lateral, system torsional, and blading modes) are compatible with the critical speeds of the machinery being supplied, and that the combination is suitable for the specified operating speed range, including any starting speed detent (hold-point) requirements of the train. A list of all undesirable speeds from zero to trip shall be submitted to the purchaser for his review, included in the technical manual for his guidance [5.2.6], and programmed into the control system to avoid these critical speeds.

2.4.2.2 The packager shall be responsible for the lateral and torsional critical speed analysis of the entire equipment system. This speed analysis shall be performed on a total load-train assembly basis. All shaft critical speeds, pertinent modes of exciting frequencies of the driver and driven equipment throughout the start-up and operating speed range, and any external exciting forces, as defined by the purchaser, shall provide specified separation margins to prevent excitation of one by another, and shall provide for an ample range of frequencies within which the supporting foundation's natural frequencies may be designed. This analysis shall be performed in time to permit coordination of the package installation design. Report requirements are specified in 5.2.6.

2.4.3 Critical Speeds.

2.4.3.1 Critical lateral and torsional speeds for driven equipment components shall be at least 10 percent above or below their operating speed range.

2.4.3.2 The dynamics criteria of Section 2.5 shall apply for all hydrodynamic radial type bearing designs.

2.4.3.3 Aircraft derivative type combustion gas turbines generally use antifriction ball and roller type bearings. Rotor dynamic response functions and associated amplitude factors will be different from those

of hydrodynamic bearing design turbines. The dynamic criteria of paragraphs 2.5.1, 2.5.2, and 2.5.3 do not apply.

2.5 Dynamics.

2.5.1 General.

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

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

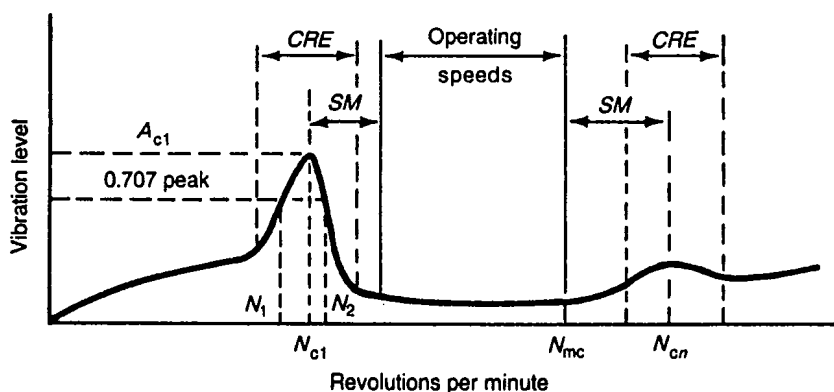
Note: The mode shapes are commonly referred to as the first rigid (translatory or bouncing) mode, the second rigid (conical or rocking) mode, and the first, second, third, ...nth) bending mode.

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

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

- Mechanical unbalance in the rotor system.
- Oil-film instabilities (whirl).
- Internal rubs.
- Blade, vane, nozzle, and diffuser passing frequencies.
- Gear-tooth meshing and side bands.
- Coupling misalignment.
- Loose rotor-system components.
- Hysteretic and friction whirl.
- Boundary-layer flow separation.
- Acoustic and aerodynamic cross-coupling forces.
- Asynchronous whirl.
- AC power generator electrical unbalance and/or cycle speeds.

2.5.1.5 Resonances of rotor bearing support systems within the packager's scope of supply shall not occur within the specified operating speed range or the specified separation margins, unless the resonances are critically damped.



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

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

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

**FIGURE 1
ROTOR RESPONSE PLOT**

2.5.2 Lateral Analysis.

2.5.2.1 The packager shall provide a damped unbalanced response analysis for each machine to assure acceptable amplitudes of vibration at any speed from zero to trip.

