

API SPECIFICATION REVIEW FOR GAS TURBINE DRIVEN TURBOCOMPRESSORS

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ABSTRACT

This tutorial provides an overview of the latest edition of American Petroleum Institute (API) Code API 616 (1998) and also provides a brief summary of API 614 (1999), 617 (2002), 670

(2000), 671 (1998), and 677 (1997) as they apply to gas turbine driven compressors. Critical sections of the codes are discussed in detail with a special focus on their technical interpretation and relevance for the purchasing scope-of-supply comparison, machine testing, and field operation. Technical compliance issues for package, core engine, instrumentation, and driven compressor are addressed individually. As API 616 (1998) forms the backbone for most oil and gas combustion turbine acquisitions, it is covered in more detail. Some recommendations for acceptance of manufacturer exceptions to API and the technical/commercial implications will be provided. A brief discussion of the relevance NFPA 70 (2002) to gas turbine driven compressor sets in oil and gas applications will also be included. This tutorial course is intended for purchasing, operating, and engineering staff of turbomachinery user companies.

INTRODUCTION

American Petroleum Institute (API) specifications are generally applied to oil and gas turbomachinery applications rather than to large industrial power generation. Oil and gas applications of gas turbines have requirements that are inherently different from those of the electric power industry. Namely, oil and gas applications, and customers require:

- High availability/reliability
- Ruggedness
- High power/weight ratio
- Efficiency often not critical

While industrial power generation customers have different critical requirements, namely:

- Cost of electricity
- Efficiency
- Cost of operation and maintenance (O&M)

Because of these inherent market differences, oil and gas customers often insist on compliance with API codes and are willing to accept the resultant higher turbomachinery package costs.

OIL AND GAS TURBOMACHINERY APPLICATIONS

Many applications within the oil and gas industry require the usage of turbomachinery equipment for compression, pumping, and generation of electricity. These applications are generally

divided into three separate areas from the production of oil to the sales of the refined product. These are upstream, midstream, and downstream. Upstream refers to the oil and gas production and gathering process, midstream is the oil and gas transportation process, and downstream is the refining and distribution of oil and gas products. For each area and definition, different processes that require turbomachinery are listed below.

Upstream

- Self-generation—Power generation to meet needs of oil field or platform
- Enhanced oil recovery (EOR)—Advanced technologies to improve oil recovery
- Gas lift—Injecting gas into the production well to help lift the oil
- Waterflood—Injection of water into the reservoir to increase reservoir pressure and improve production
- Gas reinjection—Reinjection of natural gas into the reservoir to increase the reservoir pressure
- Export compression—Initial boosting of natural gas pressure from field into pipeline (a.k.a. header compression)
- Gas gathering—Collecting natural gas from multiple wells
- Gas plant and gas boost—Processing of gas to pipeline quality (i.e., removal of sulfur, water, and CO₂ components)
- Gas storage/withdrawal—Injection of gas into underground structure for later use: summer storage, winter withdrawal

Midstream

- Pipeline compression—Compression station on pipeline to “pump natural gas” typically 800 to 1200 psi compression
- Oil pipeline pumping—Pumping of crude or refined oil
- LNG plant—Liquefied natural gas (LNG) plant; NG is cooled and compressed for transportation in liquid form
- LNG terminal—Loading and unloading of liquid natural gas onto LNG tanker (vessel)

Downstream

- Refinery—Processing of crude oil into its various sellable components
- Integrated gasification combined cycle—Advanced process to convert heavy oils and pet-coke into synthesis gas and hydrogen
- Methanol plant—Plant that produces methyl alcohol from methane (natural gas)
- Fischer-Tropsch liquid—Artificial gasoline produced from coal and/or other lower cost hydrocarbons
- Fractional distillation column—Distillation tower to separate crude oil into its gasoline, diesel, heating, oil, naphtha, etc.
- Cracking—Breaking large hydrocarbon chains to smaller chains (chocker, visbreaking, thermal, catalytic)
- Blending—Mixing of hydrocarbons to obtain sellable refinery products
- Distribution—Delivery of oil and gas products to end-users

TURBOCOMPRESSOR COMPONENTS AND LAYOUT

Most major elements of a typical turbocompressor can be classified as either inside the package or outside the package. Inside the package generally refers to all equipment inside the gas turbine enclosure, while outside the package refers to equipment connecting to the package, such as ancillaries and auxiliaries. The main turbocompressor’s equipment, classified by this definition, is listed below.

Inside the Package

- Fuel system and spark igniter
 - Natural gas (control valves)
 - Liquid (pumps, valves)
- Bearing lube oil system
 - Tank (overhead, integral)

- Filter (simple, duplex)
- Pumps (main, pre/post, backup)
- Accessory gear
- Fire/gas detection system
- Starter/helper drive
 - Pneumatic, hydraulic, variable speed alternating current (AC) motor
- Controls and instrumentation (on-skid, off-skid)
- Seal gas/oil system (compressors)

Outside the Package

- Enclosure and fire protection system
- Inlet system
 - Air-filter (self-cleaning, barrier, inertial, demister, screen)
 - Silencer
- Exhaust system
 - Silencer
 - Stack
 - Lube oil cooler (water, air)
 - Fuel filter/control valve skid
 - Motor control center
 - Switchgear, neutral ground resistor
 - Inlet fogger/cooler

Within API there are standards that address each one of the above package elements; however, the focus of most API specifications is on packaging and ancillaries, rather than on gas turbine core components.

