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Gas turbines — Procurement —

Part 3: **Design requirements**

Turbines à gaz — Spécifications pour l'acquisition —

Partie 3: Exigences de conception

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3977-3 was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

This second edition cancels and replaces the first edition (ISO 3977-3:2002), of which it constitutes a technical revision.

ISO 3977 consists of the following parts, under the general title *Gas turbines — Procurement*:

— *Part 1: General introduction and definitions*

— *Part 2: Standard reference conditions and ratings*

— *Part 3: Design requirements*

— *Part 4: Fuels and environment*

— *Part 5: Applications for petroleum and natural gas industries*

— *Part 7: Technical information*

— *Part 8: Inspection, testing, installation and commissioning*

— *Part 9: Reliability, availability, maintainability and safety*

Gas turbines — Procurement —

Part 3:
Design requirements

1 Scope

This part of ISO 3977 covers the design requirements for the procurement of all applications of gas turbines and gas turbine systems, including gas turbines for combined cycle systems and their auxiliaries, by a purchaser from a packager. It also provides assistance and technical information to be used in the procurement.

It is not intended to deal with local or national legislative requirements with which the installation may be required to conform.

This part of ISO 3977 is applicable to simple-cycle, combined-cycle and regenerative-cycle gas turbines working in open systems. It is not applicable to gas turbines used to propel aircraft, road construction and earth moving machines, agricultural and industrial types of tractors and road vehicles.

In cases of gas turbines using special heat sources (for example, chemical process, nuclear reactors, furnace for a super-charged boiler), this part of ISO 3977 provides a basis.

The relevant parts of ISO 3977 are applicable to closed and semi-closed systems.

NOTE Additional requirements for special gas turbine applications are described in ISO 3977-5.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE In cases where there are no International Standards available, national standards as shown in Annex B may be used as guidelines with the mutual agreement of the purchaser and packager.

ISO 1940-1:2003, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*

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

ISO 3977-1:1997, *Gas turbines — Procurement — Part 1: General introduction and definitions*

ISO 3977-2:1997, *Gas turbines — Procurement — Part 2: Standard reference conditions and ratings*

ISO 3977-4:2002, *Gas turbines — Procurement — Part 4: Fuels and environment*

ISO 3977-7:2002, *Gas turbines — Procurement — Part 7: Technical information*

ISO 3977-8:2002, *Gas turbines — Procurement — Part 8: Inspection, testing, installation and commissioning*

ISO 3977-9:1999, *Gas turbines — Procurement — Part 9: Reliability, availability, maintainability and safety*

ISO 7919-1:1996, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 1: General guidelines*

ISO 7919-2:2001, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*

ISO 7919-4:1996, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 4: Gas turbine sets*

ISO 10441:1999, *Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — Special purpose applications*

ISO 10442:2002, *Petroleum, chemical and gas service industries — Packaged, integrally geared centrifugal air compressors*

ISO 10494:1993, *Gas turbines and gas turbine sets — Measurement of emitted airborne noise — Engineering/survey method*

ISO 10814:1996, *Mechanical vibration — Susceptibility and sensitivity of machines to unbalance*

ISO 10816-1:1995, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*

ISO 10816-2:2001, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2: Land-based steam turbine generator sets in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min*

ISO 10816-4:1998, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 4: Gas turbine driven sets excluding aircraft derivatives*

ISO 11086:1996, *Gas turbines — Vocabulary*

ISO 11042-1:1996, *Gas turbines — Exhaust gas emission — Part 1: Measurement and evaluation*

ISO 11042-2:1996, *Gas turbines — Exhaust gas emission — Part 2: Automated emission monitoring*

ISO 13691:2001, *Petroleum and natural gas industries — High-speed special-purpose gear units*

ISO 13709:2003, *Centrifugal pumps for petroleum, petrochemical and natural gas industries*

ISO 15649:2001, *Petroleum and natural gas industries — Piping*

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

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres*

ASME, *Boiler and Pressure Vessel Code Section IX*

ASTM A 194, *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

ASTM A 307, *Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength*

NACE MR 0175/ISO 15156, *Petroleum and natural gas industries — Materials for use in H_2S containing environments in oil and gas production*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3977-1, ISO 3977-4, ISO 3977-8, ISO 3977-9 and ISO 11086, and the following apply.

3.1
aeroderivative
aircraft propulsion gas generator adapted to drive mechanical, electrical or marine propulsion equipment

3.2
anti-icing system
system to heat up the air entering the air filter or compressor to prevent the formation of frost or ice on the filters or compressor inlet

3.3
area classification
classification of an area according to differing degrees of probability with which concentrations of flammable gases or vapours may arise

3.4
atomizing air
compressed air used to aid formation of finely dispersed spray from liquid fuel nozzles

3.5
bi-fuel operation
simultaneous operation of the gas turbine on two dissimilar fuels (not pre-mixed), such as gas and distillate

3.6
back draft damper
arrangement with excentrically pivoted vane(s) designed to close and seat when through flow is reversed

NOTE Their function is to prevent backflow through a unit on standby in a spared installation. The dampers are installed in the fan discharge.

3.7
coalescing element
arrangement of fibrous material with special properties which accumulates, entraps and drains moisture from a main air stream

3.8
column mounting
arrangement whereby a baseplate is mounted at discrete points

3.9
cooling period
period in time immediately following the shutdown of the gas turbine during which precautions have to be taken to protect the unit

EXAMPLE During lubrication and turning.

3.10
critical speed
rotating speed which corresponds to resonant frequencies of the system and of the forcing phenomena

NOTE 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.

3.11
driven unit
components of plant being driven by the gas turbine

EXAMPLES Generator, pump or compressor.

3.12
dual fuel system
system which allows the gas turbine to operate on two dissimilar fuels separately

3.13
electrical and mechanical run out
total indicated reading from an inductive gap measuring transducer targeted on the rotor's designated vibration monitoring track when the rotor is rotating at very low speed (slow roll) in the gas turbine or is turned on V blocks supported on its bearing surface

NOTE This will include mechanical (eccentricity, ovality or any surface irregularity) and electrical (residual magnetism and non-uniformity of the electrical properties of the rotor surface material) effects.

3.14
enclosure
housing over the gas turbine usually designed for acoustic cooling and/or fire retention purposes

NOTE It also may be used to segregate gas turbine cooling and a hazardous area.

3.15
emergency shutdown
immediate manually or automatically initiated shutdown of the gas turbine to prevent/minimize hazards, danger to personnel or impending damage

3.16
filter stage
section of a filter system which is designed to remove specific site contaminants at a prescribed efficiency and pressure drop

NOTE 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.

3.17
foreign object damage
damage to a gas turbine component from the passage of an object not belonging to the gas turbine

3.18
high-pressure spool
compressor and turbine rotor assembly of high-pressure stages when driven by a turbine independent of the low-pressure stages

3.19
hot gas path temperatures
temperatures of the combustion gases, anywhere in the hot section of the gas turbine, normally measured at a point downstream of the combustion system

3.20
inertial mist eliminator
arrangement of vertical chord-wise curved louvres with entrainment lips on the pressure side trailing edge which separates by inertia effect, entraps and drains moisture from a main air stream

3.21
inlet plenum
compartment immediately upstream of the compressor inlet

NOTE This is more commonly applicable to aeroderivative gas turbines which require an undisturbed flow into the compressor.

3.22
landfill gas operation
operation of the gas turbine on a fuel gas which has been produced by a natural decomposition process of waste material

3.23
loading
application of load to the gas turbine via the driven unit, generator, pump or compressor

3.24
low-pressure spool
compressor and turbine rotor assembly of low-pressure stages when driven by a turbine independent of the high-pressure stages

3.25
lower explosion level
concentration of flammable gas or vapour in air, below which the gas atmosphere is not explosive

3.26
mal-synchronization
connection of an alternator to an electrical system when the phase of the alternator voltage does not match that of the system

3.27
maximum continuous speed
⟨for generator drive applications⟩ speed equal to the specified upper system frequency

3.28
maximum continuous speed
⟨for mechanical drive applications⟩ speed equal to the 105 % of the highest speed required by any of the driven machine specified operating conditions

3.29
multiplane dynamic balancing
balancing by spinning a rotor on bearings and applying corrections at balancing planes along its length

3.30
net specific energy
minimum energy within a fuel of given constant constituents without latent heat from condensation of water resulting from combustion

NOTE 1 Expressed in J/m^3 [15 °C and 101,3 kPa (1,013 25 bar)] or J/kg.

NOTE 2 Net specific energy is also known as net calorific value or lower heating value.

3.31
off-line compressor washing
procedure for cleaning the compressor by soaking in a cleaning fluid whilst slowly turning the gas turbine

3.32
on-line compressor washing
procedure for cleaning the compressor by injecting cleaning fluid into the compressor inlet with the gas turbine loaded

3.33
operating speed range
range from the minimum to maximum continuous speed defined by the requirements of the application, as limited by the gas turbine design

3.34
packager
supplier having responsibility for coordinating the technical aspects of the equipment, and all auxiliary systems included in the scope of the supply

NOTE This includes 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.

3.35
potential maximum power
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

3.36
process controller
control of a process variable, such as driven unit pump suction pressure, via the control of the gas turbine speed

3.37
quill shafts
shaft of reduced section designed to be torsionally and laterally flexible

NOTE It may also be designed to fail when the drive torque exceeds a predetermined value.

3.38
reset
action, usually manual, to allow the control system to prepare for a further start attempt following a fault shutdown or unsuccessful start condition

3.39
residual magnetism
magnetism inducted into a magnetic material by exposure to magnetic fields during manufacture or service

3.40
ribbon cable wiring
multiple conductors arranged in parallel, insulated from each other in a flat form

3.41
rotor blade
blade fitted to the rotor (sometimes referred to as a bucket) as opposed to the blades fitted to the stator (referred to as blades, stator blades or nozzles)

3.42
rotor dynamics
analysis of the motion of a rotor-bearing support system with respect to lateral and torsional perturbations

3.43
safe area
area in which explosive atmospheres are expected to be present in low quantities so that special precautions for the ignition sources are not necessary

3.44
self-sustaining speed
minimum speed of rotation of the gas turbine's rotor under normal operation in which no external power supplied by a starting device is required to maintain steady-state operation

3.45
service life
duration that a component will fulfil its function under operating conditions

3.46
shear type coupling
shear pin
coupling which drives through a bolt(s) in shear which has (have) a reduced cross section, in line with the coupling flange to flange interface, which is designed to fail when the drive torque exceeds a predetermined value

3.47
shutdown, automatic
stopping of the gas turbine which is fully executed by the control system from a single operator action

NOTE This type of stopping normally will not lock out further start attempts, and will not require reset action.

3.48
shutdown, manual
stopping of the gas turbine which is manually initiated or controlled at each step

NOTE This type of stopping normally will not lock out further start attempts, and will not require reset action.

3.49
shutdown, semi-automatic
shutdown of the gas turbine which is in part manually initiated or controlled

NOTE This type of shutdown normally will not lock out further start attempts, and will not require reset action.

3.50
starting
action of starting the gas turbine, through all parts of the package start cycle

3.51
stranded conductors
cable having a multiplicity of wires making up the core conductor

3.52
un-interruptible power supply
power supply that is maintained for a stated period under main grid failure conditions

3.53
Wobbe index
WI
heating value of the fuel divided by the square root of the specific gravity (relative to air)

[ISO 3977-4]

NOTE 1 The heat input from the gas fuel through the governor fuel valve under defined conditions is directly proportional to the Wobbe index.

NOTE 2 Alternative definitions for Wobbe index exist and the way of defining the Wobbe index for gases should be agreed upon between the purchaser and packager.

3.54
Zone I/Div I
area in which an explosive atmosphere is likely to occur in normal operation

3.55
Zone II/Div II
area in which an explosive atmosphere is not likely to occur in normal operation and, if it occurs, it will only exist for a short time

4 Basic requirements

4.1 General

This clause covers the basic requirements for the procurement of gas turbines and gas turbine systems for all applications, including combined-cycle systems, and their auxiliaries by a purchaser from a packager. Additional requirements for special gas turbine applications are described in ISO 3799-5. It provides assistance and technical information to be used in the procurement.

4.2 Site-specific conditions

4.2.1 Site conditions

The purchaser shall furnish accurate site condition data to the packager on data sheets such as those shown in Annex A. The purchaser shall specify whether the package is intended for indoor or outdoor installation.

4.2.2 Site operating point

The purchaser shall specify the site-specific operating point(s) on the data sheets (similar to those included in Annex A, Table A.1). Unless otherwise specified, the gas turbine shall be designed to provide site rated power with no negative tolerance, at the heat rate tolerance quoted.

4.2.3 Preliminary design review

Many factors (such as piping and ducting loads, alignment at operating conditions, supporting structure and assembly at the site) can 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.

4.3 Operational requirements

4.3.1 Operational criteria

The package shall operate on the test stand and/or on its permanent foundation within the specified acceptance criteria.