2.5.2.2 The damped unbalanced response analysis shall include but shall not be limited to the following considerations.

- a. Support (base, frame, and bearing-housing) stiffness, mass, and damping characteristics, including effects of rotational speed variation. The packager shall state the assumed support system values or shall use those as provided by the purchaser.
- b. Bearing lubricant-film stiffness and damping changes due to speed, load, preload, oil temperatures, accumulated assembly tolerances, and maximum to minimum clearances.
- c. Rotational speed, including the various starting-speed detents, operating speed, and load ranges (including agreed upon test conditions if different from those specified), trip speed, and coast down conditions.
- d. Rotor masses, including the mass moment of coupling halves, stiffness, and damping effects (for example, accumulated fit tolerances, fluid stiffening and damping, and frame and casing effects).
- e. Asymmetrical loading (for example, partial arc admission, gear forces, side streams, and eccentric clearances).

2.5.2.3 The effects of other equipment in the train shall be included in the damped unbalanced response analysis (that is, a train lateral analysis shall be performed).

2.5.2.4 As a minimum, the damped unbalanced response analysis shall include the following:

- a. A plot and identification of the mode shape at each resonant speed (critically damped or not) from zero to trip, as well as the next mode occurring above the trip speed.
- b. Frequency, phase, and response amplitude data at the vibration probe locations through the ranges of each critical speed, using the following arrangement of unbalance for the particular mode. This unbalance shall be sufficient to raise the displacement of the rotor at the probe locations to the vibration limit defined by 2.3.6.1.

The unbalanced weight or weights shall be placed at the location or locations within the bearing span that have been analytically determined to affect the particular mode most adversely (for example, at mid span for translatory modes, or near both ends and 180 degrees out of phase for conical modes). For bending modes with maximum deflections at the shaft's ends, the amount of unbalance shall be based on the overhung mass rather than the static bearing loading.

- c. Modal diagrams for each response in item b, above, indicating the phase and major-axis amplitude at each coupling engagement plane, the centerlines of the bearings, the locations of the vibration

probes, and each seal area throughout the machine. The minimum design diametral running clearance of the seals shall also be indicated.

- d. For the purpose of the verification test [2.5.3], in an attempt to raise the amplitude at the probes to the API vibration limit, an additional plot of a test unbalance, not less than two times or more than eight times API unbalance limits as specified in item b. above (based on static bearing loading for rigid modes or based on overhung mass for bending modes), with maximum deflection at the shaft end, which shall be placed at a location determined by the packager [2.5.3.2.1].

- e. When specified, a stiffness map of the undamped rotor response from which the damped unbalanced response analysis specified in item c. above was derived. This plot shall show frequency versus support system stiffness, with the calculated support system stiffness curves superimposed.

2.5.2.5 The damped unbalanced response analysis shall indicate that the machine in the unbalanced condition described in 2.5.2.4, item b., will meet the following acceptance criteria [Figure 1].

- a. If the amplification factor is less than 2.5, the response is considered critically damped and no separation margin is required.
- b. If the amplification factor is 2.5-3.55, a separation margin of fifteen percent above the maximum continuous speed and five percent below the minimum operating speed is required.
- c. If the amplification factor is greater than 3.55 and the critical response peak is below the minimum operating speed, the required separation margin (a percentage of minimum speed) is equal to the following:

$$SM = 100 - [84 + 6/[AF-3]] \quad (2)$$

- d. If the amplification factor is greater than 3.55 and the critical response peak is above the trip speed, the required separation margin (a percentage of maximum continuous speed) is equal to the following:

$$SM = [126 - 6/[AF-3]] - 100 \quad (3)$$

- e. The above specified margins of separation are intended to prevent the overlapping of the critical response envelopes into the operating speed range. The margins of separation shall be increased to prevent any actual overlaps.

2.5.2.6 Amplification Factor, for lateral critical speeds, shall not exceed 8 while going through criticals. Values of Amplification Factors less than 5 are preferred. This measurement shall be recorded on deceleration (coast down) with the slowroll (300-600 RPM) total run-out (electrical and mechanical) subtracted by vectorial run-out compensation. This recorded shaft relative data shall include speed, peak-to-peak displacement, and phase angle.

2.5.2.7 The calculated unbalanced peak-to-peak rotor amplitudes [2.5.2.4, item b.] at any speed from zero to trip shall not exceed 75 percent of the minimum design diametral running clearances throughout the machine (with the exception of floating-ring seal locations).