GAS TURBINE PACKAGE SYSTEMS

As turbocompressors are complex mechanical devices, they require electronic and mechanic controls as well as instrumentations. The control system of a gas turbine driven compressor must, as a minimum, provide the following functions through the use of a human machine interface (HMI):

- Machinery monitoring and protection
 - Equipment startup, shutdown, and protective sequencing
 - Stable equipment operation
 - Alarm, shutdown logic
 - Backup (relay) shutdown
- Driven load regulation
 - Fuel/speed control
 - Process control
 - Surge control
- Communication (supervisory control and data acquisition, SCADA) interface

API sets minimum functionality, redundancy, alarms, and shutdown requirements of the HMI. The control system also interfaces gas turbine instrumentation for sensing and emergency alarms/shutdowns. Typical instrumentation that is provided with a turbocompressor package can be divided into sensors for control instruments and alarm/shutdown instruments. Control sensing provides feedback for supervisory control of the machine while alarm/shutdown sensors (or switches) are primarily intended to protect the machine from damaging failures. However, there are a number of instruments on the package that serve both functions. For example, compressor discharge temperature measurements can be used both for control and high temperature shutdown. A list of typical instrumentation, classified as sensing and control versus alarm and shutdowns devices, is shown below.

Sensing and Control Instrumentation

- Temperature sensors (resistance temperature detectors [RTDs] and thermocouples)
 - Lube oil drains
 - Lube oil cooler in/out

- Lube oil header
- Fuel gas
- Bearing metal (radial and axial thrust bearings)
- Gas path (T1, T2, T4, T5-spread)
- Driven compressor (Ts, Td)
- Driven generator stator coils
- Pressure sensors
 - Gas path (P1, P2, P4)
 - Fuel gas
 - Air inlet filter Delta P
 - Lube oil header
 - Lube oil filter Delta P
 - Driven compressor (Ps, Pd)
- Flow sensors
 - Surge control (driven compressor)
- Position sensors (proximity probes)
 - Measures relative movement between housing and shaft
 - Gas turbine (GT) bearings X, Y, Z
 - Gearbox bearings X, Y, Z
 - Driven equipment X, Y, Z
- Velocity probes or accelerometers
 - Measures absolute motion
 - Gas turbine case
 - Main gearbox case
 - Auxiliary gearbox case
 - Driven equipment case

Critical Alarm and Shutdown Switches

- Lube oil level, temperature, and pressure
- Lube/seal oil filter Delta P
- Lube oil drain temperature
- Casing vibration
- Proximity probe vibration
- Axial thrust position
- Fuel gas temperature and pressure
- Gas and fire detectors
- Inlet filter Delta P
- Magnetic speed pickup (shaft speed)
- Exhaust temperature T-5 spread
- Flame-out (flame detector)
- Bearing metal temperatures
- Compressor discharge pressure
- Seal gas or oil pressure and temperature (driven compressor)
- Seal vent leakage (dry gas seal)
- Buffer air Delta P
- Synchronization/grid frequency (driven generator)
- Manual emergency shutdown (ESD) button

COMPRESSOR STATION LAYOUT

Most turbocompressors are installed in gas compression applications, most often along major gas pipelines. Since turbocompressor codes and standards sometimes affect equipment outside the package, the turbocompressor is tightly integrated into the station process. The major equipment at a pipeline compression station is listed below:

- Turbocompressors and ancillaries/auxiliaries
- Surge recycle loop with surge control valves
- Gas coolers (intermediate, discharge)
- Suction scrubbers, discharge scrubbers
- Station isolation and bypass valves
- Suction and discharge valves
- Compressor loading and bypass valves
- Unit and station control room
- Fuel gas heaters
- Fuel gas filter and control skid
- SCADA system
- Fire fighting water system

- Fire fighting CO₂ system
- Emergency power supply (diesel generators, tanks)
- Instrument and seal gas air compressor
- Slug catcher, scrubbers, filters
- Flare and/or blowdown
- Station and unit flowmeters
- Pig launcher
- Gas treatment plant (dehydration, CO₂ removal, sour gas treatment)

CODES AND STANDARDS

Many codes and standards are used by turbocompressor manufacturers and users to specify, select, and characterize their equipment. Codes are generally used for the following purposes:

- Codes provide design guidelines and definitions
 - *Example:* Vibrations, materials, service connections, package design
- Intent to facilitate, manufacture, and procurement
- No code “designs” a gas turbine
- Codes are by nature rather general. Any particular application may require modifications.

For turbomachinery applications in the oil and gas sector, the most commonly used standards are:

- API 616 (1998)—Gas turbines
- API 617 (2002)—Centrifugal compressors
- API 614 (1999)—Lube oil system
- API 670 (2000)—Machinery protection
- API 613 (2003)—Load and accessory gear
- API 677 (1997)—Accessory drive gear
- API 671 (1998)—Flexible couplings
- NFPA 70 (2002)—Electric code
- ASME PTC-22 (1997)—Gas turbine testing
- ASME PTC-10 (1997)—Compressor testing
- ASME B133—Gas turbines
- API RP 686 (1996)—Machinery installation

Some other international codes that are also applicable are:

- ISO codes (ISO 3977, 1995-2002—Gas turbines)
- IEC/CENELEC (electrical and fire systems)
- Local government codes
- European Union environmental and health compliance
- User specific specifications
 - Upstream—Most companies follow API specifications.
 - Midstream—Some companies utilize API, but interpretation is generally handled with more flexibility.
 - Downstream—API is a critical specification for most downstream process applications.