The gas turbine package shall be mechanically designed for continuous service at design power output. All components of the package shall be designed for service at potential maximum power corresponding to the peak load or low ambient temperature characteristics; i.e. components such as couplings, gears and driven machines shall not impose a mechanical limit on the output from the unit.

When a unit operates intermittently at a rating higher than peak rating, it may have components rated at higher power levels or with shorter life expectancy.

The purchaser shall specify the available utility supplies on the data sheets. The packager shall provide the required utility requirements on the data sheets (see Annex A, Table A.1).

4.3.2 Temperature and speed limits

Within the packager's allowable temperature range, the following requirements shall be satisfied.

Equipment shall be run without damage or need for inspection at the overspeed resulting from the instantaneous loss of maximum potential load with the speed control system fully functional.

Equipment shall not fail at the overspeed resulting from the following:

a) instantaneous loss of maximum potential load with the fuel control valve failed in the full open position;

b) instantaneous loss of load resulting from failure of the main drive coupling (e.g. shear pin coupling).

The packager shall advise the purchaser of any inspection that would be required if such overspeed conditions occur.

Attention is drawn to the necessity of also ensuring that all coupled equipment (including auxiliaries, etc., electrically, mechanically or hydraulically coupled) will withstand the corresponding overspeed.

4.3.3 Starting requirements

The purchaser shall define any operating requirements which impact the start cycle sequence or duration.

The package design shall permit immediate restarting from any condition (i.e. hot starts or cold starts). Any restrictions shall be defined in the proposal. Any turning device necessary to meet this requirement shall be provided by the manufacturer (see 6.2).

4.3.4 Transient requirements

Operational stability under transient load conditions shall meet the requirements as specified by the purchaser. These requirements should be clearly defined by a relationship of load, speed and time parameters.

4.3.5 Control requirements

The package control system designed by the packager 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 (see Clause 6).

4.3.6 Instrumentation and communication

The purchaser shall specify requirements for instrumentation, data acquisition, data transmission and system interface with the total facility (see Clause 6).

4.3.7 Fuels

The fuel system shall be operable with the normal fuel or any alternative or starting fuel specified in ISO 3977-4. The packager shall advise the purchaser of the effects of the fuel(s) on gas turbine package operation and equipment life.

4.3.8 Exhaust emissions

The exhaust emissions from gas turbines (mainly NO_x, CO, UHC, SO_x, smoke and particulates) depend to a large extent on the fuels used and the operating conditions of the gas turbine. Therefore the conditions for the specified exhaust emission limits to be met shall be agreed between the purchaser and packager.

If not otherwise specified, the limit values required by national legislation valid in the country where the gas turbine operates shall be met. Where no national legislation exists, the limit values shall be agreed between the purchaser and packager.

In all cases, the exhaust emission measurement shall be carried out according to ISO 11042-1 and ISO 11042-2. The exhaust emissions control technique shall be specified by the purchaser (see 4.6.2 and 5.2.8.5).

4.3.9 Noise emissions

If sound control is specified, the requirements of ISO 3977-4 shall apply. Any special near field or far field or neighbourhood sound restrictions that are applicable shall be specified by the purchaser in the data sheets.

The permitted near-field, far-field and inside-buildings noise levels shall be provided by the purchaser.

The noise emission measurement of the gas turbine and gas turbine package shall be carried out according to ISO 10494.

4.4 Service requirements

4.4.1 Design life

Unless otherwise specified, the gas turbine packages covered by this part of ISO 3799 shall be designed and constructed by the packager for the following minimum design criteria (corresponding to class D, range IV, defined in ISO 3977-2:1997):

- a design life of 20 years or 100 000 operating hours, whichever occurs first;
- a hot gas path inspection interval of 8 000 h;
- a time between major overhauls of 24 000 h.

Shorter inspection and major overhaul intervals may result from

- operation with fuels other than natural gas,
- applications with water or steam injection,
- operating regimes other than class D, range IV, or
- special designs.

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.

4.4.2 Responsibility for the unit

The packager shall be responsible for the gas turbine package performance and mechanical integrity, provided the package is operated and maintained as per the packager's instructions.

4.4.3 Inspection schedule

Recommended inspections, normal maintenance and major overhaul intervals shall be stated in the packager's proposal.

All equipment shall be suitable for periods out of operation up to a minimum of 4 weeks, under specified site conditions, without requiring any special maintenance procedures.

4.4.4 Inspection and maintenance access

The package shall be designed for ease in servicing and to provide adequate clearances necessary to perform all maintenance to be done between hot gas path inspection. Special tools and procedures shall be stated in the packager's proposal.

Provision shall be made for the complete inspection of all rotating gas path and combustion system components, using borescopes or other devices, without major disassembly of the gas turbine. The packager shall provide details of the procedures and any special equipment to be used.

4.4.5 Power train maintainability

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, modules and the rotating elements shall preferably be replaceable at site. If required, 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 carrying out such repairs.

4.5 Rotating equipment requirements

4.5.1 Coupling

Couplings shall be sized for maximum continuous torque, based on the potential maximum power capability that can be delivered.

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.

The 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.

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

Coupling spacer length shall allow removal and replacement of bearings and seals without disturbing the main equipment casings. Where this is impractical, the removal of components shall be kept to a minimum and the driven equipment should not be disturbed.

When specified, the main load couplings shall conform to ISO 10441. The coupling make, type and mounting arrangements shall be agreed by the purchaser and packager. A spacer-type coupling shall be provided unless otherwise specified.

4.5.2 Auxiliary gears

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

Auxiliary gears shall comply with an agreed standard, and shall be rated for at least 110 % of the maximum power transmitted.

4.5.3 Load gears

Unless otherwise specified, the load gear design, testing and application shall comply with ISO 13691 and the purchaser's specifications. Pertinent gear loading data shall be designated by the purchaser.

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

The minimum load shall also be considered in the design of the load gear, taking into account critical speeds and bearing stability. The purchaser shall specify the minimum load.

4.5.4 Driven equipment

4.5.4.1 General

Typically the gas turbine driven equipment will comprise

a) axial compressors,

b) centrifugal compressors,

c) centrifugal pumps,

d) a.c. power generators,

or combinations thereof.

4.5.4.2 Centrifugal and axial compressors

Unless otherwise specified, centrifugal compressor design, testing and installation shall be in accordance with ISO 10442 and the purchaser's specifications. For axial compressors, ISO 10442 may be used as a guideline.

Compressor equipment may 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. If separate systems are specified, the means of preventing interchange of oil between the two systems shall be described in the packager's proposal.

Compressor performance requirements, including gas flow rates, operating pressure, temperature ranges and gas composition, shall be provided by purchaser.

4.5.4.3 Centrifugal pumps

Unless otherwise specified, centrifugal pump design, testing and installation shall be in accordance with ISO 13709 and the purchaser's specifications.

Centrifugal pump performance requirements with regard to flow rates, operating pressures and temperature ranges, and liquid fluid properties shall be provided by purchaser.

4.5.4.4 Reciprocating compressors

Gas turbine driven reciprocating compressor packages are not addressed by this part of ISO 37899. The purchaser and packager shall mutually agree upon the unique design issues of torsional vibration and specific packaging provisions associated with reciprocating compressors.

4.5.4.5 Generators

Generators shall be designed according to the purchaser's requirements and specifications and meet the requirements of IEC 60034-1.

The generator rating, as well as the electrical hardware and instrumentation to be provided by the packager, shall be specified by the purchaser.

The packager shall provide equipment as indicated on data sheets such as given in Annex A, Table A.6. The purchaser and the packager shall agree on the scope of the supply and location of the required equipment.

When specified, inspection and testing shall be in accordance with ISO 3977-8.

The package design shall be capable of withstanding short-circuit conditions, or malsynchronisation, without permanent damage to the machinery train. Where these requirements cannot be satisfied without the use of torque limiting devices (i.e. shear pins, quill shafts, etc.), then this fact shall be adequately outlined in the packager's proposal.

4.5.5 Mechanical drives (variable speed application)

The output shaft operating speed range of gas turbine units for mechanical drive applications shall be suitable for meeting all the operating conditions specified by the purchaser on the data sheets. Where only one operating condition is specified for an application, the speed range for single-shaft machines is typically a maximum of 25 % (from 80 % to 105 % of the rated speed) and the speed range for two or more shaft machines is typically a maximum of 55 % (from 50 % to 105 % of the rated speed). The actual speed range shall be mutually agreed between the purchaser and packager. The gas 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.

The startup and shutdown procedures can only be initiated when certain predefined safety criteria associated with the process plant, which have to be agreed between the purchaser and packager, are met. This also implies that the plant control valves will be activated in a predefined sequence. Mechanical constraints and process limitations shall be considered in establishing these procedures (see 6.2).

4.6 Other equipment requirements

4.6.1 Compartment enclosure(s)

When specified, suitable enclosure(s) shall be provided to meet the purchaser's acoustical, weatherproofing and/or fire protection requirements. Enclosure(s) shall be designed to ensure that the package can meet the operation, maintenance, service life and safety requirements.

4.6.2 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 (see 5.2.8.5).

4.6.3 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.

4.6.4 Motor and electrical

Motors, electrical components, and electrical installations within hazardous zones shall meet the requirements of the relevant parts of IEC 60079. Area classification shall be carried out by the supplier, or packager, in respect of all potential sources of release that are likely to create an explosive atmosphere in accordance with IEC 60079-10.

NOTE If effective and reliable isolation of flammable substances is provided, it may be possible to demonstrate that an installation is safe when shut down and that unprotected electrical equipment may be used at such times.

4.6.5 Special tools and dynamics

When special tools and fixtures are required by the purchaser 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 packager. These or similar special tools shall be used during shop assembly and post-test disassembly of the equipment.

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.

4.6.6 Dry low emissions combustion

When specified by the purchaser, the gas turbine shall be equipped with dry low emissions combustion (DLE) to control NO_x and CO emissions. On request, the packager shall demonstrate to the purchaser that the likelihood of a damaging thermal acoustic and flashback phenomena occurring from the combustion system is acceptably improbable.

4.6.7 Exhaust catalytic converters

When specified by the purchaser, the gas turbine shall be equipped with an exhaust catalytic converter to meet more stringent emissions legislation.

4.7 Vibrations and dynamics

4.7.1 General

This section is concerned with the rotordynamics of the gas turbine as well as with the associated driven equipment.

Vibrations affect availability and safety, and can cause damage to equipment. Vibrations are generally the response of systems to excitations. The best known excitation of turbomachinery is unbalance, causing lateral vibrations. The rotor speed at resonance condition is also called the critical speed. Lateral vibrations can be measured and are used for monitoring and protection. Balancing reduces the unbalance excitation and is applied during assembly and maintenance. The sensitivity to unbalance excitation shall be addressed in the engine design. Torsional excitations cause torsional vibrations. This is more difficult to measure. It shall be addressed in the design phase of a shaft train because torsional vibration modes have generally low damping.

The packager shall ensure that each component meets the rotordynamic design requirements as an isolated, singular component in accordance with the applicable component standards.

Rotating machinery can encounter very high vibrations when components are coupled by their shafts and foundations even though they operate satisfactorily while uncoupled. A system analysis of the shaft train in the design stage permits corrective actions against vibration problems during operation.

The packager shall ensure that the resonance frequencies of the complete power train (rotor lateral, system torsion and blading modes) are in the acceptable ranges. The combination shall be suitable for the specified operating speed range, including any starting speed hold-point requirements of the train. A list of all undesirable speeds shall be submitted to the purchaser. This also shall be included in the technical manual and preferably should be programmed into the control system in order to avoid the undesired speed ranges.

Generally the packager is responsible for the lateral and torsional vibration analysis of the entire system. All shaft critical speeds, pertinent modes of exciting frequencies of the driver and driven equipment throughout the startup 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. All these modes shall provide for ample frequency ranges within which the supporting foundation's natural frequencies can be designed. This analysis shall be performed before the package installation design.

4.7.2 Lateral vibrations (critical speeds)

4.7.2.1 General

An analysis of the lateral vibration characteristics of the system is recommended if the gas turbine is the first of its kind, or if its load coupling is modified, or if rigid couplings are employed, or if a bearing support has been modified. Flexible couplings or slender intermediate shafts allow the lateral analysis to be carried out separately for the individual components.

Lateral vibrations shall be measured and monitored during operation. The required type and number of vibration pick-ups for a rotor train depend on the type of machine support. Therefore the relative shaft vibration measurement or the bearing vibration measurement can be selected according to specific machine structural characteristics, as follows.

a) Stiff support

If the dynamic support stiffness is significantly higher than the dynamic stiffness of the oil film, the relative shaft vibration measurement is more sensitive and shall be applied for machine protection purposes.

b) Flexible support

If the dynamic support stiffness is significantly lower than the dynamic stiffness of the oil film, the bearing vibration measurement is more sensitive and shall be applied for machine protection purposes.

In the case of uncertainty between these two options, the measured sensitivities of both measurements on the machine at transient and steady-state operation may be used to make a decision.