2.5.2.8 If, after the purchaser and the packager have agreed that all practical design efforts have been exhausted, the analysis indicates that the separation margins still cannot be met, or that a critical response peak falls within the operating speed range, acceptable amplitudes shall be mutually agreed upon by the purchaser and the packager, subject to the requirements of 2.5.2.7.

2.5.3 Shop Verification of Unbalance Response Analysis.

2.5.3.1 Shop test verification procedures for rotor design unbalance response analysis for the gas turbine, centrifugal compressor, and centrifugal pump rotors shall be in accordance with the applicable sections of API Standards 616, 617, and 610 respectively.

2.5.3.2 Shop test verification procedures for rotor design unbalance response analysis for generator and flexible shaft main load gear elements shall be in accordance with the following:

2.5.3.2.1 The actual critical speed responses, as revealed on the test stand with a rotor unbalance vectorially additive in phase to the residual unbalance of a magnitude in accordance with 2.5.2.4, item d., placed at a location determined by the packager (usually the coupling), shall be the criteria for confirming the validity of the damped unbalanced response analysis.

Note: It is recognized that the dynamic response of the machine on the test stand will be a function of the agreed-upon test conditions. Unless test-stand conditions duplicate the fields foundation characteristics and the same pressure, temperature, speed and load, the results obtained on the test-stand will not correlate with those obtained during field operations.

2.5.3.2.2 The parameters to be measured during the test shall be speed and shaft vibration amplitudes with corresponding phase angle. The vibration amplitudes and phase angle from each pair of x-y vibration probes shall be vectorially summed at each response peak to determine the maximum amplitude of vibration. The major-axis amplitude of each response peak at the probe location shall not allow the vibration limits specified in 2.3.6 to be exceeded. The gain of the recording instrumentation used shall be predetermined and preset before the test so that the highest response peak is within 60-100 percent of the recorder's full scale on the test-unit coast-down (deceleration).

Note 1: It is recognized that vectorial subtraction of slow-roll (300-600 revolutions per minute) total electrical and mechanical runout is normally required for this verification and that vectorial addition of bearing-housing motion may be required.

Note 2: The phase on each vibration signal, x or y, is the angular measure, in degrees, of the phase difference (lag) between a phase reference signal (from a phase transducer sensing a once-per-revolution mark on the rotor, as described in API Standard 670) and the next positive peak, in time, of the synchronous (1x) vibration signal. (When proximity probes are used, this is the lag angle between the vibration probe and the high spot on the rotor.)

Note 3: The major-axis amplitude is properly determined from a lissajous (orbit) display on an oscilloscope, oscillograph, or equivalent. When the phase angle between the x and y signals is not 90 degrees, the major-axis amplitude can be approximated by $(x^2 + y^2)^{1/2}$. When the phase angle between the x and y signals is 90 degrees, the major-axis value is the greater of the two vibration signals.

2.5.3.2.3 Additional testing per 2.5.3.2.4 will be required if, from the test data described above and/or a phase or amplitude indication in the damped unbalanced response analysis (based on the unbalance conditions described in 2.5.2.4, item b.), it appears that either of the following conditions exists:

- a. Any critical response will fail to meet the separation margin requirements [2.5.2.5] or will fall within the operating speed range.
- b. The requirements of 2.5.2.7 have not been met.

2.5.3.2.4 Rotors which fail to meet the criteria specified in 2.5.3.2.2 shall require additional testing as follows.

a. Unbalance weights shall be placed as described in 2.5.2.4, item b. Unbalance magnitudes shall be achieved by adjusting the residual unbalance that exists in the rotor from the initial run to raise the displacement of the rotor at the probe locations to the vibration limit defined by 2.5.2.4, item b at the maximum continuous speed; however, the unbalance shall be no less than twice the unbalance limit specified in 2.3.6.6. The measurements from this test, taken in accordance with 2.5.3.2.2, shall indicate the following acceptance criteria for the machine.