Of the above codes, API 616 (1998) and 617 (2002) are the most critical codes when evaluating or purchasing a turbocompressor package. However, API 614 (1999) and 670 (2000) are strongly referenced in both API 616 (1998) and 617 (2002) and should, thus, also be critically reviewed when purchasing a turbocompressor.

WHAT IS API?

The American Petroleum Institute is the primary trade organization for the U.S. petroleum industry. API has over 400 member companies that cover all aspects of the oil and gas production. API is an accredited American National Standards Organization (ANSI) and started developing industry specific codes in 1924. Currently, API publishes about 500 standards, which are widely referenced by the Environmental Protection Agency (EPA), Occupational Safety & Health Administration (OSHA), Bureau of Land Management (BLM), American Society of Mechanical Engineers (ASME), and other codes and

regulations. API's philosophy for developing codes is based on the following principals:

- Improve safety
- Improve environmental performance
- Reduce engineering costs
- Improve equipment interchangeability
- Improve product quality
- Lower equipment cost
- Allow for exceptions *within reason*

However, as with most other codes, API specifications often lag technology developments, especially in the rapidly changing gas turbine and compressor markets.

API STANDARDS AS PURCHASING SPECIFICATIONS

API standards are often used as a convenient purchasing document. They provide the means for a customer to normalize the quotations by forcing all machinery vendors to quote on similar scopes. API codes also provide a common language and set of rules between vendor and customer to limit misunderstandings (e.g., definitions of efficiencies, test procedures, vendor data, data sheets).

All API codes clearly state in their foreword that *exceptions are allowed*, if they lead to an improved or safer technical offer. For gas turbine applications in the oil and gas sector, API 616 (1998) is the foundation for almost all purchase specifications. API 617 (2002) is used for most centrifugal compressor applications. Also, API references National Fire Protection Agency (NFPA) NFPA 70 (2002) electric code for hazardous locations. This specification is fundamental in most machinery standards and is, thus, a critical requirement for oil and gas applications. Namely, oil and gas turbocompressors must at least meet Class 1, Division 2 (Zone 2), Group D. Some Applications require Division 1 (Zone 1).

API STANDARD TOPICS

The API 616 (1998) and 617 (2002) codes can be divided by a set of standard topics. These are:

- Definitions
 - ISO rating, normal operating point, maximum continuous speed, trip speed, etc.
- Mechanical integrity
 - Blade natural frequencies, critical speeds vibration levels, balancing requirements, alarms and shutdowns
- Design requirements and features
 - Materials, welding, accessories, controls, instrumentation, inlet/exhaust systems, fuel systems
- Inspection, testing, and preparation for shipment
 - Minimum testing, inspection, and certification
- Documentation and drawing requirements

Often overlooked, but critically important are the API data sheets as they clearly form the technical basis of a typical proposal. Within these data sheets, the application specific issues are addressed, such as customer site, operating conditions, basic equipment selection, and equipment minimum integrity requirements. Thus, for a purchaser of a turbocompressor it is important to always fill out (as a minimum) the data sheets for API 616 (1998, gas turbine), API 617 (2002, compressor), API 614 Appendix D (1999, lube oil system), and API 670 Appendix A (2000, machinery protection).

When filling out these data sheets a couple of industry accepted norms should be remembered:

- Cross-out requirements that are not required or cannot be complied with.
- Include notes for critical technical comments. By including them on the data sheets these comments are elevated to a contractual technical requirement.

- Fill out as much info as is available—even a partially filled out sheet is better than no sheet.

API 616—GAS TURBINE

The following section describes a brief review of some critical points of API 616 (1998) with engineering opinions, interpretations, and comments (in italics). Some common manufacturer exceptions are also discussed. This discussion (in italics) presents only an engineering opinion of the authors, and the opinions are clearly debatable and open to other interpretations. A careful review of API specification applicability should be performed for every gas turbine purchase based on the specifics of the application.

The reader should note that API 616 (1998) does not apply to aeroderivative gas turbines (i.e., it is intended for industrial type gas turbines only).

Section 1.0—Alternative Designs

Section 1.0 reemphasizes that alternative designs are allowed. This is also briefly discussed in the API 616 (1998) Foreword. *It is important to note that when alternative designs are proposed, the manufacturer must explicitly state the deviation and explain why the alternative design is superior to the API standard. These explanations should focus on safety, reliability, and efficiency of the equipment, while cost is generally not an acceptable justification for an API deviation.*

Section 2.0—References

All reference standards included in this section are automatically included in the standard. *As this is difficult to review and be accountable for all referenced specifications, all manufacturers of machinery take general exception to this requirement.*

Section 3.0—Definitions

Section 3.0 provides a valuable discussion of common nomenclature and basic definitions. Some of the more critical items in this section are:

- 3.17—ISO conditions are defined as T = 15C, P = 1.0133 bar, RH = 60 percent.
- 3.19—Maximum allowable speed: speed at which unit can safely operate continuously per manufacturer
- 3.22—Maximum continuous speed: 105 percent highest design speed
- 3.26—Normal operating point: Usually the performance guarantee (heat rate, power) point for a gas turbine. *This is defined by speed, fuel, and site conditions.*
- 3.38—Rated speed: power turbine speed at which site rated power is achieved
- 3.42—Site rated conditions: The worst site condition at which still site rated power can be achieved. *This must be provided by the user as a requirement.*
- 3.45—Site rated power: The maximum power achievable at site rated conditions. *This must be provided by the manufacturer. Note: Unless specifically stated by purchaser, this is not a guarantee point. Thus, it is recommended that the user explicitly states that this must be a guarantee point.*
- 3.50—Turbine trip speed: speed where controls shut unit down from the fuel gas supply to the gas turbine
- 3.51—Unit responsibility: Prime package contractor that has contractual responsibility to the purchaser. *Either GT or compressor manufacturer can be prime, but in more complex projects the compressor vendor is usually selected prime (gas turbine is off-the-shelf—compressor is customized). As the compressor is usually only about 30 percent of the cost of the turbocompressor package, this arrangement often leads to commercial complexities and project financing requirements for the compressor vendor.*

Section 4.0—Basic Design

This section in API 616 (1998) covers the basic design of the gas turbine itself. Included in this section are pressure casing requirements, combustor design, casing connections, shafts, bearings, seals, dynamic requirements, and material quality standards. This section is very comprehensive. However, as most gas turbine manufacturers are generally unwilling to make customized changes to their core engine, this is also the section in which most critical exceptions can be expected. A number of relevant items of this section are discussed below:

- 4.1.1—Equipment must be designed for 20 years and three years of uninterrupted service. Hot section inspection must be performed every 8000 hours. *Many gas turbines on the market cannot reach three years of uninterrupted service and/or require combustion inspections at 4000 hours. However, as this is a design requirement, vendor interpretations of this vary widely.*
- 4.1.2—The gas turbine vendor has unit responsibility unless otherwise specified.
- 4.1.5—Speed range operating requirements are: Two-shaft gas turbines 50 to 105 percent rated speed, single-shaft gas turbines 80 to 105 percent rated speed. *This refers to the output shaft only.*
- 4.1.14—On-skid electric must meet NEC NFPA 70 (2002). *This is a critical requirement that generally applies throughout all oil and gas plants and has many significant packaging implications, which will be discussed later.*
- 4.1.16—Most gas turbine internals shall be exchangeable at site. *This requirement disqualifies most aeroderivative gas turbines as they are usually overhauled by core-engine exchange only.*
- 4.1.17—Unit shall meet performance acceptance criteria, both in the factory and at site. *Most manufacturers take exception to site performance guarantee unless a field test is specified and performed.*
- 4.1.18—Vendor shall review customer's installation drawings. *However, this does not imply that vendor certifies or warrants the customer's installation design.*
- 4.1.21—Gas turbine must meet site rated power with no negative tolerances. *This does allow for additional test uncertainties.*
- 4.2.1—Casing hoop stresses must meet ASME Section VIII (2004). *A standard requirement throughout API. This defines hydro test procedures.*
- 4.2.7—Openings for borescope inspection must be provided for entire rotor without disassembly. *Borescope inspection of the first compressor stages can be through the inlet and power turbine through the exhaust. Few manufacturers provide borescope points that allow access to all compressor stages.*
- 4.2.9—Field balancing (if required) without removal of casing is acceptable.
- 4.3—Combustor design: *As this section aims to apply to all types of combustors (can, can-annular, annular, dry low emission [DLE], diffusion) it is somewhat general.*
- 4.3.1—Combustors must have two igniters or igniters and cross-fire tubes (in each combustor for multiple cans). *This requirement is not clear for annular combustors and most can design combustors have a single ignitor in each can but do have cross-fire tubes.*
- 4.3.2—A temperature sensor is required in each combustor. *This is not feasible in most gas turbine designs, as a thermocouple will not survive extended periods of operation at gas turbine firing temperatures. Most manufacturers provide T4 (gas generator turbine outlet) for two-shaft engines and/or T5 (exhaust temperature) for single-shaft engines. Firing temperature (T3) is usually calculated and displayed on HMI.*
- 4.3.7—Fuel Wobbe Index range must be indicated in the proposal. *Most small gas turbines can handle ± 10 percent variation, even with DLE combustion.*
- 4.4—Casing connections: *Section outlines good design practices. Most manufacturers have few exceptions in this section or have reasonable justifications in their deviations.*
- 4.5.1.2—Shafts shall be single piece heat-treated steel. *Stacked rotors with a tie-bolt are not allowed. This is difficult to meet for most manufacturers and is not critical if a stacked rotor has been operationally proven and meets API dynamic requirements. Stacked rotors also have significant advantages for repair and maintenance.*
- 4.5.2.1—Rotor shall be designed for overspeed up to 110 percent of trip speed. *This does not imply that the rotor must be tested to this speed.*
- 4.5.2.2—All rotor components must withstand instantaneous loss of 100 percent shaft load. *Namely, coupling failure should not lead to catastrophic power turbine failure.*
- 4.6—Seals: Renewable seals are required at all close clearance points. *Some manufacturers utilize internal lip-seals. This requirement makes the most sense for interstage seals.*
- 4.7—Rotordynamics: *This extensive section describes minimum rotordynamic requirements and basic operational definitions.*
- 4.7.1—Critical speeds: When the frequency of a periodic forcing phenomenon corresponds to a natural frequency of that system, the system may be in a state of resonance. When the amplification factor is greater than or equal to 2.5, that frequency is called a critical speed. *Most gas turbines operate above their first critical speed. API provides required separation margin between the operating speed range and the critical speeds. The most common source of excitation is unbalance but other sources include rubs, blade pass, gear mesh, and acoustic. The flexibility and potential resonances of the supporting structure should be considered, especially for three-point mount baseplates.*
- 4.7.2—Lateral analysis: *This section recognizes that gas turbines are designed as standard products. Once the design is established, no modifications should be required on a particular application. An exception to this is if the drive coupling mass is significantly different from the design coupling. A new lateral analysis is only required on new prototype engines.*
- 4.7.3—Torsional analysis: *Torsional analysis is required, but many manufacturers take exception to this for gas turbine drives. API requires that intersections between the torsional natural frequencies and one-times (1 \times) the running speed must be separated by at least 10 percent. API also states that intersections at two and higher orders of running speed shall preferably be avoided, but most manufacturers take exception to this.*
- 4.7.4—Vibration and balancing: *A progressive balancing procedure where no more than two components are added to the rotor at a time between corrections is required by API. However, since most gas turbines' rotors are built-up designs with tie-bolts, this procedure is not possible. For these built-up rotors, component balancing should be performed and careful attention to rotor-runout should be made after assembly. Blade mass sorting routines help to minimize the amount of correction required. Sufficient speed during low speed balance should be made to ensure that the blades are seated in the roots or fur-trees. During assembly balance, one should distribute the correction planes to several locations along the rotor, since the exact location of unbalance is not known. A residual unbalance check is encouraged by API, but given the resolution of modern balance machines, this check is not required. High speed balancing of the entire rotor is acceptable but is discouraged. Clearly, rotors that require high speed balancing to achieve vibration limits during test will likely require field balancing. The required API balance limits are reasonable and should be adhered to on both the component and assembly level. Care should be made to minimize electromechanical runout by the proximity probes. API permits subtraction of the run-vector from the vibration level at running speed, but few customers accept this practice.*
- 4.8—Bearings: *applies to all gas turbine bearings.*
- 4.8.1.1—Hydrodynamic radial and thrust bearings are preferred. *These should be thrust-tilt pad, radial-tilt pad, or sleeve bearings.*