ISO 10814 establishes methods to assess the modal sensitivity of machines to unbalance and these methods shall mainly be applied in the design analysis phase. Gas turbines are referred as Type II machines in ISO 10814, which also gives the required frequency separation margin for vibration response peaks (also referred to as "critical speed", "mode" or "resonance"). It applies to lateral vibrations based on unbalance response calculations or on measurements from the same or a similar machine. A high modal sensitivity according to this method (designated with range D or E) is a warning, indicating that at least one of the following actions is recommended:

— shifting either the exciting frequency or the critical speed;

— increasing the damping;

— performing a stress response analysis demonstrating that the resonance in question has no adverse effect on any part of the shaft train.

NOTE 1 Aeroderivative type combustion gas turbines generally use antifriction ball and roller type bearings. Rotordynamic response functions and associated amplitude factors will be different from those of hydrodynamic bearing design gas turbines.

NOTE 2 In shaft trains with gears, the interaction of close torsional and lateral critical speeds can cause slight deviations of the eigenfrequencies calculated with uncoupled models.

4.7.2.2 Measurements

4.7.2.2.1 General

Vibration measurements may be taken either on rotating or stationary elements. The packager shall define the type and location of vibration measurements most suitable for the equipment. Levels of vibration for alarm and for automatic protective interventions shall be indicated by the packager and programmed in the control system.

During a factory test or commissioning of the assembled gas generator/gas turbine the vibration level (measured at the manufacturer's standard sensor locations, shaft or casing vibration) shall be measured. It shall not exceed two thirds (2/3) of the manufacturer's alarm set point value at any steady-state speed within the specified operating speed range. This limit may be based on filtered or unfiltered data.

Beyond the requirements of the International Standards cited in 4.7.2.2.2 to 4.7.2.2.4, it is recommended that at any speed outside the specified operating speed range, up to and including the trip speed of the rotor, the vibration level shall not exceed 200 % of the maximum value allowed at the maximum continuous speed.

NOTE The design details, including mass and stiffness distribution as well as accessibility of the parts, determine the most significant locations for vibration measurement.

4.7.2.2.2 Relative shaft displacement vibrations

The requirements of ISO 7919-1, ISO 7919-2 and ISO 7919-4 apply. ISO 7919-1 provides general guidelines for shaft displacement vibrations in power trains. ISO 7919-2 applies to steam turbines and large generators. If not otherwise agreed, the assessment of vibration levels of gas turbine driven generators shall be based on ISO 7919-2.

ISO 7919-4 gives applicable measurements and evaluation criteria for relative shaft vibrations for gas turbines (except small or aero-derivative gas turbines). If not otherwise agreed, the assessment of vibration levels of gas turbines shall be based on ISO 7919-4. However, ISO 7919-4 does not cover all types of gas turbines. In these cases mutual agreement shall be sought between the purchaser and packager.

Beyond the requirements of the relevant part of ISO 7919, the following is recommended. Electrical and mechanical runout shall be determined and recorded by rolling the rotor in bearing shells, V blocks, or in another appropriate setup while measuring runout with a non-contacting vibration probe and a dial indicator at the same shaft location. Electrical and mechanical runout, for the full 360° at each probe location, shall be included in the mechanical test records. The packager shall demonstrate that electrical and mechanical runout is in accordance to the relative parts of ISO 7919.

NOTE 1 In order to derive the effective vibration amplitudes, this runout can be vectorially subtracted from the measured vibration values.

NOTE 2 If the runout requirement according to ISO 7919-1 cannot be kept, the cause may be a mechanical shape deviation of the rotor or residual magnetism.

4.7.2.2.3 Bearing housing vibrations

The requirements of ISO 10816-1, ISO 10816-2 and ISO 10816-4 shall apply. ISO 10816-1 establishes a basis for the evaluation of mechanical vibration of machines by measuring the vibration response of support structures. This is also called "seismic measurement".

ISO 10816-2 shall be the basis for the assessment of vibration levels of gas turbine-driven generators, if not otherwise agreed.

ISO 10816-4 applies to bearing housing vibration measurements on gas turbines. If not otherwise agreed, the assessment of vibration levels of gas turbines shall be based on ISO 10816-4.

In any case where the above International Standards do not cover the shaft train in question completely, mutual agreement shall be sought between the purchaser and packager.

On gas turbines where case-mounted (seismic) vibration systems are used, or which are not covered by ISO 10816-4, the manufacturer shall provide the purchaser with the acceptable vibration limits, taking account of the following:

a) locations and types of transducers;

b) filtration and signal conditioning;

c) operating conditions;

d) quoted limits;

e) shop/field experience factors from previous/similar units.

4.7.2.2.4 Absolute shaft displacement vibrations

The ISO 7919 series treats absolute shaft displacement vibrations too. These may be measured by vectorial summing of relative vibration with the seismic probe, but this is normally not used. If it is installed, it is mainly applied for diagnosis. Installation of such measurements may be done if mutually agreed between the purchaser and packager.

4.7.2.3 Balancing

Balancing the finally assembled rotors reduces the unbalance excitation. The main machine rotors shall be multi-plane dynamically balanced in the machine or in a special spin pit. In the case of several machines combined into one train, an extra balancing after the addition of no more than two major components is recommended. Balancing correction masses shall only be applied to the components added. Minor correction of other components may be required during the final trim balancing of the completely assembled equipment. On rotors with single keyways, the keyway shall be filled with a fully crowned half-key.

ISO 1940-1 indicates the allowable balance quality grade for gas turbines as G 2.5. A better balance quality requirement than this applies only if mutually agreed between the purchaser and packager.

If mutually agreed between the purchaser and packager, the methods and criteria given in ISO 11342 may be used.

In the case of a stacked rotor assembly where the rotor is progressively assembled and cannot be removed as a unit, the manufacturer shall develop a standard procedure to achieve the above balance quality grade.

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

Final residual unbalance levels (in gram millimetres) shall be recorded with the rotational speed of balance and unbalance phase angle locations for each rotor assembly.

4.7.3 Torsional vibrations

The packager shall carry out an analysis of the torsional vibration characteristics of the complete system. A minimum separation margin of 10 % is recommended between each torsional eigenfrequency and any possible torsional excitation frequency. If this cannot be fulfilled, a torsional response calculation shall be performed. For all generator drives, a response calculation for excitation by mal-synchronization and by short-circuit shall be done. The torsional response calculations shall demonstrate that all stress responses remain in safe limits.

NOTE 1 Torsional excitation sources can include, but are not limited to, the following:

— for trains with generators or electric motors, one and two times the rotation speed should be considered as excitation frequencies; if electronic frequency converters are used, other integer multiples of the speed can excite torsional modes too;

— gear unbalance or pitch line runout;

— hydraulic governor control-loop resonance.

NOTE 2 For generator disturbance response calculations, no widely accepted standard is available. The packager may apply an appropriate internal standard.

5 Packaging and auxiliary equipment

5.1 Basic design

5.1.1 Basic scope of supply

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 practical. Exceptions should be mutually agreed between the packager and the purchaser:

a) baseplate(s);

b) combustion gas turbine or gas generator;

c) controls and instrumentation;

d) couplings and guards;

e) exhaust collector and/or diffuser;

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;

l) control panel;

m) inlet ducting;

n) inlet filtration system;

o) inlet silencer;

p) combustion system;

q) protection systems.

It is recognized that for some package designs some of the above-listed items will be shipped separately.

5.1.2 Optional equipment

Any other equipment required shall be specified by the purchaser and shall be included in the packager's scope of supply. 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 or absorption chiller cooler combination;

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 gas turbine performance enhancement;

l) starting system auxiliaries;

m) Steam or water injection fluid conditioning system;

n) Gas turbine load train condition monitoring equipment;

o) Uninterrupted power supply for controls, instrumentation, and operation;

p) Waste heat recovery systems and associated dampers;

q) Foundation anchor bolt;

r) barring equipment.

This equipment shall also be assembled (packaged) to the maximum extent practical.

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

5.1.3 Materials of package construction

5.1.3.1 General

Materials used of package construction shall be the manufacturer's standard for the specific site operating and environmental conditions. Specific attention shall be given to the choice of materials and protective coating systems to prevent

a) corrosion,

b) stress corrosion cracking,

c) galvanic corrosion, and

d) brittle fracture.

Materials for sour (acid) gas service shall comply with the recommendations of NACE MR-0175 or adequate international or national standards as shown in Annex B.

Materials shall be identified in the proposal.

Structure steel and piping shall be identified in the proposal.

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.

5.1.3.2 Non-metallic materials

Non-metallic 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.

5.1.4 Welding

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 Boiler and Pressure Vessel Code, or relevant international or national standards given in Annex B.

Welding of piping shall be in accordance with ISO 15649, or relevant international or national standards given in Annex B.

Welding on baseplates, non-pressure ducting, lagging and control panels, shall be performed in accordance with AWS D1.1, or relevant international or national standards given in Annex B.

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

Repair welds shall be non-destructively tested by the same method used to detect the original flaw.

5.1.5 Flange connections

The packager shall provide details of all the purchaser's connections to the package and shall state the acceptable forces and moments that these connections will tolerate. The acceptable loading for connections to connected equipment, such as compressors, pumps or steam turbines, shall not be less than that specified in the relevant standards for these items.

5.1.6 Bolting

The quality of bolting for pressure joints including piping shall be determined from the actual bolting temperature as defined by ISO 15649, or relevant international or national standards given in Annex B.

Nuts shall conform to ASTM A 194, Grade 2 or 2H, for A 194 bolting, and ASTM A 307, Grade B case-hardened for A 307 bolting, or relevant international or national standards given in Annex B.

5.1.7 Nameplates

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

The nameplate shall, as a minimum, include the purchaser's item number, the vendor's name, the machine's serial number, and the machine size and type. Additional information may include the 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. SI units shall be used.

Rotation arrows shall be of corrosion-resistant material and cast in or attached to each major item of the rotating equipment.

5.2 Auxiliary equipment

5.2.1 Starting systems

The packager shall furnish the type of starter system specified by the purchaser. Typical starters are electric motors, gas expansion turbines, steam turbines, hydraulic motors, internal combustion engines, air/gas motors, small gas turbines and generators in the motor mode. All starter units shall be suitable for satisfactory operation with the specified electrical power characteristics, inlet and exhaust steam pressure and temperature, air/gas or fuel.

If the plant is designed for contracted black start capability, it should contain its own power source for start: batteries, diesel or alternatives.

Starting units and associated power transmission equipment shall be suitable for the acceleration of the 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 % 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.

For single-shaft gas turbines, anticipated process variations which can affect the sizing of the starter (such as changes in pressure, temperature or properties of the fluid handled, and special plant start-up conditions) shall be specified by the purchaser. For single-shaft gas turbines for mechanical drive applications, the packager shall prepare a speed torque curve for the gas turbine and driven equipment with the starting driver torque superimposed. Gas expansion starters using flammable gas as motive power shall be designed for zero leakage from the seals to the immediate surroundings. 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 (see Clause 6).

Electrical drive starting systems shall be capable of starting the gas turbine when the supply voltage has fallen to the minimum level mutually agreed between the packager and purchaser.

5.2.2 Mounting systems

5.2.2.1 General

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 the purchaser's foundation. The purchaser shall specify the type of foundation on the data sheets.

5.2.2.2 Anchoring systems

When a baseplate is installed directly on a concrete foundation, accessibility shall be provided for grouting under all load-carrying structural members. Single-level foundation for the baseplate shall be used.

Mounting surfaces that are not to be grouted shall be coated with a rust preventive immediately after machining.

The packager shall specify the size, number and location of anchor bolts required for the specified method of fastening the package to the foundation.

5.2.2.3 Baseplate design

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

When specified, the baseplate shall be provided with levelling pads or targets protected with removable covers. The pads or targets shall be accessible for field levelling after installation, with the equipment mounted and the baseplate on the foundation.

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 packager.

The baseplate shall be provided with attachment points for at least a four-point lift. If lifting lugs are used, weld joints shall be full-penetration, full-length continuous welds, and non-destructively tested. Lifting the baseplate complete with mounted equipment shall not permanently distort or otherwise damage the baseplate or the machinery mounted on it. The purchaser and packager shall mutually agree on lifting arrangements based upon available facilities at the purchaser's site or other limiting factors.

When specified, non-skid decking or grating covering all walk and work areas shall be provided on the top of the baseplate. All deckplates shall be positively attached to each crossing structural member.

Baseplate shall be furnished with vertical jackscrews, where practical, adjacent to each anchor bolt. Otherwise, means shall be provided to raise the baseplate readily to facilitate alignment *in situ*.

Baseplate(s) shall be provided with drip containment and low point drains.

5.2.2.4 Equipment mounting

Provisions for axial, lateral and vertical jackscrews alignment shall be provided for the package train. Where jackscrews are used, they shall be arranged to prevent marring of shimming surfaces.

The packager shall furnish suitable shim packs under all machinery mounting feet.

5.2.3 Enclosure and fire protection

5.2.3.1 General

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.