1. Shaft deflections shall not exceed 55 percent of the minimum design running clearances (exclusive of abradable seals) or 150 percent of the allowable vibration limit at the probes, at any speed within the operating speed range (0 to trip), including separation margins [2.5.2.4, item b].
 2. Shaft deflections shall not exceed 90 percent of the minimum design running clearance at any speed outside the operating speed range, including the separation margins.
- b. The internal deflection limits specified in Items 1. and 2. above shall be based on the calculated displacement ratios between the probe locations and the areas of concern identified in 2.5.2.4, item c. Actual internal displacements for these tests shall be calculated by multiplying these ratios by the peak readings from the probes. Acceptance will be based on these calculated displacements, not on inspection of seals after testing; however, damage to any portion of the machine, as a result of this testing, shall constitute failure of the test. Minor internal seal rubs that do not cause clearance changes outside the component manufacturer's new-part tolerance do not constitute damage.

2.5.4 Torsional Analysis.

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

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

2.5.4.2 The torsional resonances of the complete train shall be at least ten percent above or ten percent below any possible excitation frequency within the specified operating speed range (from minimum to maximum continuous speed).

2.5.4.3 Torsional criticals at two or more times running speeds shall preferably be avoided, or in systems in which corresponding excitation frequencies occur shall be shown to have no adverse effect [2.5.4.4]. In addition to multiples of running speeds, torsional excitations that are not a function of operating speeds or that are nonsynchronous in nature shall be considered in the torsional analysis when applicable. Identification of these frequencies shall be the mutual responsibility of the purchaser and the packager.

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

2.6 Materials of Package Construction.

2.6.1 General.

2.6.1.1 Materials of package construction shall be manufacturer's standard for the specified operating conditions. See 3.6.1 for auxiliary piping material requirements. Specific attention shall be given to the need for and extent of corrosion-resistant materials and components as well as the type of protective coating systems for the particular site conditions.

2.6.1.2 Materials shall be identified in the proposal with their applicable ASTM, AISI, ASME, or SAE numbers, including the material grade. When no such designation is available, the packager's material specification, giving physical properties, chemical composition, and test requirements, shall be included in the proposal.

2.6.1.3 Minor parts that are not identified (such as nuts, springs, washers, gaskets, and keys) shall have corrosion resistance at least equal to that of specified parts in the same environment.

- **2.6.1.4** The purchaser will specify any corrosive agents present in the motive and process fluids and in the environment, including constituents that may cause stress corrosion cracking.

Note: When dissimilar materials with significantly different electrical potentials are placed in contact in the presence of an electrolytic solution, galvanic couples that can result in serious corrosion of the less noble material may be created. If such conditions

exist, the purchaser and the packager should select materials in accordance with the NACE Corrosion Engineer's Reference Books.

2.6.1.5 Where mating parts such as studs and nuts of AISI Standard Type 300 stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an antiseizure compound of the proper temperature specification.

Note: Torque loading values will be considerably different with and without antiseizure compound.

2.6.1.6 Low carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or low temperatures. Therefore, only fully killed, normalized steels made to fine grain practices are acceptable. The use of ASTM A-515 steel is prohibited.

2.6.1.7 For the selection of pressure containing materials other than austenitic stainless steel for service below -20°F (-29°C), the packager shall require a Charpy V-notch impact test of the base metal and of the weld joint.

Note: To avoid brittle failure during operation, maintenance, transportation, erection, and testing, good design practices shall be followed in the selection of fabrication methods, welding procedures, and materials for vendor-furnished carbon steel piping and appurtenances that may be subject to temperatures below the ductile-brittle transition point. The published design-allowable stresses for many materials in the ASME Code and ANSI standards are based on minimum tensile properties and do not differentiate between rimmed, semikilled, fully killed, hot-rolled, and normalized material, nor do they take into account whether materials were produced under fine or coarse-grain practices. The packager shall exercise caution in the selection of materials intended for service between -20°F (-29°C) and 100°F (38°C).

2.6.2 Welding.

2.6.2.1 Welding of pressure-containing parts, as well as any dissimilar-metal welds and weld repairs, shall be performed and inspected by operators and procedures qualified in accordance with Section VIII, Division 1, and Section IX of the ASME Code.