- 4.8.2.5—If rolling element bearings are used they must meet 50,000 hours of continuous operation. *Few industrial gas turbines utilize rolling element bearings and aeroderivative engines are not applicable to API 616 (1998).*
- 4.8.3.3—The bearing shells shall be horizontally split. *Many original equipment manufacturers (OEMs) take exception to this requirement.*
- 4.8.4.2—Hydrodynamic thrust bearings shall be selected at no more than 50 percent of the ultimate load rating at site power. *This requirement should not be taken exception to.*
- 4.8.5.2—Bearing housings: Replaceable labyrinth type buffer seal required. *Lip-seals are not acceptable—this cannot be met by some manufacturers.*
- 4.8.5.3—Two radial proximity probes in all radial bearings (X, Y), two axial proximity probes in the thrust bearing, and a key phasor should be provided (when space allows). *Many manufacturers will only provide a single thrust bearing proximity probe.*
- 4.9 —Lubrication: *specifies lubrication requirements and refers to API 614 (1999).*
- 4.9.2—Synthetic lube oil is acceptable in the lube oil system. *However, most users prefer mineral oils for cost reasons.*
- 4.9.5—Integrated or separate lube GT/compressor oil systems are both acceptable.
- 4.9.7—Lube oil system must meet API 614 (1999). *Most modern gas turbines have the lube oil tank integrated into the skid but an overhead tank is also acceptable.*
- 4.10—Materials: *This section describes basic material, casting, welding, and forging requirements and essentially states that good design rules should be followed. Low grade carbon steel is not permitted.* All materials of construction must be stated in the vendor proposal (*and most manufacturers do not comply with this*). Purchaser may require 100 percent radiography, magnetic particle inspection, and/or liquid penetrant inspection on all welds.
- 4.11.3—A stainless steel (SS) nameplate to include rated performance and conditions, critical speeds, maximum continuous speed, overspeed trip, and fuel type. *Few manufacturers provide this relatively simple and valuable requirement adequately, unless the purchaser insists.*

Section 5.0—Accessories

Section 5 deals with all accessories that are required to operate a gas turbine (i.e., mostly package items, instrumentation, controls, and inlet/exhaust systems). Section 5 also includes critical sections on gas and liquid fuel systems. Some of the main points of this section are:

- 5.1—Starting and helper drivers: *Starter motors decouple from the turbine shaft after startup while helper motors stay connected.*
 - 5.1.1.1—Electric, pneumatic, electrohydraulic, gas engine, and steam turbine are all acceptable starter/helper motors. *Most modern gas turbines utilize AC starter motor with variable frequency drives (VFD).*
 - 5.1.1.7—Starter motors must be supplied with all necessary gears, couplings, and clutches.
 - 5.1.2.1—Starters shall be rated 110 percent of starting torque required. Vendor to supply torque curves. *Most AC starter motors are severely underrated for the application and overheat after multiple starts.*
 - 5.1.3—Turning gear: Device to slowly rotate to avoid shaft deformation. Must be separate device from starter motor. *This is generally not required on smaller turbines, and, if required, most manufacturers utilize the starter motor.*
- 5.2.1—Vendor to supply accessory gear for starting, auxiliary equipment (e.g., lubricating oil pump). Vendor to also supply separate load gear, if required. All gears shall meet API 613 (2003). Accessory gears shall be rated for 110 percent of required load. *Most gas turbine lube oil systems utilize engine driven main pump, undersized AC pre-post pump, and undersized direct current (DC) backup pump.*
- 5.2.2—Vendor to supply all couplings and guards for load and accessory shafts. Couplings to be sized for maximum continuous torque and meet API 671 (1998).
- 5.3—Gas turbine to be supplied on single mounting plate (baseplate). *This is typically interpreted to allow for skid mounting.* Skid to be designed to limit worst-case shaft alignment change to 50 micrometers. *For some offshore applications this is difficult to meet without gimbed three-point mount. Supporting the baseplate at three points can result in baseplate vibration modes in the operating speed range of the GT or driven equipment. This foundation flexibility may also adversely affect the critical speeds. Careful finite element analysis should be performed, although it is not required by API 616 (1998).*
- 5.3.2—A single piece baseplate is preferred. The baseplate shall extend under driven equipment. *As the compressor and gas turbine are often supplied by different vendors, this requirement is often not practical; tightly bolted gas turbine and compressor skids are common and generally function well when properly engineered.*
- 5.3.2.4—Skid to permit field leveling.
- 5.4.1.2—All controls and instrumentation shall be suitable for outdoor installation. *This is usually not necessary or practical for inside enclosure devices and devices that are in a control room.*
- 5.4.1.3—Gas turbine instruments and controls shall meet API 670 (2000).
- 5.4.1.4—GT control system must provide for safe startup, operation, and shutdown of gas turbine. *There is an implicit guarantee in this statement that the gas turbine must function/operate properly.*
- 5.4.1.6—Unit shall continue to operate for specified time after AC failure. *This is only possible with redundant control system and not practical for some applications as safe relay shutdown on backup batteries is preferred (i.e., if the unit operation is not critically important, it is often safer from a system perspective to shut down on an AC failure than to continue operating).*
- 5.4.2.1—Automatic start to require only single operator action. *Although most modern control systems have a single button start-stop operation, in reality the operator has to usually acknowledge and reset a host of alarms during the startup process.*
- 5.4.2.2—Control system to completely purge unit prior to startup. *This is a critical safety requirement to avoid explosions in a restart attempt. A purge crank of five to 10 minutes is typical.*
- 5.4.3.4—Load control to limit driven equipment speed to 105 percent rated speed.
- 5.4.4.1—Alarm/shutdown system to be provided to protect unit and operator. Both normal and emergency (fast) shutdown (i.e., cut off fuel supply) must be available.
- 5.4.4.3—Fuel control must include separate shutoff and vent valves, separate from fuel control valve, with local and remote trip. *A control valve that also acts as a shutdown valve is not permitted and should not be accepted by purchasers for safety reasons.*
- 5.4.4.8.1—Alarm and shutdown switches shall be separate. *This is often not practical for gas turbine internal sensors (e.g., flame detector, axial thrust position).*
- 5.4.4.8.3—Alarm and trip settings should not adjustable from outside housing. *This is not relevant with modern control systems. Most alarm and shutdown levels are set from the unit control system.*
- 5.4.4.9—All instruments (other than shutdown switches) shall be replaceable without shutting unit down. *This is often not practical on alarm/shutdown switches from a single sensor (refer to 5.4.4.8.1).*
- 5.4.5.1.1—Off-skid or on-skid control system to be supplied with unit. *As most oil and gas facilities have a control room available that does not have NFPA 70 (2002) hazardous area requirements, it is more common to utilize off-skid control system.*
- 5.4.5.1.1—Any on-skid control system must meet hazardous area requirements (NFPA 70, 2002).
- 5.4.6.2—On-skid electric systems must meet NFPA 70 (2002).

- 5.4.7—Instrumentation: *The API 616 (1998) data sheets must be filled out by purchaser to indicate the required instrumentation. Manufacturers will often cross out lines to indicate noncompliance. The vendor must include in his proposal a full list of instrumentation. API 670 (2000) governs basic requirements for temperature and vibration sensors.*
- 5.5.3.1—Air inlet and exhaust system including inlet filter, inlet/exhaust silencers, ducting, and joints must be provided by vendor. *As this is application specific, some vendors will take exception to this.*
- 5.5.3.3—Inlet system shall be designed for maximum 4 inch H₂O pressure drop at site rated power. *In very humid or moist environments, it is difficult to meet this requirement with wet barrier filters, especially during startup.*
- 5.5.3.4—Inlet/exhaust system design life is 20 years. *For marine environments this requirement implies the use of SS, which is very expensive.*
- 5.4.2.2—Bolts, rivets, or fasteners are not permitted in inlet system.
- 5.5.3.9—A gas turbine compressor cleaning system must be provided. *This is quoted as an option by most manufacturers.*
- 5.5.4.4—Inlet filter system requires walkways and handrails. *This is not necessary for very small gas turbine units.*
- 5.5.5—Inlet/exhaust silencer: Internals to be SS. External can be carbon steel.
- 5.7.3—Unit must be supplied with gas detection system, fire detection system, and fire suppression system to meet NFPA. Fire suppression shall be automatic based on thermal detection. *Typical systems are: Thermal, thermal gradient, lower explosive limit (LEL), and flash detector. CO₂ and water mist are typically utilized for suppression. Water is safer for personnel but also requires more maintenance.*
- 5.7.5—When enclosure is supplied it must be weatherproof and include fire detection/suppression, ventilation/purging, lights, and doors and windows.
- 5.8.1.2—Gas fuel system: Must include strainer, instrumentation, manifolds, nozzles, control valve, shutoff valve, pressure regulator, and vent valve. *A strainer is often not supplied. Some vendors provide a cartridge filter instead. If a strainer or filter is used, they should be supplied with a differential pressure sensor.*
- 5.8.1.3—Fuel gas piping must be stainless steel. *This is critically important, especially in sour gas applications.*
- 5.8.1.4—Liquid fuel system: Must include pump, atomizing air, two shutoff valves, instrumentation, control valves, flow dividers, nozzles, and manifolds. *Newer systems usually employ a variable speed pump instead of a positive displacement pump with a control valve.*
- 5.81.5.2—If dual fuel system is provided it must allow bumpless bidirectional transfer. *All gas turbine vendors require a reduction in load during fuel transfer.*
- 5.8.2.2.2—Vendor must review customer's fuel supply system. *This does not imply a vendor certification of guarantee.*
- 5.8.2.4—Heating value of fuel cannot vary by more than ±10 percent. *This often protects the manufacturer against warranty claims.*
- 5.8.4.2—Purchaser must specify required site emissions levels for NO_x, CO, UHC, et al., to manufacturer (*i.e., it is the purchaser's responsibility to assure that the gas turbines meet environmental codes. The vendor only confirms [or not] the required emissions values.*).