5.2.3.2 Construction

Enclosures shall be resistant to the ingress of dust, and outdoor enclosures shall be additionally weatherproof. Water and/or dust leakage through the enclosure wall and roof seams is unacceptable. Panels shall be designed to minimize internal moisture build-up and corrosion of the panel. Panel materials shall be non-hydroscopic, non-combustible, and insect and vermin resistant.

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

If necessary, removable roof sections, side panels or hinged bulkhead walls shall be provided for heavy maintenance. The construction of maintenance accessways shall permit easy return to the original condition. Caulking is not acceptable.

Access doors and/or manways shall be provided for routine maintenance and inspection. Seals shall be used around the perimeter of the accessway. Accessways shall be lockable.

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 or are to be equipped with quick connection couplings.

When specified, windows shall be provided, preferably located in access doors on either side of the enclosure, opposite each other. Each window shall be double pane, of wire-reinforced glass, with a dead air space between panes.

If specified, lighting for general observation shall be provided within the enclosure.

Lube oil filling points used during operation shall be outside the engine enclosure or remote from hot parts of the engine.

5.2.3.3 Fire and gas protection

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

a) a fire suppression system;

b) a fire detection system;

c) a gas detection system for:

   1) gas fuelled units,

   2) when the driven machine handles flammable gas,

   3) when operating in a hazardous area (see 6.4.4, 6.10.7 and 6.10.8).

5.2.3.4 Ventilation and purging

The enclosure shall be provided with a forced or induced ventilation (cooling) and purging (hazardous area declassification) air system designed to provide 100 % of the ventilation and purging load in the most severe climatic/load conditions.

The ventilation shall be sufficient to avoid heat damage to the equipment within the enclosure.

The purge air shall be distributed to ensure it sweeps around all areas of the gas turbine and through all areas of the enclosure in sufficient quantity to avoid dead spots where gases could accumulate in explosive concentrations.

Furthermore, in cases of fuel gases heavier than air and/or gas mixtures with low autoignition temperature, sufficient dilution and scavenging of the lower portion of the enclosure shall be provided. The ability of the ventilation system to fulfil these requirements shall be demonstrated.

The purchaser shall specify on the data sheets system redundancy requirements and whether positive or negative pressure is required.

The ventilation system shall include air filtration and silencing equipment if required.

Ventilation systems shall be designed to operate satisfactorily over the ambient temperature range specified.

Overcooling under low ambient temperatures shall be avoided.

Ventilation and purging flow shall leave the enclosure via a flanged exhaust port(s). Each port shall be equipped with a fire-suppression medium damper and, where specified, with a back-draft damper. The purchaser shall specify if additional ventilation ducting is required.

If cool-down ventilation is required to prevent damage to the gas turbine major auxiliary or instrumentation systems within the enclosure, a separate back-up fan shall be provided.

5.2.4 Air inlet system

5.2.4.1 General

The air inlet system typically consists of the following:

a) inlet filter (either single or multi-stage);

b) silencer;

c) ducting;

d) expansion joints (as required);

e) pressure drop test connections at the gas turbine inlet;

f) instrumentation and protection devices.

Optional features, when specified, may include the following:

g) anti-icing system;

h) evaporative cooler with downstream moisture separation;

i) insect/bird screens;

j) washing system (on- and/or off-line);

k) walkways, handrails, platforms and ladders required for access and maintenance;

l) absorption chillers;

m) weather louvres;

n) facility to service filter replacements, i.e. lifting into position and removal;

o) high efficiency vane separator upstream of the air filters to prevent water ingress;

p) bypass door which opens after reaching a specified pressure drop.

Unless otherwise specified, the inlet system shall be designed for a maximum total pressure drop of 1 kPa with a clean air filter and a maximum at-site air flow.

Unless otherwise specified, provision shall be made to permit the maintenance and cleaning of prefilters on multi-stage filters during operation of the gas turbine.

Bolts, rivets or other connectors that can become loose and be carried in the air stream shall not be used in the inlet system downstream of the final filter media.

Unless otherwise specified, reinforced coarse mesh (stainless-steel screen) shall be provided upstream of the gas turbine inlet to minimize the potential of foreign object damage (FOD screens). The actual location shall be mutually agreed upon by both the packager and purchaser, considering such facilities as cleaning systems, access plates, vaned elbows and aerodynamic disturbance at the intake volute or the bellmouth.

When specified, all metallic air path components shall be stainless steel.

When carbon steel air path components are provided, corrosion protection of the filter, ducting and silencer is required. Protective material or coating and details of the surface preparation proposed shall be submitted by the packager for approval with proposal.

An indication of the life of the surface coating should be provided by the packager. Grades of stainless steel that are sensitized by welding should be avoided.

The purchaser shall specify whether the filter house is to be at grade level or elevated. If elevated, the packager shall provide all structural support to grade.

To minimize the ingress of airborne dust, it is recommended that the air intake be not less than 5 m above grade or any adjacent large flat surface such as a roof.

5.2.4.2 Inlet filters

Filter systems shall be of a design well proven for the environmental conditions specified on the data sheets. The purchaser and the packager shall agree on the type of inlet filtration system. If single-stage filtration only is specified, the purchaser may specify if provisions are to be made for the future addition of extra stages. Debris screens and weather louvres shall not be considered stages.

The packager shall provide in his proposal the filter system performance data as required on the data sheets (see Annex A, Table A.3).

Unless otherwise specified, a high efficiency mist eliminator shall be furnished as the first stage for marine environments. Metallic filter or non-absorbent type filter elements such as glass or polypropylene fibre shall be provided.

All filter systems require the following design features.

a) All wiring and conduit located downstream of the air filter elements shall be outside of the airpath.

b) All supporting structural steel shall be of bolted and welded design.

c) Modular construction with each module shall be fully factory assembled, wired and plumbed. Each module shall have lifting provisions to be used for loading and unloading and for lifting into the final assembled position.

d) All seams and joints on the clean air side of each filter system shall be airtight. All welded seams shall be continuously seal welded.

5.2.4.3 Inlet silencers

Silencer attenuation shall be capable of meeting the system noise limitations specified by the purchaser.

Silencers shall preferably be flanged and sufficiently rigid to be supported only by the end flanges when mounted in a horizontal or vertical duct system.

The construction of the silencer baffles shall prevent the entry of the baffle packing material into the air stream.

The silencer shall be designed to prevent damage resulting from acoustical or mechanical resonances.

Lifting provisions shall be incorporated on the silencer for handling.

The direction of flow shall be indicated on silencers, vents and cascade bends.

5.2.4.4 Inlet ducting

The duct system shall be arranged to give the minimum number of bends. Turning vanes shall be provided at changes in direction when required to ensure uniform flow distribution at the gas turbine flange. The leading and trailing edge of each vane shall be tapered and smooth. Vanes shall be attached to the duct by a continuous weld and shall be designed to avoid resonance conditions.

For transition sections between duct components of different cross-sectional areas, the angle between the sides and the axis of the duct should be minimal to reduce pressure drop. In general, the angle should not exceed 15°.

The ducts shall be supported to allow lateral as well as axial growth due to temperature changes. The ducting and supports shall be designed to remain stationary when sections near the gas turbine are removed to provide access for unit maintenance. Ducts shall be sufficiently rigid to avoid vibration.

Where not restricted by size, access shall be provided in each duct adjacent to the gas turbine inlet flange to allow final cleaning and inspection of the entire duct system before operation. Covers, if required, shall be designed to permit their removal at any time without risk of fasteners or other objects being ingested by the gas turbine. They shall be gasketed and secured to ensure positive leakproof closure.

Gastight expansion joints shall be provided to remove all loads between the ducting and gas turbine inlet flanges. These joints shall accommodate the relative movement of the ducting, regenerator (if any) and gas turbine in the vertical and horizontal directions.

5.2.4.5 Evaporative cooling system

Evaporative cooling can be used to reduce the ambient temperature as perceived by the gas turbine, thereby giving extra output. Evaporative cooling systems may be based on either a rigid media or a compressor spray. The rigid-media type shall consist of the cooling media, pump, sump, drains and all necessary controls for water circulation and cooler control. The compressor spray shall consist of high-pressure pumps and a control system.

Evaporative cooler performance shall be based on the maximum possible airflow and the most severe site environmental conditions. The cooler system shall be designed to prevent liquid carryover. The cooler percent efficiency, E, as stated on the data sheet, is defined as:

$$E = \frac{T_\text{d} - T_\text{e}}{T_\text{d} - T_\text{w}} \times 100 \qquad (1)$$

where

T_e is the cooler exit temperature;

T_d is the dry bulb inlet temperature;

T_w is the wet bulb inlet temperature.

A corrosion-resistant inertial mist eliminator or coalescing element shall be provided in the ducting, downstream of the evaporative cooler. The mist eliminator or coalescer shall be selected to minimize moisture carryover from the inlet air stream.

Cooler water circulation shutdown shall occur on air temperature control. To prevent icing a temperature probe shall be provided to automatically shut down water circulation when the exit air temperatures are less than 10 °C.

All evaporative cooler metallic housing and internal structural supports shall be of stainless steel. All metallic downstream air path components shall be of stainless steel.

The evaporative cooler, mist eliminator or coalescer, and exit ducting shall be designed for complete drainage. The bottom of each shall slope towards a flush drain. Protrusions or standpipes at the drain nozzles are not permitted. Each drain nozzle shall be arranged to prevent unfiltered air from being drawn into the ducting. Emergency overflow capability is required in addition to the primary drain system.

When specified, walkways, handrails, access ladders and manways shall be provided to service both upstream and downstream of the evaporative cooler media, mist eliminator or coalescer, and ducting downstream of the cooler.

The packager shall specify the quality and quantity of the evaporative cooler water that is necessary to minimize cooler and water system operating problems.

If the gas turbine drives a generator, the packager should ensure that the generator and other electrical equipment can cope with the extra electrical output without overheating.

5.2.4.6 Absorption chillers

Under certain ambient conditions (high ambient temperature and high humidity) it may be desirable for the purchaser to consider the use of an absorption chiller to artificially reduce the ambient temperature as perceived by the gas turbine. This may be used instead of an evaporative cooling system which is generally used when ambient temperature is high and humidity is low.

When specified, the vendor shall furnish an integrated packaged system in such way as to keep installation and commissioning time to an absolute minimum.

The purchaser shall specify the preferred source of heat for the absorption chiller (i.e. steam, hot water or gas fired) and the available temperatures and pressures thereof. Absorption chillers are available as single- or double-effect refrigerant machines.

Due consideration shall be given to the chilled coil arrangement and design within the gas turbine air inlet system to maintain pressure loss at the minimum possible level.

For coastal locations, the material of the chilling coils should be marine grade to avoid corrosion problems. All inlet duct work downstream of the cooling coils should be of suitable corrosion-resistant material.

If the chilling coils need to be drained in the winter, then coils should be of suitable corrosion-resistant material.

The absorption chiller shall be designed for the optimum duty condition (cooling effect).

The scope of supply for the system shall include the absorption chiller package, including evaporators, condensers, chilling coils, transfer pumps, instruments and associated control panels (interfacing with the gas turbine control system) and auxiliaries.

The purchaser shall indicate or specify if the waste heat (hot water) is required for other purposes.

Sufficient flexibility shall be accommodated in the system design to facilitate operation at conditions other than full load. The chilling capacity must therefore be variable and controllable.

Controls, instrumentation and equipment necessary for both the modulation and safe operation of the plant shall be included and integrated into the gas turbine control system.

Features shall be incorporated in the design to support a philosophy of minimum maintenance. It shall be possible to operate the gas turbine in the event that the chiller is rendered inoperative and to maintain the chiller when the gas turbine is in operation.

Refrigerants used shall conform with the environmental requirements.

All utility requirements, quality and quantity, shall be defined by the packager, i.e. a.c. power, water treatment, etc.

The unit shall be tested to the manufacturer's standard prior to dispatch to ensure satisfactory operation of the unit.

If the gas turbine drives a generator, the packager should ensure that the generator and other electrical equipment can cope with the extra electrical output without overheating.

5.2.4.7 Water wash system

When specified, the packager shall provide a water wash system for off-line compressor washing of the gas turbine compressor section. The packager shall provide fluid quality and quantity and utility requirements with the proposal. Flow isolating drains shall be provided at suitable locations within the gas turbine with facilities for collection of the drainage and its subsequent removal. The packager shall provide access to the inlet plenum for compressor inlet bell mouth area inspection.

When specified, the packager shall also provide a complete on-line washing system.

The water wash system(s) shall be fully described in the proposal, including a system schematic.

The packager shall provide operational procedures for the water wash system with the proposal.

5.2.4.8 Anti-icing system

When site ambient temperatures are below 5 °C, the purchaser and packager shall agree on the need and type of automatic anti-icing system. This may be either at the front face of the filter or downstream of the filter stage(s). The effect on package performance shall be identified and quantified.

The system selected may rely upon heating of the inlet combustion air or use of air-activated pulse-type filters.