2.6.2.2 Welding of piping shall be in accordance with ANSI B31.3.

2.6.2.3 Welding on baseplates, nonpressure ducting, lagging, and control panels, shall be performed in accordance with AWS D1.1.

2.6.2.4 The packager shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat treated and nondestructively examined for soundness and compliance with the applicable qualified procedure.

2.6.2.5 Repair welds shall be nondestructive tested by the same method used to detect the original flaw.

2.6.3 Piping and Tubing.

2.6.3.1 Piping and tubing materials shall comply with Table 1 [3.6.1], Minimum Requirements for Piping and Tubing Systems.

2.6.3.2 Piping and tubing materials for sour gas service shall comply with the recommendations of NACE MR-01.

2.6.4 Structural. Carbon steel for structural applications such as baseplates, modules, etc., shall comply with ASTM A-36 as a minimum for plate and structural shapes. Structural steel tubing shall be to ASTM A-500, Grade B, minimum. Structural steel members shall be limited to standard sizes, shapes, and weights per AISC Manual of Steel Construction.

2.6.5 Galvanized Steel. Galvanized material which is to remain unpainted shall be of the hot-dipped type to ASTM A-525 to a minimum of 3 ounces per square foot. Galvanized material which will be subject to a finish coating of paint or similar material shall be of the electro-galvanized type in accordance with ASTM A-591.

2.6.6 Nonmetallic materials such as elastomers shall be compatible with the process or motive fluids with which they come into contact during normal operation or maintenance functions.

2.6.7 Bolting.

2.6.7.1 The quality of bolting for pressure joints including piping shall be determined from the actual bolting temperature as defined by ANSI B31.3 and shall be at least equal to that shown in Table 1, [3.6.1].

2.6.7.2 Nuts shall conform to ASTM A-194, Grade 2 or 2H, for A-193 bolting, and ASTM A-307, Grade B case hardened, for A-307 bolting.

2.7 Nameplates.

2.7.1 A nameplate shall be securely attached at a readily accessible point on the package and on other major pieces of equipment within the package.

2.7.2 Rotation arrows shall be cast in or attached to each major item of rotating equipment. Nameplates and rotation arrows (if attached) shall be of AISI Standard Type 300 stainless steel or of nickel-copper alloy (Monel or its equivalent). Attachment pins shall be of the same material. Welding is not permitted.

2.7.3 The purchaser's item number, the vendor's name, the machine's serial number, and the machine's size and type, as well as its minimum and maximum allowable design limits and rating data (including pressures, temperatures, speeds, and power), maximum allowable working pressures and temperatures, hydrostatic test pressures, and critical speeds, shall appear on the machine's nameplate. The purchaser will specify on the data sheets whether customary or SI units are to be shown.

SECTION 3 ACCESSORY SYSTEMS

3.1 Starting Systems.

- **3.1.1** The packager shall furnish the type of starter system specified by the purchaser. Typical starters include electric motors, gas expansion turbines, steam turbines, hydraulic motors, internal combustion engines, air/gas motors, and small gas turbines. All starter units shall be suitable for satisfactory operation with the specified electrical power characteristics, inlet and exhaust steam pressure and temperatures, air/gas or fuel.
- 3.1.2** Starting units and associated power transmission equipment shall be suitable for the acceleration of the combustion gas turbine unit/driven load equipment train, and for extended operation during purge and compressor cleaning cycles. The packager shall determine the ratings which shall be at least 110 percent of the starting and acceleration torque required by the gas turbine (and the driven equipment train for single shaft machines) from standstill to self-sustaining speed throughout the specified ambient temperature range. Utilities required for the starting system shall be defined by the packager in his proposal.
- **3.1.3** For single shaft machines, anticipated process variations which may affect the sizing of the starter, (such as changes in pressure, temperature or properties of the fluid handled, and special plant start-up conditions) will be specified by the purchaser. For single shaft turbines, the packager shall prepare a speed torque curve for the turbine and driven equipment with the starting driver torque superimposed.
- 3.1.4** Steam turbines used as starting gas expanders shall be general purpose turbines per API Standard 611. Electric motor starters larger than NEMA frame size shall be in accordance with API RP 541.
- 3.1.5** Gas expansion starters using flammable gas as motive power shall be designed for zero leakage at the seals.
- 3.1.6** Packager shall supply any clutches, speed changing gears, torque converters, or other power transmission equipment and controls required for the starting units.
- 3.1.7** Any starting driver shall disengage automatically and shut down before reaching its maximum allowable speed. The starters normally are disengaged at turbine governing speed and idle, or are at rest during operation. Failure of the starting driver to disengage shall automatically abort the starting sequence.