Section 6.0—Inspection, Testing, and Preparation for Shipment

In this section basic inspection, testing and shipping requirements are defined. Some important issues in this section are:

- 6.3.2.3—Hydrostatic tests: Vessels and piping must be per ASME Section VIII (2004).
- 6.3.3—Mechanical running test: A required four-hour no load,

full speed (maximum continuous speed) test to verify that the complete gas turbine package (including all auxiliaries except for inlet/exhaust system) operates within vibration and operational control limits. Contract coupling should be used. Rotordynamic signature and vibrations must be recorded. *This is a basic mechanical integrity test, and compliance with these requirements is critical.*

- 6.3.4—Optional tests: *These tests are not optional if purchaser marks them in the API 616 (1998) data sheets.*
- 6.3.4.1—Optional performance test: unit full load tested to ASME PTC 22 (1997) (discussed later).
- 6.3.4.2—Optional complete unit test: Similar to mechanical run test but to include driven equipment. *This test is often combined with a performance test and is called a full load string test.*
- 6.3.4.3—Gear test: Gear must be tested with unit during mechanical run test.
- 6.3.4—Other optional test: sound level, auxiliary equipment, fire protection, control response, spare parts.
- 6.3.4.6—If unit fails mechanical run test, complete disassembly and reassembly are required.
- 6.4—Preparation for shipment: Short-term shipping is just a plastic wrapping or tarp. Long-term shipping requires crating, surface anticorrosion treatment, inert gas (nitrogen) fill of all vessels including GT casing. *Generally, long-term shipping preparation is recommended as there are often delays in the commissioning of a new plant, which may lead to extended storage times of the equipment.*

Section 7.0—Vendor's Data

In this section the minimum documentation requirements from the proposal to as-built drawings are defined. The detailed document requirements are listed in the API 616 (1998) data sheets. *Most manufacturers take exception to specific document requirements by crossing out lines in the API data sheets. As a minimum, the purchaser should insist on performance maps, performance calculations, mechanical, hydraulic, layout, and electrical drawings, process and instruments diagram (P&IDs), test and inspection results, as-built parts lists, operation and maintenance manuals, installation manual, and technical data.*

API 614—HIGHLIGHTS

API 616 (1998) refers to API 614 (1999) for the lubricating oil system. API 614 (1999) is a generic specification for all lubricating oil (LO) systems, but a couple of important requirements and issues should be emphasized:

- LO system must be design for 20 years service life. *This implies all SS for marine applications.*
- A single full capacity pump with a full size backup pump is required. *Most GT manufacturers provide smaller sized backup pumps that only allow for a safe shutdown but not continued operation.*
- Duplex oil filters with smooth transfer are required (*i.e., no shutdown should be required when replacing filter cartridges*).
- All wetted surfaces must be stainless steel. *Most manufacturers will provide a coated carbon steel LO tank integrated into the skid.*
- Lube oil tank must have minimum of eight minutes retention time. *Manufacturers with integrated skid LO tanks generally cannot meet this requirement, especially if a combined compressor LO system with wet seals is utilized.*
- All pumps, valves, switches, and sensors to have block and bleed valves.
- Sight indicators and levels sensors for are required for tanks.
- A skid integrated lube oil tank is acceptable; an overhead gravity feed tank is preferred. *This provides continues flow in case of an electrical failure and sometimes eliminates the need for a DC backup pump.*
- Tank must have vent with flame trap, and an exhaust fan is preferred *to avoid the flammable vapor gas mixture accumulation.*

API 670 HIGHLIGHTS

API 670 (2000) covers machinery protection and control system such as alarm and shutdown switches. It is beyond the scope of this paper to cover API 670 (2000) but a couple of important items are listed below:

- API 670 (2000) provides minimum design, installation, and accuracy standards for package alarms/shutdown switches and sensors. It covers all instruments specified in the API 616 (1998) data sheets.
- All instrumentation and wiring must meet NFPA 70 (2002) hazardous area classifications.
- Signal and power wiring must be separate.
- Alarms and shutdown switches must be separate and separate stainless steel housings. *This is often not practical with modern sensors and control systems.*
- Bearings must have metal temperature sensors. *Most manufacturers only offer this as an optional feature.*
- Axial thrust bearings must have two proximity probes. *Only one proximity probe is usually provided.*

FACTORY PERFORMANCE TESTS

There are a number of tests that are performed on a gas turbine driven compressor in the factory. The gas turbine performance test specification most commonly used is ASME Performance Test Code 22 (ASME PTC-22, 1997) or manufacturer specific derivatives of it. For the driven compressor, API requires only a mechanical test run, but most operators insist on a closed loop test also to characterize the performance. Closed loop tests are usually performed per ASME PTC-10 (1997).