The packager may recommend the fitting and control of compressor air intake anti-icing to prevent ice build-up on the intake bell mouth and first-stage blading (see 6.10.3).

5.2.5 Exhaust system

When specified by the purchaser, a complete exhaust system shall be furnished consisting typically of the following:

a) turbine-to-exhaust duct expansion joint;

b) exhaust silencer;

c) exhaust ducting;

d) exhaust system structural supports;

e) exhaust drains;

f) stack.

The purchaser shall specify special design considerations, such as:

g) insulation requirements for areas where personnel protection is required;

h) exhaust system discharge flange orientation, location and installed configuration;

i) pressure drop associated with equipment supplied by others, e.g. waste heat recovery units;

j) emission sampling port(s).

The maximum allowable back-pressure, specified by the packager, shall be considered.

For regenerative cycle gas turbines, the packager shall supply and prefit the regenerator, the necessary air piping and exhaust ducting between the gas turbine and regenerator, including all required expansion joints, supports, structures and necessary insulation and controls.

The basic material for construction of the exhaust system shall be selected with suitable temperature- and corrosion-resistant material, taking into account the turbine operating cycle and site operating conditions.

Components of the exhaust system shall be connected for ease of installation and maintenance. All components shall be furnished with suitable provisions for lifting.

Acoustic and/or thermal insulation, whether externally or internally applied, shall be suitably captured to prevent its deterioration over time when subjected to a normal exhaust system environment.

The exhaust joints shall be constructed of metal or reinforced high-temperature fabric. Expansion joints shall be designed to prevent undue flutter, joint deterioration or pressure drop. The fabric shall be replaceable without removal of major components.

Where not restricted by size, access shall be provided in the exhaust system to allow for cleaning and inspection of the exhaust system.

If required, structural supports shall be furnished for the portion of the exhaust system provided by the packager. These supports shall be designed to allow for thermal growth and to reduce duct loads at the gas turbine flanges to within the manufacturer's specified limits. The ducting and supports shall be designed to remain stationary when duct sections near the gas turbine are removed to provide access for gas turbine maintenance.

5.2.6 Piping

5.2.6.1 General

The packager shall furnish all piping systems, including mounted appurtenances, located within the confines of the main unit's base area, any oil console base area, or any auxiliary base area. The piping shall terminate with connections at the edge of the base. Unless otherwise specified, the purchaser shall furnish only interconnecting piping between equipment groupings and off-base facilities.

The design of piping systems shall achieve the following:

a) proper support and protection to prevent damage from vibration or from shipment, operation and maintenance;

b) proper flexibility and normal accessibility for operation, maintenance, and thorough cleaning;

c) installation in a neat and orderly arrangement adapted to the contours of the machine without obstructing access openings;

d) elimination of air pockets by the use of valved vents or non-accumulating piping arrangements;

e) complete drainage through low points without disassembly of piping.

Piping systems furnished by the packager shall be fabricated, installed in the shop, and properly supported.

Welding shall be performed by operators in accordance with procedures specified in Section IX of the ASME Boiler and Pressure Vessel Code, or relevant international or national standards given in Annex B.

5.2.6.2 Oil piping

Gravity oil return piping shall be sized to run no more than half full when flowing and shall be arranged to ensure good drainage (recognizing the possibility of foaming conditions). Horizontal runs shall slope continuously towards the reservoir. If possible, not more than one lateral in any transverse plane should enter the drain headers at a 45° angle in the direction of flow.

Pressure piping downstream of oil filters shall be free from internal obstructions that could accumulate dirt. Unless otherwise specified, the material for all piping downstream of the oil filter shall be stainless steel.

5.2.6.3 Instrument piping and tubing

The packager shall supply all necessary piping, valves and fittings for instruments and instrument panels.

Separate secondary block and bleed-type isolating valves are required for each instrument on a common connection. Where a pressure gauge is to be used for testing pressure alarm or shutdown switches, connections according to national or purchaser's safety regulations are required for the pressure gauge and switches.

Unless otherwise specified, control-air and instrument tubing shall be of stainless steel.

5.2.6.4 Steam or water injection piping system

Unless otherwise specified, piping, fittings, valves and tubing materials for steam/water injection into combustion systems shall be of stainless steel.

5.2.6.5 Process piping

The extent of the process piping to be supplied by the packager shall be specified by the purchaser.

When specified, the packager shall review all piping, appurtenances (intercoolers, aftercoolers, separators, knockout drums, air-intake filters and expansion joints), and vessels connected immediately upstream and downstream of the equipment components and their supports. The purchaser and packager shall agree on the scope of this review.

5.2.7 Oil systems

Unless otherwise specified, the oil system required for the drive train components (gas turbine, main load drive gear and driven equipment) shall preferably be integrated into the gas turbine and/or driven equipment package. When any international or national standard is applied, the extent of compliance shall be mutually agreed upon between the purchaser and packager.

The oil system may be a single common system or two separate systems. One of the two systems may be dedicated to an aeroderivative gas turbine or any other component which uses a synthetic lubricant. Synthetic and mineral oil systems, including vents and drains, shall be segregated.

A mineral oil based system may be used to supply the compressor sealing requirements (if applicable) with approval of the purchaser.

The packager shall provide a complete description of the oil systems in the proposal, including schematic diagrams and lists of materials.

Unless otherwise specified, a pressurized oil system(s) shall be furnished to supply oil at a suitable pressure or pressures, as applicable, to the following:

a) the bearings of the driver and of the driven equipment (including any gear);

b) the continuously lubricated couplings;

c) the governing and control-oil system;

d) the seal-oil system;

e) the hydraulic oil system for hydraulic starter(s) when required.

Where oil is supplied from a common system to two or more machines (such as a compressor, a gear and a turbine), the characteristics of the oil shall be specified on the data sheets by the packager. The packager shall ensure that the specified oil meets the requirements of the different machines.

When the usual lubricant employed in a common oil system is a hydrocarbon oil, the oil shall correspond to ISO viscosity grade 32, 46 or 68, as specified in ISO 3448.

Pressure lubrication systems shall typically consist of the following:

a) a supply and return system;

b) an oil cooler (when required);

c) a full flow (nominal) filter;

d) a low lube-oil pressure shutdown;

e) steel oil-containing pressure components;

f) a main oil pump, full capacity, separately driven, and automatically controlled when the package main oil pump is not shaft driven;

g) standby (spare) pumps;

h) a prelube/postlube/cool-down lubrication system when required;

i) a lubrication system capable of safe coast down in the event of loss of a.c. current;

j) instrumentation to indicate operating parameters such as temperature or pressure.

5.2.8 Fuel system

5.2.8.1 General

The packager shall supply the system for receiving precompressed, superheated (if necessary) and filtered fuel from the purchaser. The interface between the purchaser's and the packager's supply shall be agreed upon. The fuel system shall be operable with any specified and agreed upon fuel(s).

When specified, the packager shall review the purchaser's fuel system.

NOTE The purchaser may specify a day tank for liquid fuel operation to allow start-up and sustained operation for a reasonable period of time.

The purchaser and packager shall mutually agree on the type, grade, composition, range of lower heating values, temperature(s), delivery pressure(s) and contaminants of the proposed fuel in the inquiry specification.

The contaminants likely to be found in fuels depend on the kind of fuel involved, such as pipeline natural gas and producer gas. Some of the contaminants that are likely to be found include:

a) water and gas hydrates;

b) sand, iron oxides and other solids;

c) naphthalene;

d) hydrogen sulfide, sulfur dioxide, sulfur trioxide and total sulfur;

e) alkali metals;

f) chlorides, carbon monoxide and carbon dioxide.

Concentrations of hydrogen sulfide, sulfur dioxide, sulfur trioxide, total sulfur, alkali metals, chlorides, carbon monoxide and carbon dioxide are corrosive agents that will cause elevated temperature corrosion of turbine nozzles and blading materials and ambient temperature corrosion of fuel control valves and systems.

The total sulfur content shall be considered and the temperatures at any point in the exhaust system must be above the acid dewpoint (approximately 150 °C) in order to prevent the formation of sulfurous and sulfuric acid which will accelerate corrosion and reduce component life.

The ignition system shall include an ignition transformer and igniter plugs. Ignition shall be automatically de-energized and fuel flow stopped if the gas turbine fails to establish combustion.

Fuel distribution piping and tubing shall be of stainless steel. The use of flexible hoses shall be minimized and, when used, limited to locations where relative movements must be accommodated. All fuel hoses shall be made of stainless steel and covered with abrasion-resistant braiding.

5.2.8.2 Gaseous fuel

5.2.8.2.1 General

The packager shall advise the purchaser of maximum/minimum fuel temperatures and pressures required at the packager's fuel gas inlet connection. The maximum temperature is set by the gas turbine fuel system design (e.g. seals, brackets, valves and instrumentation). The minimum temperature is set primarily by a specified margin above the dewpoint of the fuel gas and may be limited in extreme cases by the gas turbine fuel system design. As the dewpoint cannot be consistently measured, the packager and purchaser shall mutually agree on a gas analysis as a basis for the dewpoint calculation. A safety margin of typically 20 °C to 30 °C is required. The pressure is set by a specified margin above the gas turbine pressure ratio, which is a function of the particular gas turbine ambient temperature load (base or peak) and site elevation. This margin is influenced by the pressure drop of valves, pipings, filters, etc.

Gas shall be free of liquids and solids at the purchaser's connection to the package. Special provisions by the purchasers, such as separators or knockout drums, may be required to eliminate condensate in situations where condensation could occur. Also liquid hydrocarbons shall be eliminated.

5.2.8.2.2 Net specific energy

The range of net specific energy of each gas shall be specified by the purchaser. For variations of Wobbe index of more than 5 %, the rate of change shall be specified by the purchaser as special equipment may be required.

5.2.8.2.3 Fuel gas system

A gaseous fuel system shall typically include the following:

a) Y-type fuel strainer(s);

b) necessary instrumentation;

c) a manifold and nozzles;

d) two fuel shut-off valves with an intermediate vent valve for automatic operation and system purging prior to starting;

e) a fuel control valve;

f) a fuel gas pressure regulator, if required.

When specified, a fuel bypass valve and vent valve for purging the fuel gas line shall be provided.

If the fuel gas pressure required by the packager is higher than that available, a fuel gas compression system shall be furnished by the packager when specified by the purchaser. The packager shall state the maximum allowable fuel gas temperature supplied by the purchaser.

5.2.8.3 Liquid fuel

A liquid fuel system shall typically include the following:

a) duplex fuel filters with a continuous flow transfer valve;

b) fuel charge pump;

c) atomizing air compressor (if required by the packager);

d) two fuel shut-off valves for automatic operation;

e) necessary instrumentation;

f) fuel control valve;

g) fuel flow dividers, if required;

h) fuel nozzles and manifold;

i) draining facilities.

For dual fuel engines where the principal fuel is gas, a single fuel filter may suffice.

To prevent coking and plugging, the packager's design shall include facilities to purge or drain liquid fuel from the fuel manifold system.

Unless agreed otherwise, dual fuel filters shall be accessible and capable of being cleaned while in operation. The transfer valve shall have a carbon-steel or stainless-steel body with stainless-steel plugs and plug-jacking devices.

5.2.8.4 Dual fuel operation

When specified, the gas turbine should preferably be provided with the necessary equipment to permit normal (starting and continuous) operation on any of the fuels; i.e., liquid/natural gas, liquid/liquid or gas/gas. The dual fuel system shall provide the capability of automatic transfer from one fuel source to another while under full or part load operation.

When operating on gas fuel, the liquid fuel lines, nozzles, manifolds, etc. shall be prevented from plugging, coking or overheating either by continuously purging or other means.

The packager shall provide a project-specific flow diagram, complete with a bill of material and a written technical description of the dual fuel system, with the proposal. Water/steam injection requirements during fuel transfer shall be stated in the technical description (see Annex A, Table A.4).

5.2.8.5 Water/steam injection operation

The water/steam injection system shall be capable of providing the specified power augmentation or specified levels of NO_x and CO suppression.

The packager shall provide a project-specific flow diagram, complete with a bill of material and a written technical description of the water/steam injection system, with the proposal (see Annex A, Table A.4).

Water/steam quality and supply requirements shall be stated in the proposal (see Annex A, Table A.4).

5.2.8.6 DLE combustion

When specified, the gas turbine shall be provided with a DLE combustion system to suppress emissions of NO_x and CO. The purchaser shall specify whether dual fuel capability is required and whether dry-dry or dry-wet mode is acceptable.

5.2.9 Electrical systems

The characteristics of the electrical power supplies, such as those used for motors, heaters and instrumentation, shall be specified by the purchaser.

Electrical controls may be either a.c. or d.c. and shall be described in the packager's proposal. The purchaser shall specify whether the d.c. power supply is to be provided by the packager. When a.c. power is specified, an uninterruptible power supply (UPS) shall be provided. The purchaser shall specify whether the UPS is to be provided by the packager. When specified, the control system shall be designed to maintain operation and unit protection for a period to be stated by the purchaser in the event of interruption in the utility a.c. supply.