3.2 Mounting Systems.

- **3.2.1 General.**
 - 3.2.1.1** The package support base shall be of structural steel design and shall be of sufficient strength for shipment and installation, and to transmit equipment generated forces and couples to Purchaser's foundation. The Purchaser will specify the type of foundation on the data sheets. The system shall be designed as a complete package to support all equipment.
 - 3.2.1.2** The packager shall furnish drawings which contains the requirements for mounting all equipment on the foundation.

3.2.1.3 Baseplates refer to the fabricated structures on which equipment is mounted. Baseplates may either be mounted direct to the foundation or on soleplates. Soleplates refer to separable plates which are leveled and fastened to the foundation, then the package is fastened to the soleplates.

3.2.2 Anchoring Systems.

- 3.2.2.1** When a baseplate is installed directly on a concrete foundation, accessibility shall be provided for grouting under all load-carrying structural members. The mounting surfaces on the bottom of the baseplate shall be in one plane to permit use of a single-level foundation.
- **3.2.2.2** When epoxy grout is specified on the data sheets, the vendor shall precoat all the grouting surfaces with a catalyzed epoxy primer applied to degreased near-white metal. The purchaser will specify the primer and the method of application.
- 3.2.2.3** Mounting surfaces that are not to be grouted shall be coated with a rust preventive immediately after machining.
- 3.2.2.4** As a minimum, mounting surfaces that are to be grouted shall have 2-inch radiused (50 millimeter) outside corners in the plan view.
- 3.2.2.5** Anchor bolts will be furnished by the Purchaser. Packager shall specify the size, number, and location of anchor bolts required for the specified method of fastening the package to the foundation.

3.2.3 Baseplate Design.

3.2.3.1 A baseplate shall be a single fabricated steel unit, unless the purchaser and the packager mutually agree that it may be fabricated in multiple sections.

Note: A baseplate with a nominal length of more than 40 feet (12 meters) or a nominal width of more than 12 feet (3.6 meters) may have to be fabricated in multiple sections because of shipping restrictions. Gross weight shipping restrictions from point of manufacturing to point of destination must also be considered in determining if sectioned baseplates are required.

- **3.2.3.2** When specified, the baseplate shall be provided with leveling pads or targets protected with removable covers. The pads or targets shall be accessible for field leveling after installation, with the equipment mounted and the baseplate on the foundation.
- **3.2.3.3** When specified, the baseplate shall be suitable for column mounting, with sufficient rigidity to be supported at specified points, without continuous grouting under structural members. The baseplate design shall be mutually agreed upon by the purchaser and the packager.
- 3.2.3.4** The baseplate shall be provided with lifting lugs for at least a four-point lift. Lifting lug weld joints shall be full penetration, full length continuous weld, and nondestructive tested. Lifting the baseplate complete with mounted equipment shall not permanently distort or otherwise damage the baseplate or the machinery mounted on it. Purchaser and Pack-

ager shall mutually agree on lifting arrangements based upon available facilities at Purchaser's site or other limiting factors.

- **3.2.3.5** When specified by the Purchaser, lifting frame(s) and/or spreader bar(s) shall be supplied by the packager to permit single or multipoint lift capability.
- **3.2.3.6** When specified, nonskid decking or grating covering all walk and work areas shall be provided on the top of the baseplate. All deckplate shall be positively attached to each crossing structural member.
- 3.2.3.7** Baseplate shall be furnished with vertical jack screws adjacent to each anchor bolt.
- 3.2.3.8** Baseplate(s) shall be provided with drip containment and low point drains.