PTC-10 Compressor

- Closed loop test to determine performance of compressor
- Can also identify aerodynamic stability issues if tested to full load
- Type I: actual gas and full pressure; Type II: simulated gas and reduced pressure
- Type I typically used for high pressure/high energy applications
- Reduces risk of startup delays due to vibrations or lack of performance

PTC-22 Gas Turbine

- Full speed, full load test for four hours
- Typically against a water break or generator/load cells
- Determines maximum output power, specific fuel consumption, and efficiency

Some operators opt to perform field testing instead of extensive factory testing. The risk of this test is that if problems are identified in the field it may be difficult to easily correct them. However, if testing is intended to only verify a very tight performance guarantee, field testing is typically adequate.

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) 70

API specifications refer to the NFPA 70 (2002) code for electrical wiring and safety requirement. To identify the proper classification of a subject, NFPA 70 (2002) provides the following guidelines.

Hazardous Location Summary Electrical Requirements

- Class 1—Flammable gases, vapors, or liquids
- Class 2—Dust and combustible dust that can form explosive mixtures
- Class 3—Fibers or flyings suspended in air that are easily ignitable

Divisions Within Class 1

- Class 1, Division 1
 - (Zone 0 and Zone 1)—Ignitable concentration of flammable mixtures exist most of the time.
- Class 1, Division 2
 - (Zone 2)—Ignitable concentrations of flammable mixtures are not likely to exist under normal conditions.

Most oil and gas applications require Class 1, Division 2. Some offshore and refinery applications require Class 1, Division 1. NFPA 70 (2002) applies principally to the following turbocompressor package items:

- On-skid electrical
 - Wiring and cables
 - Electric motors (pumps, fans, starter)
 - Instruments and alarms
 - Junction boxes
 - Lights and heaters (if applicable)
- On-skid fire systems
 - Ultraviolet/infrared (UV/IR) flash sensors
 - Flammable mixture detectors
 - Temperature, temperature rise detectors
 - Smoke detectors (if used)
 - CO₂ (or other) fire fighting system
- Air inlet and lube oil electrical elements

NFPA 70 (2002) does not apply to nonelectrical components and exception to NFPA 70 (2002) can often be taken for:

- Off-skid control system
- Battery charger and batteries
- Starter motor variable frequency drive
- Synchronization panel

There are many requirements in NFPA 70 (2002) for Class 1, Divisions 1 and 2 (details are in NFPA 70, 2002, Sections 500 and 501), but some of the most critical requirements are:

- Grounded explosion-proof conduit for all wiring
- Conduit and conduit connections are copper free
- Gas sealed conduit connections
- Instruments, connectors, terminals in explosion-proof boxes
- Motors rated explosion-proof
- Fire detection system (UV/IR, thermal gradient, flash detectors)
- Gas (flammable mixture) detectors (LEL)
- Fire fighting system (inert gas or water mist)

API 617—Axial and Centrifugal Compressors and Expander-Compressors for Petroleum, Chemical, and Gas Industry Services

API 617 (2002) is a code that is applied to the centrifugal compressor used in GT packages. This specification is prevalent for offshore and refinery applications. It is usually less prevalent in pipeline applications. API 617 (2002) is often referenced within user-company specific purchase specifications, but all manufacturers have various amounts of comments and exceptions. API 617 (2002) has similar technical definitions as API 616 (1998), and these are, therefore, not repeated here. However, in general API 617 (2002) covers the following equipment:

- Centrifugal and axial compressors
- Integrally geared compressors
- Expander compressors

SCOPE OF API 617

API 617 (2002) covers the minimum requirements for axial and centrifugal compressors, single-shaft and integrally geared process

centrifugal compressors and expander-compressors for use in the petroleum, chemical, and gas industry services that handle air or gas. This standard does not apply to fans (covered by API 673, 2002) or blowers that develop less than 34 kPa (5 psi) pressure rise above atmospheric pressure. This standard also does not apply to packaged, integrally-gear centrifugal plant, and instrument air compressors, which are covered by API 672 (1996). Furthermore, hot gas expanders over 300°C (570°F) are not covered in this standard.

As with all other API codes, the equipment vendor may offer alternative designs if these designs improve the safety or performance of the equipment. Otherwise all designs should comply with this standard. If exceptions to the standard are taken, they must be clearly stated in the proposal.

SUMMARY

This tutorial provides an overview of the applicable codes related to typical industrial gas turbine packages, including API 616 and the supporting API Standards 614 (1999), 617 (2002), 670 (2000), 671 (1998), and 677 (1997), as well as NFPA 70 (2002). As the authors have presented, one size does not fit all in the selection and procurement of gas turbines and many exceptions to API are made. However, the API standards represent sound engineering practice based on many years of experience. Therefore, exceptions to these standards should be kept to a reasonable minimum.

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