Power and control wiring within the confines of the baseplate shall be resistant to oil, heat, moisture and abrasion. Protection relevant cabling shall be fire resistant to ensure the safe shutdown of the unit.

Stranded conductors shall be used within the confines of the baseplate and in other areas subject to vibration. Thermocouple and control panel ribbon cable wiring may be solid conductors. The wiring system shall be suitable for the environmental conditions specified.

Earthing systems shall be provided as well as suitable plugs and sockets.

Unless otherwise specified, all leads on terminal strips, switches and instruments shall be permanently tagged for identification.

To facilitate maintenance, clearance shall be provided for all energized parts (such as terminal blocks and relays) on turbine and auxiliary equipment.

Electrical materials, including insulation, shall be as corrosion resistant and non-hygroscopic as possible (see 5.1.3). When a tropical location is specified, materials shall be given the treatments specified below.

a) Parts (such as coils and windings) shall be protected from fungus attack.

b) Unpainted surfaces shall be protected from corrosion by plating or other suitable coating.

Control, instrumentation and power wiring (including temperature element leads) within the limits of the baseplate shall be either steel wire armored or installed in rigid metallic conduits and boxes as specified by the purchaser, properly supported to minimize vibration and isolated or shielded to prevent electromagnetic interference.

Conduits may terminate (and, in the case of temperature element heads, shall terminate) with a liquid-tight flexible metallic conduit or explosion-proof flexible fittings (as applicable to the area classification). All flexible conduit shall be long enough to permit access to the unit for maintenance without removal of the conduit.

Steel wire armored cabling shall be suitably glanded through junction box penetrations.

6 Control and instrumentation

6.1 Control systems

6.1.1 General

The gas turbine power plant shall be provided with a control system to enable the operator to sequence the gas turbine and its load device through its duty cycle (start-up, loading, operation, shutdown and stand-by). The system shall also provide protection for the equipment via alarm and trip functions, and shall, where specified by the purchaser, provide information to the operator for condition monitoring. Control of ancillary systems such as exhaust reduction emissions systems, plant auxiliaries and combined cycle shall, where specified by the purchaser, be included.

Where the control equipment has to meet national standards, it shall be the responsibility of the purchaser to advise the packager of the latest relevant standards.

6.1.2 Control and protection systems

Turbine control and protection systems shall be designed as "fail safe" unless otherwise agreed between the purchaser and packager. Fail safe for the purposes of this specification, when applied to a digital control system, shall be as follows.

a) Digital instrument

A digital input instrument (e.g. pressure switch) used to protect the gas turbine shall be designed as "normally open" and is then closed when the gas turbine is running and re-opened again on fault.

b) Analog instrument circuit

An analog instrument (e.g. thermocouple input) used to protect the gas turbine, shall be continuously monitored for open circuit and input value "out of range" detection. Either state shall cause the control system to take appropriate action, depending on the criticality of the parameter monitored and the level of redundancy (if any).

c) Digital control output circuit

A digital output (e.g. relay output) shall be arranged to be "energized to run" and electrical power failure shall cause all digital outputs to move the process to a safe state.

d) Analog control output circuit

The device being controlled shall be continuously monitored for position, directly or by inference; a position error shall cause the demand signal to be driven to its safe level.

e) On-line testing of control and protection devices

Modern digital control systems normally have some degree of redundancy on critical circuits and/or provide continuous health monitoring of many instrument loops, e.g. thermocouple open circuit and out of range detection. The packager shall advise the purchaser of the available facilities. The final scope shall be by agreement between the purchaser and packager.

f) On-line replacement of instruments and controls

When specified, all instruments and controls other than shutdown sensing devices shall be installed with sufficient valving to permit their replacement while the system is in operation. When isolation valves are provided for shutdown sensing devices, the packager shall provide means of locking the valves in the open position.

6.2 Starting

The starting control system, including any start requirements such as turning, should be fully automatic with a minimum of manual intervention. The start sequence should be initiated from a single action up to minimum governed speed (or ready to synchronise in the case of a generating set). Start hold and release stages or dwells may be built into the sequence according to the packager's design requirements and the purchaser's operational requirements (see 4.3.3, 4.5.5, 4.7.3.1 and 5.2.1).

6.3 Loading

Subsequent loading of the set may be manual, or automatic up to demanded power level, as specified by the purchaser. Manual operation requires the operator to raise the output to the desired set point. Automatic loading is when the output is automatically increased to the set point without manual intervention. Automatic loading may directly follow the starting sequence without any additional action of the operator.

In any mode of loading, periods of dwell at specific outputs may be introduced to meet warm-up requirements.

Where a generator requires synchronizing to a particular system prior to loading, this may be achieved by manual or automatic means, as specified by the purchaser.

6.4 Unloading and shutdown

6.4.1 General

This may be achieved by manual, semi-automatic or automatic means, as specified by the purchaser. Manual operation requires the operator to perform or initiate each step. Semi-automatic requires the operator to perform some function such as unloading manually while other parts of the sequence are automatic. Automatic operation is carried out from a single operator command. In each case, however, the principal sequence of operations shall be as follows.

6.4.2 Controlled shutdowns: Generator drives

The sequence shall be:

a) controlled unloading to nominal zero output whilst remaining synchronized;

b) opening the circuit breaker;

c) reduction to idling speed and period of cooling under fired conditions (where applicable);

d) fuel cut-off and shutdown of auxiliaries not required for turning;

e) turning period, (if necessary);

f) shutdown of remaining auxiliaries, for example lubricating oil pumps, after gas turbine cool down;

g) reset to starting conditions.

6.4.3 Controlled stop: Mechanical drives

The sequence shall be:

a) controlled unloading to minimum load conditions, or to idling speed;

b) cooling period (where applicable);

c) fuel cut-off followed by shutdown of auxiliaries not required for turning;

d) turning period, (if necessary);

e) shutdown of remaining auxiliaries, for example lubricating oil pumps;

f) reset to starting conditions.

6.4.4 Emergency protection system

6.4.4.1 General

The emergency protection system shall protect the gas turbine and connected equipment against hazards or impending damage and shall, where appropriate, detect and operate independently of the governor. In order to maximize the life of the gas turbine, under certain circumstances, it may not always be necessary to immediately execute an emergency stop, by tripping to minimum self-sustaining speed or minimum load as follows.

6.4.4.2 Protective load shedding

Under certain fault conditions, the sequence may allow for the gas turbine to go to minimum load, no load (generator breaker open) or trip to self-sustaining speed for a period of time, allowing for cooling before the fuel is shut off automatically and the gas turbine is shut down. The packager shall advise the purchaser when this is the case.

Under certain fault conditions, mutually agreed between the purchaser and packager, the sequence may allow for the gas turbine to go to a partial load for a period allowing the fault time to correct itself. Failing this, the fuel is shut off automatically and the gas turbine is shut down. Assuming the fault clears, the set may be reloaded automatically or manually.

The requirement to decelerate to minimum load or trip to minimum self-sustaining speed is set by the core gas turbine manufacturer, but the feature may be of interest when designing the process for the driven unit or heat recovery systems to reduce the number of potential full shutdowns. The application shall be agreed between the purchaser and packager.

6.4.4.3 Emergency shutdown

Emergency shutdown may be manually initiated but shall occur automatically on operation of applicable gas turbine/process plant protection devices as agreed with the purchaser. The system shall operate directly on the fuel shut-off valve to stop the gas turbine fuel supply.

Following emergency shutdown, normal turning and shutdown sequences, as appropriate, shall subsequently take place. An automatic restart shall not be possible without a manual reset unless mutually agreed between the packager and purchaser and supported by the package safety assessment.

6.4.5 Fire, gas detection and ventilation failure shutdown

Should a serious fault be detected, such as fire, gas leakage at trip level, or ventilation failure, shutdown shall occur automatically as a result of the function of automatic detection devices. The system shall operate directly on the fuel shut off and vent valves. The gas turbine shall be shut down immediately without ramping to minimum load or cooling period.

In the case of gas detection at an enclosure ventilation outlet (but not the inlet), the ventilation fans shall be retained on to purge remaining gas from the enclosure.

If an unacceptable level of explosive atmosphere is detected at a ventilation inlet, the ventilation fans shall be tripped where applicable as the source is most probably external to the enclosure, and shutdown of the gas turbine shall occur.

6.4.6 Shutdown of generator sets

For electric generation, means shall be provided, either on the gas turbine or on the generator, for prevention of motoring of the generator when the fuel stop valve is closed. Where synchronous compensation or generator starting is specified, these requirements may be operationally over-ridden.

6.4.7 Shutdown of mechanical drive sets

Automatic means shall be provided upon shutdown for isolating the driven equipment from the system it supplies in order to prevent rotation or reverse flow.

6.5 Ventilation and purging

6.5.1 Turbine enclosure

Ventilation air movement should be monitored and interlocked with the automatic start sequence. Only after a satisfactory purge of the enclosure where no unacceptable level of explosive atmosphere has been detected shall the automatic start sequence continue. Unless national regulations state otherwise, the purging cycle shall displace normally at least three times the volume of the enclosure before the starting sequence is allowed to proceed.

6.5.2 Gas turbine purging

The starting control system shall provide an automatic turbine purge period of sufficient duration to ensure safe operation of the gas turbine and down stream components.

Unless national regulations state otherwise, the purging cycle shall displace normally at least three times the volume of the entire exhaust system (including the stack) before firing the unit. In cases where alternative precautions are taken, this may not be necessary.

Where large exhaust system volumes lead to excessive purge times, reduced cycle times may be agreed between the parties involved.

6.5.3 Special precautions

Where liquid fuels of a highly volatile nature are used, such as naphtha or gases with a density greater than air, special precautions may be necessary (see 5.2.3.4). These shall include, but are not limited to, automatically operated fuel dump valves, segregation of fuel handling equipment, special hazardous atmosphere detectors and liquid detectors.

6.6 Fuel control

6.6.1 General

The fuel supply shall be automatically controlled during starting and running so as to maintain the gas turbine within its safe operating envelope and to maximize the life of the machine. Where necessary to meet environmental limits for emissions, the fuel supply shall also be controlled to meet combustion design criteria.

6.6.2 Dual fuel system operation

When specified by the purchaser, the control system shall be capable of controlling the gas turbine on gas fuel(s) and/or liquid fuel(s) and shall allow for automatic (bi-directional) changeover throughout the full operating power range. Any restrictions on transient changes in speed or load shall be advised to the purchaser by the packager. Initiation of the transfer shall be a signal provided by the purchaser.

6.6.3 Bi-fuel operation

When specified by the purchaser, the control system shall be capable of proportionally controlling each fuel in parallel to maximize the use of the primary fuel according to availability. The packager shall advise the purchaser of any limitations with regard to the minimum percentage for each fuel.

6.6.4 Low specific energy gas operation

Where the gas turbine is to be designed to run on very low specific energy gasses, such as some landfill or coal derived gases, it may be necessary to start the unit on liquid fuel or natural gas from other sources, which shall be made available by the purchaser. It may also be necessary to continuously pilot on one of these fuels to prevent the combustion flame from blow out on transient load changes.

6.6.5 Variable specific energy gas fuel control

Where specified by the purchaser, the control system shall be capable of automatically compensating for a varying specific energy gas supply, maintaining stable operation over the full load range.

The purchaser shall specify the range of specific energy and Wobbe index of the proposed gas supply, which shall be confirmed as acceptable by the packager.

6.6.6 Fuel shut-off (gas and liquid fuel)

6.6.6.1 Fuel shut-off block valving

In addition to the governor fuel valve(s), two independent means shall be provided to shut off all gas fuel to the gas turbine on any shutdown condition and shall not open until all permissible firing conditions have been satisfied.

If the gas governor fuel valve is of a tight shut-off design, and fail safe closed, this may be accepted as one of the shut-offs.

In the case of liquid fuel operation, the shutdown of the fuel pump, if it is of a positive displacement design, may be considered as one means when backed up by a shut-off valve.

6.6.6.2 Vent valving

For gaseous fuels, appropriate vent valve(s) shall be used to reduce the risk of leakage into the gas turbine when the gas turbine is shut down.

6.6.6.3 Block and vent valving (gas turbine enclosures)

For installation where the gas turbine is located in an enclosure and gaseous fuels are used, appropriate block and vent valve(s) shall be used to reduce the risk of leakage into the enclosure when the gas turbine is shut down and ventilation fans are not running.

The requirement of 6.6.6.2 and 6.6.6.3 may be met using common equipment providing the primary block valve is located outside the enclosure.

6.7 Governing and limiting

6.7.1 Speed demand

The control system shall provide for both manual and automatic speed demand via an auto/manual selector. The speed range shall be the same for both and designed for bumpless transfer at any point after achieving self sustaining speed.

a) Constant speed (generator set applications)

Unless otherwise agreed between the purchaser and packager, no-load speed shall be adjustable, while running, within the range of 95 % to 105 % of the rated speed.