3.2.4 Equipment Mounting.

3.2.4.1 Axial, lateral, and vertical jackscrews shall be provided for all equipment in the package train. Vertical jackscrews shall be arranged to prevent marring of shimming surfaces.

3.2.4.2 Package train component supports shall be provided with AISI Standard Type 300 Stainless Steel Shim packs, 1/4-1/2 inch (6.3-12.7 millimeters) thick, with jackscrews for easy removal or addition of shims. All shims shall straddle hold-down bolts and jackscrews. Laminated shims are prohibited.

3.3 Enclosure and Fire Protection.

3.3.1 General.

- **3.3.1.1** When specified, an enclosure system shall be supplied consisting of the following:
 - a. An enclosure surrounding the gas turbine and/or driven equipment.
 - b. An enclosure ventilation and purging system.
 - c. A fire protection system.
- **3.3.1.2** If sound control is specified, the requirements of paragraph 2.1.10 shall apply. Any special "far field" or neighborhood sound restrictions that are applicable will be specified by the purchaser.

3.3.2 Construction.

3.3.2.1 Enclosures shall be weather proof and dust tight. Water and/or dust leakage through the enclosure wall and roof seams is unacceptable. Panels shall be designed to minimize panel internal moisture buildup and corrosion. Panels shall be moisture resistant; fire resistant; insect, and vermin resistant [2.1.9].

3.3.2.2 Enclosures shall be designed to permit easy on-site maintenance.

3.3.2.2.1 Removable roof sections, side panels, or hinged bulkhead walls shall be provided for heavy maintenance. Construction of maintenance accessways shall permit easy return to the original condition. Caulking is not acceptable.

3.3.2.2.2 Access doors and/or manways shall be provided for routine maintenance and inspection. Double acoustic self adjusting seals shall be used around the perimeter of the accessway. Accessways shall be lockable.

3.3.2.2.3 Conduits, fire prevention systems, gas detection, etc., shall not be attached to the underside of the roof or any other panels that must be removed for maintenance.

3.3.2.3 At least one window shall be supplied on each side of the enclosure; preferably located on an access door and opposite each other. Each window shall be double pane wire reinforced glass with a dead air space between panes.

3.3.2.4 Adequate lighting for general observation is to be provided within the enclosure. Lights are to be operated by three-way switches located at the accessway on each side of the enclosure.

3.3.3 Fire Protection.

3.3.3.1 A fire protection system shall be furnished when an enclosure is specified, unless specifically deleted from packager's scope of supply by the purchaser. The system shall consist as a minimum of the following:

- a. A fire suppression system.
- b. A fire detection system.
- c. A gas detection system for gas fueled units only.

• **3.3.3.2** The fire suppression system shall be designed in accordance with the applicable NFPA standard. The purchaser will specify any special design considerations to be included in the suppression system, including the specific fire suppression medium.

3.3.3.3 The primary method of actuation of the suppression system shall be automatic. A manual actuation system is also required. A manual release station shall be located externally on each side of the enclosure.

• **3.3.3.4** The fire detection system shall be designed in accordance with NFPA-72E. Rate compensated thermal detection shall be considered the minimum level of detection. Additional levels of detection, such as optical, will be specified by the purchaser, if required.

3.3.3.5 The gas detection system shall be designed in accordance with NFPA-72E.

3.3.3.6 All fire suppression and detection devices utilized within the enclosure shall be designed to operate throughout the entire range of operational service conditions encountered within the enclosure.

3.3.4 Ventilation and Purging.

• **3.3.4.1** The enclosure shall be provided with a fan driven forced ventilation and purging air system designed to provide 100 percent of the ventilation and purging load in the most severe climatic/load conditions. Purchaser will specify on the data sheets fan system redundancy requirements and whether positive or negative pressure is required.

3.3.4.2 Ventilation system shall include air filtration and silencing equipment if required.

3.3.4.3 Fan motors shall be single speed for warm environments. Where climatic conditions exist, which can cause abnormal cooling of the enclosure, two speed fan motors may be used.