The speed changer, when remotely operated, shall be compatible with other speed changers on units running in parallel. The rate of load reduction from maximum site rated load to zero load shall be agreed between the purchaser and packager.

b) Variable speed (pump and compressor drive applications)

Where the pump or compressor is required to run at varying speeds to meet process demand, the control system shall be capable of accepting an input from the process controller to regulate turbine speed demand over an output shaft operating speed range as specified by the purchaser.

6.7.2 Speed control

6.7.2.1 Governor transient performance (single-shaft gas turbine generator set applications)

The governor shall limit the output speed at 105 % of the rated speed under all conditions of steady state. The governor systems for electric generator drive shall prevent the gas turbine from reaching the gas turbine trip speed after an instantaneous loss of maximum potential load. This assumes the gas turbine is operating under conditions within the limits of capability set by specified ambient conditions with design fuel pressure, temperature and fuel specific energy, and with the speed changer set and controlling at the rated speed.

6.7.2.2 Governor transient performance (twin-shaft gas turbine generator set applications)

The speed governor shall control the speed rise of the gas turbine and/or power turbine to a value which will permit a restart without need for an inspection of the gas turbine after shedding of maximum potential load (see 4.3.2).

The packager shall advise the purchaser of the maximum single step load that may be applied to the unit.

NOTE In the case of a free power turbine, this can be significantly less than 100 % load due to relative low inertia.

6.7.2.3 Dead band

The dead band at rated speed and at any power output up to and including the maximum power output shall not exceed 0,1 % of the rated speed.

6.7.3 Speed control stability

6.7.3.1 Capability

The speed governing system controlling the fuel rate for the gas turbine operating between zero and its maximum power, shall be capable of stable control of:

a) the speed of the gas turbine when the driven equipment is operated in isolation;

b) the fuel energy input to the gas turbine when the driven equipment is operating in parallel with other driven equipment.

6.7.3.2 System stability

The system shall be considered stable under the following conditions.

a) The driven equipment is operated and under sustained load demand, provided that the magnitude of the sustained oscillations of turbine speed produced by the speed governing system and fuel control system does not exceed a specified percentage of the rated speed (e.g. 0,12 % to 0,25 % of rated speed).

b) The magnitude of the sustained oscillations of energy input produced by the speed governing system and fuel control system does not produce a change in output exceeding ± 2 % of the rated output when the driven equipment is operated at rated speed in parallel with other driven equipment at constant speed and under sustained load.

6.7.4 Governor fuel valve

The fuel governor valve shall return to the closed or minimum position after any turbine shutdown condition (see 6.6.6.1).

6.7.5 Temperature limiting

The fuel control system shall include an override system to prevent exceeding the gas turbine rated firing temperature, or maximum gas generator speed, whichever is the more stringent limit.

6.7.6 Temperature limit stability

The temperature control and fuel control systems shall be capable of reliably controlling the temperatures of the gas turbine, when the gas turbine is operating on temperature control, at the set limit for the ambient conditions existing, when the driven equipment is operating in parallel with other driven equipment.

The temperature limiting or control system and fuel control system shall be considered stable when the driven equipment is operating in parallel with other driven equipment at constant speed, provided the magnitude of the sustained oscillation of turbine fuel energy input produced by the temperature limiting or control system and the fuel control system does not produce a change in output exceeding 6 % of the rated power output.

6.7.7 Other limits

Other control limits may be applied to the fuel control system as required by the packager. Limits may be applied, for example, to the LP or HP spools of a gas generator speed, power turbine speed, compressor delivery, temperature or pressure and power turbine exit temperature.

6.8 Emission control

6.8.1 General

The gas turbine control system shall incorporate all the functions to sequence, monitor and control the combustion process to meet the specified emissions levels using the specified emissions control technique (DLE, water or steam injection).

6.8.2 Emission monitoring

To satisfy the requirements of some national regulations, it may be necessary to provide emission monitoring systems. These may be based on measurements (continuous or intermittent) or on predictive calculations.

6.9 Overspeed protection

6.9.1 General

Each separate shaft shall be fitted with an overspeed protection system unless it can be shown that dangerous overspeeding is not aerodynamically possible.

The overspeed protection system, if electronic, shall employ a minimum of two independent sensors and circuits.

6.9.2 Overspeed settings

The main function of the overspeed protection system is to cause the fuel to be cut off near the burner(s) by means which are independent of the main governor valve(s).

The overspeed setting on a single-shaft generator set shall not be set above 110 % of the synchronous speed.

For twin-shaft (free power turbine) generating sets, the setting shall exceed the speed resulting from sudden loss of maximum potential power with a margin that avoids spurious trips but does not result in overstressing of the rotor(s).

For twin-shaft (free power turbine) mechanical drive sets, the setting shall be 5 % above the maximum continuous speed.

NOTE See 4.3.2.

6.9.3 Overspeed testing

Provision shall be made for testing of the overspeed trip. This may be manual or automatic operation, and may or may not require interruption of normal operation. The design shall be agreed between the purchaser and packager.

6.9.4 Additional protection

Gas turbines with separate power turbines or with heat-exchangers may require additional protection against overspeeding due to stored heat or large stored volumes of high pressure air, or both. Such protection may, for example, take the form of blow-off valves actuated by the main governor or overspeed trip, or both.

6.10 Protection systems

6.10.1 Flame monitoring

Direct or inferred (indirect) flame failure sensing shall be provided to monitor the presence of a combustion flame at the appropriate point during the start cycle and subsequently during normal operation. Should the burner(s) fail to light within a safe time period, or extinguish while running, the fuel supply shall be shut off.

Unless otherwise agreed between the purchaser and packager, the above shall be considered a firm requirement.

6.10.2 Bearing temperature

Gas turbines with main shaft bearings of the hydrodynamic type shall be equipped with temperature monitoring, which shall measure the bearing metal and/or return-oil temperatures, and actuate alarms and/or shutdowns should an abnormal temperature be detected.

6.10.3 Air intake icing

The packager shall install the necessary equipment to automatically control the action of any anti-icing system fitted to the gas turbine inlet air filtration system or intake bellmouth/first-stage blading (see 5.2.4.8).

6.10.4 Air intake pressure drop

The intake system shall be instrumented to provide indication of, and actuate alarm and/or trips on, high differential pressure between the ambient and intake flange, as agreed between the purchaser and packager.

6.10.5 Exhaust system back pressure

Where exhaust heat is to be utilized directly or recovered through the use of a waste heat recovery unit, the packager shall advise the maximum acceptable total system back pressure. To protect the gas turbine from excessive back pressure, fault monitoring shall be provided; either damper position or pressure monitoring may be used as agreed between the packager and purchaser. In all cases, the packager shall ensure that the method used is fast enough to prevent damage to the gas turbine or system components.

6.10.6 Vibration and axial position monitoring

6.10.6.1 General

A vibration and axial position monitoring system shall be supplied to warn the operator of changing vibration levels or shaft axial position, and to trip the machine if they change by an unacceptable value.

NOTE The purchaser may specify a system in accordance with API 670.

6.10.6.2 Aeroderivative gas turbines

Case-mounted seismic acceleration sensors (integrated to read velocity) are normally fitted. If the gas turbine is of a multispool design, it may be necessary to employ a monitoring system with tracking filters to isolate spool specific frequencies.

Shaft axial position monitoring is not fitted to this type of gas turbine.

6.10.6.3 Industrial gas turbines

Industrial gas turbines shall be fitted with shaft displacement vibration probes and axial position indicators. The fitment of casing mounted acceleration/velocity sensors may be considered, providing the packager can demonstrate satisfactory correlation between his measured acceptance levels and the absence of long-term damage (see 4.7.2.2). The final selection shall be as agreed between the purchaser and packager.

6.10.6.4 Gearboxes and driven units

The design and scope of supply for vibration monitoring on gearboxes and driven units shall be agreed between the purchaser and packager.

6.10.7 Fire detection and protection

Where the gas turbine is installed in an enclosure, suitable means shall be provided to monitor for the outbreak of fire within the enclosure. The fire suppression system and fire detection system shall be designed

a) to satisfy the national or regional requirements, and

b) in accordance with the mutual agreement between the purchaser and packager.

Rate-compensated thermal detection shall be considered the minimum level of detection. Additional levels of detection, such as optical (ultraviolet, infrared) or smoke, shall be specified by the purchaser.

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.

Halon or other ozone-depleting agents shall not be used for fire suppression.

The shutdown sequence shall be treated as in 6.4.5 unless otherwise agreed between the purchaser and packager. The shutdown sequence shall include the isolation of the ventilation fans, closing of fire dampers and the release of extinguishant to bring the fire under control.

The fire extinguishant shall be automatically released unless agreed otherwise between the purchaser and packager. In the case of automatic release, a delay may be necessary after an alarm to warn personnel of the situation. When CO_2 is used as a fire extinguishant, a warning and a delay is required.

A means shall be provided to safely isolate the release during maintenance and entry into the enclosure.

NOTE 1 Isolation for entry may not be required if non-toxic or non-asphyxiant extinguishant is used.

A manual actuation system shall be provided. A manual release station shall be located externally on each side of the enclosure.

Following a fire in the enclosure, the extinguishant shall be sustained at an adequate level for a period of time to allow cool down of the gas turbine to a level below self ignition of any flammable fluid that may be present in the enclosure. For large heavy-duty gas turbines this is not possible due to excessive need of extinguishant. In these cases, the sufficient extinguishant level shall be kept until the engine is at low speed (typically 15 min to 30 min). Other measures like supervision and foam application have to be prepared to prevent re-ignition.

NOTE 2 An agreement with the local fire marshal or authorities is recommended.

NOTE 3 The purchaser may specify any special design considerations to be included in the suppression system, including the specific fire suppression medium.

6.10.8 Gas detection

A gas detection system shall be provided where

a) the gas turbine is gas fuelled, and/or

b) when the gas turbine is operating in a hazardous area.

NOTE Additional fire explosion risks relating to the driven unit should be considered and properly addressed.

Suitable means shall be provided to monitor for gas leaks entering or within the enclosure, and for alarm and shutdown at appropriate concentrations. The shutdown shall be treated as in 6.4.4.

In an environment where gas can occur in the atmosphere (gas plants, LPG plants, etc.) a gas detector should be placed at the air intake of the gas turbine.

The philosophy of initiation and warning and shutdown levels for the gas detector(s) shall either

a) satisfy local or national regulations, or

b) be agreed between the purchaser and packager.

Gas detectors shall monitor for gas leakage and shall be arranged so that their efficiency is not impaired by adverse air flow, i.e. by a high air demand for heat removal. When the gas alarm system detects a specified percentage [typically in the range of 5 % to 10 % at the vent outlet of the lower explosive limit (LEL)], it shall give an alarm. When the gas alarm system detects a specified higher percentage (typically in the range of 10 % to 25 % of the LEL at the vent outlet), the gas turbine should trip, as described in 6.4.5.

6.10.9 Lubrication

The control system shall provide for full automatic control, monitoring and protection as specified by the packager. This shall cover the following conditions:

a) prestart priming, to establish minimum lubricating oil pressure;

b) starting, changeover of pumps as necessary;

c) running, continuous monitoring of supply pressures and temperatures;

d) shutdown, including the starting of any emergency oil pumps;

e) any post-shutdown cool-down period.

The gas turbine supply oil temperature or bearing differential temperature shall be continuously monitored for operation within safe limits as specified by the packager.

6.10.10 Exhaust temperature loading

An array of temperature detectors shall be provided to monitor the temperature of the gas turbine exhaust or the temperature before a separate power turbine. Sufficient detectors shall be provided to detect asymmetric failure or deterioration of the combustion system or turbine nozzles. An alarm shall be initiated if an abnormal temperature deviation is detected. When higher deviation is specified, deloading, shutdown or trip shall occur.

Appropriate action should be taken in accordance with 6.4.4.

6.11 Compressor wash system

A compressor on-line and/or off-line wash system with manual or automatic control may be supplied as recommended by the packager or specified by the purchaser (see 5.2.4.7). In the case of automatic control, the control system shall provide the automatic sequence of the cycle(s) and all the necessary safety interlocks and overrides to prevent improper use.

6.12 Control system considerations

6.12.1 Architecture (digital systems)

6.12.1.1 Simplex systems

Where the control system reliability figures can be shown to be better than the gas turbine and in line with the purchaser's requirements, a simplex control and instrumentation system shall be considered acceptable. A simplex system shall employ adequate safeguards (“watchdogs”) to monitor for a processor hardware or software failure and take necessary executive action to force the outputs to a safe state or watchdog trip.

6.12.1.2 Fault tolerant systems

Where it is vitally important that unscheduled shutdowns are kept to a minimum as specified by the purchaser, the control systems, power supplies, engine instruments and end devices may, as agreed between the purchaser and packager, be provided with up to triplicated hardware providing two out of three voting and on-line change-out of the offending control component or instrument where practical.

6.12.2 Man machine interfacing (MMI)

When specified by the purchaser, the control system shall provide the operator with a computer/monitor based display system, providing plant mimics, displays, performance information, trend information, and alarm and shutdown logs.

6.12.3 Alarm and annunciation

6.12.3.1 Fault shutdown

The control system shall employ a "first up lock out" shutdown sequence, the output of which may be displayed on a conventional lamp box style annunciator or monitor system, as agreed between the purchaser and packager. The fault output annunciation shall not clear itself until manually reset.

6.12.3.2 Fault warning

The control system shall employ a warning annunciator to alert the operator of impending failure. The output shall clearly indicate the sequence in which the faults occur. The fault output annunciation shall not clear itself until manually accepted and the fault level has returned to normal. The alarm annunciator may be integrated with the shutdown annunciator.

6.12.3.3 Status information

The control system shall clearly indicate to the operator the status of the gas turbine during start-up, running and shutdown, and shall advise the operator when a command input is required. Status information may be integrated into the fault warning and shutdown display.

6.12.3.4 Audible alarm

The control system shall be provided with audible panel alarms and outputs to drive a remote klaxon when specified by the purchaser.

6.12.4 Recording of hours run and starts

The control system shall be provided with a means of recording the number of hours run and the number of starts made. The hours run may be segregated by the fuel used and in the form of normal and peak power as specified by the packager.

6.12.5 Indication of shaft speed and hot gas path temperature

The control system shall be provided with a permanently installed means of displaying turbine shaft speed(s) and hot gas path temperature(s) downstream of the combustor.

The display may be in the form of analog or digital meters, or may be built into a monitor display system, as agreed between the purchaser and packager.

6.12.6 Performance monitoring

When specified by the purchaser, the control system shall provide the operator with adequate data to determine when compressor fouling has reached a level which requires that on-line or off-line washing be performed.

6.12.7 Trouble-shooting aids

6.12.7.1 Controls and instrumentation

Where specified by the purchaser, the control system shall be supplied with fault diagnostic capability to help identify instrument and control component faults.

6.12.7.2 Gas turbine

Where specified by the purchaser, the control system shall be supplied with fault diagnostic capability to help identify transient faults in the operation of the gas turbine.

6.12.8 Electromagnetic compatibility

The control panel shall be so designed and constructed that external electromagnetic radiation does not interfere with its operation and that any emissions are limited to the extent necessary for its operation.

Where national regulations exist, the packager shall comply with these regulations.

6.12.9 Spare termination

The packager shall allow for 10 % spare termination capacity, and adequate space for additional I/O circuit boards. This spare capacity may be used during the engineering of the project. The minimum amount of spare capacity remaining at the point of delivery shall be agreed between the purchaser and packager.

6.12.10 Control system power supplies

Where the purchaser desires to supply his own uninterruptible power supply systems, the packager shall advise on the voltage range and tolerance, and both static loading and inrush current conditions.

6.12.11 Internal control panel wiring

Internal control panel wiring shall be to the packager's standard, providing this complies with national standards as specified by the purchaser.

6.13 Control panel installation

Where the installation is to be carried out by the purchaser, the packager shall advise all special requirements with respect to earthing and cabling to maintain electromagnetic compatibility.

The purchaser shall specify any special installation requirements with regard to dust, humidity, water, temperature and isolation from any source of vibration.

The purchaser shall specify the area classification for the location of the control panel and operator stations.

The purchaser shall specify the location of the control panel with respect to the gas turbine, and shall also specify any additional operator stations (e.g. local to the machine, central control room). The purchaser shall also state the degree of control and monitoring required at each position.

The packager shall advise the purchaser of any cable segregation requirements and the maximum cable length that the control panel may be mounted away from the gas turbine.

6.14 Operability and diagnostics

The gas turbine shall be adequately instrumented for ease of operation, maintenance and diagnosing of fault conditions as agreed between the purchaser and packager.

If specified by the purchaser, the packager shall offer a support service employing the use of telecommunications (modem interfaces) to aid in the identification of faults on gas turbines and their control systems, which require specialist diagnostic knowledge.

6.15 Data communications

The purchaser shall specify if any serial communication facilities are required. The purchaser and packager shall agree about the protocols to be used, the scope of data and control facilities over the link, data-transfer rates and time-tagging requirements.

6.16 Special applications

6.16.1 Dynamic positioning and marine propulsion

6.16.1.1 Emergency and safety critical shutdown (marine propulsion)

Where gas turbines are being used for marine propulsion duty, emergency and safety critical shutdowns shall be kept to a minimum in line with the Classification Society's Rules and Regulatory Authority's Requirements.

6.16.1.2 Marine survey authority requirements

The packager shall meet the Classification Society's Rules and Regulatory Authority's Requirements with respect to certification for environment, vibration, and electromagnetic compatibility of the control panel.

6.16.2 Emergency power gas turbine generator sets

Where gas turbines are being used for emergency applications, defined as maintaining power under life-threatening circumstances due to earthquake, fire or flood, the controls and instrumentation requirements specified in 6.1.2 e) to 6.15, excluding 6.9, may be relaxed and the following shall take preference.

a) National regulations

Where national regulations exist for the safe reliable operation of an emergency plant, the gas turbine control system shall be designed to meet these regulations.

b) Quick starting/loading

The requirement for a rapid, reliable start-up is of prime importance on emergency generator sets. The start sequence shall be initiated automatically from the detection of an emergency condition such as power failure in earthquake and fire-fighting situations and shall be designed to minimize the time required to start and load the set from cold.

c) System protection considerations

The requirement for uninterrupted operation is of prime importance on emergency generator sets. The number of shutdown protection circuits shall be kept to a minimum and shall be designed to maximize availability during emergency conditions even though the gas turbine may be damaged by continued operation.

d) Fault alarms/shutdowns

To maintain uninterrupted operation, it is not unusual to only allow manual shutdown following a critical alarm annunciation; only extremely critical faults such as overspeed are allowed to automatically shut down the set.

Annex A
(informative)

Data sheets

Table A.1 — Data sheets — General

ISO 3977 DATA SHEETS

JOB No. ________ ITEM ________
P.O. No. ________ DATE ________
INQUIRY No. ________ BY ________
REVISION ________ DATE ________

GENERAL

APPLICABLE TO: O PROPOSAL O PURCHASE O AS BUILT
O FOR ________ O UNIT ________
O SITE ________ O SERIAL No. ________
O SERVICE ________ O NO. REQUIRED ________
O GEOGRAPHIC LOCATION ________ O SEISMIC REQUIREMENTS ________
O PACKAGER ________ MODEL ________ SHOP ORDER ________
DRIVER MANUFACTURER ________ MODEL ________ SERIAL No. ________
DRIVEN EQUIPMENT TYPE ________ MANUFACTURER ____ MODEL ____ SERIAL No. ____
ADITTIONAL DRIVEN EQUIPMENT TYPE ________ MANUFACTURER ____ MODEL ____ SERIAL No. ____
TYPE ________ MANUFACTURER ____ MODEL ____ SERIAL No. ____
O OUTPUT REQUIRED ________
O OPERATING SPEED RANGE REQUIRED ________
CYCLE: O REGEN O SIMPLE O EXHAUST HEAT RECOVERY TYPE OF GAS TURBINE: ✧ SINGLE SHAFT ✧ MULTI SHAFT
DUTY: O CONTINUOUS O INTERMITTENT O STANDBY OPERATION: O ATTENDED O UNATTENDED
NOTE: INFORMATION TO BE COMPLETED O BY PURCHASER BY PACKAGER
✧ BY PACKAGER IF NOT BY PURCHASER

PERFORMANCE

GAS TURBINE; INCLUDING ALL ENGINE DRIVEN PARASITIC LOSSES

O SITE RATE NORMAL DUTY
O SITE MAX TEMP
O SITE MIN TEMP

O DRY BULB TEMP., °C ________
O RELATIVE HUMIDITY, % ________
O BAROMETER, kPa ________
OUTPUT, kW (HP) (1) ________
HEAT RATE, LHV, kJ/kW-H ________
✧ OUTPUT SHAFT SPEED, r/min ________
INLET AIR FLOW, kg/s ________
INLET AIR SYSTEM, Δp, kPa ________
FIRING TEMP., °C ________
EXHAUST FLOW, kg/s (1) ________
EXHAUST SYSTEM, Δp, kPa ________
EXHAUST TEMP., °C ________
(1) INCLUDING EFFECTS FOR O STEAM O WATER INJECTION
O DRIVEN EQUIPMENT, SEE SEPARATE DATA SHEETS
✧ EMISSION CONTROL ✧ AUGMENTATION
STEAM FLOW, kg/h ________
WATER FLOW, l/s ________

LOCATION

O GEOGRAPHIC LOCATION ________
O SEISMIC REQUIREMENTS ________

O INDOOR O OUTDOOR
O HEATED O UNDER ROOF
O UNHEATED O PARTIAL SIDES

O ELECTRICAL AREA CLASSIFICATION

	NON-HAZARDOUS	CL/GRP/DIV
GAS TURBINE AREA	O	/ /
GAS TURBINE ENCLOSURE	O	/ /
CONTROL PANEL	O	/ /

O MARINIZATION REQUIRED WINTERIZATION REQUIRED
O TROPICALIZATION REQUIRED
USUAL CONDITIONS: O DUST O FUMES
O OTHERS: ________

PACKAGE SOUND LEVEL (4.3.9)
O SOUND POWER LEVEL ____ dBA
O SOUND PRESSURE LEVEL ____ dBA at 1 m

Table A.1 *(continued)*

ISO 3977 DATA SHEETS	JOB No. ________________ P.O. No. ________________ INQUIRY No. ____________ REVISION ______________	ITEM ___________________ DATE __________________ BY _____________________ DATE __________________

GENERAL (continued)	
SHIPMENT REQUIREMENTS	**EMISSIONS (4.3.8)**
O WEIGHT/DIMENSIONAL LIMITATIONS ________________ O SPECIAL CONSIDERATIONS ______________________ O DOMESTIC O EXPORT O EXPT BOXING REQUIRED O OUTDOOR STORAGE MORE THAN 6 MONTH O OCEAN TRANSPORT PREPERATION TYPE ___________ O LIFT SLINGS/SPREADERS BY PACKAGER ___________	O NO_x REQUIREMENTS ______________________________ NO_x EMITTED ____________________________________ EMISSIONS REDUCTION METHOD (IF REQUIRED) ✧ WATER INJECTION ✧ SCR ✧ STEAM ✧ DRY COMBUSTOR ✧ OTHER ____ O SO_x REQUIIREMENTS ______________________________ O SULFUR CONTENT OF FUEL ________________________ SO_x EMITTED (BASED ON STATED SULFUR CONTENT) ____ O CO REQUIREMENTS _________________________________ CO EMITTED ______________________________________ O PARTICULATE REQUIREMENTS ______________________ PARTICULATE EMITTED ___________________________ O UNBURNED HC REQUIREMENTS ____________________ O APPLICABLE EMISSIONREGULATION _________________
PAINTING	OTHER ____ ____
O MANUFACTURER´S STD. _________________________ O OTHER ____ ____	

Table A.2 — Data sheets — Utilities and connections

ISO 3977 DATA SHEETS	JOB No. ____	ITEM ____
	P.O. No. ____	DATE ____
	INQUIRY No. ____	BY ____
	REVISION ____	DATE ____

UTILITIES AND CONNECTIONS

O UTILITY CONDITIONS

STEAM	AUX DRIVERS:		HEATING:	
INLET MIN.	____ kPa	____ °C	____ kPa	____ °C
NORM	____ kPa	____ °C	____ kPa	____ °C
MAX.	____ kPa	____ °C	____ kPa	____ °C
EXHAUST MIN.	____ kPa	____ °C	____ kPa	____ °C
NORM	____ kPa	____ °C	____ kPa	____ °C
INLET MIN.	____ kPa	____ °C	____ kPa	____ °C
MAX.	____ kPa	____ °C	____ kPa	____ °C

	STARTING:		INJECTION:	
INLET MIN.	____ kPa	____ °C	____ kPa	____ °C
NORM	____ kPa	____ °C	____ kPa	____ °C
MAX.	____ kPa	____ °C	____ kPa	____ °C
EXHAUST MIN.	____ kPa	____ °C	____ kPa	____ °C
NORM	____ kPa	____ °C	____ kPa	____ °C
MAX.	kPa	°C	kPa	°C

ELECTRICITY (4.6.4):

	MOTORS	HEATING	CONTROL	SHUTDOWN
VOLTAGE	____	____	____	____
HERTZ	____	____	____	____
PHASE	____	____	____	____

COOLING WATER:

TEMP: INLET	____ °C	MAX. RETURN	____ °C
PRESS NORM	____ kPa	DESIGN	____ °C
MIN. RETURN	____ kPa	MAX. ALLOW ΔP	____ kPa
TEMP: INLET	____ °C	MAX. RETURN	____ °C

DESIGN ____

WATER SOURCE ____

INSTRUMENT AIR PRESSURE; kPa:

MAX. NORMAL MIN.

TOTAL UTILITY CONSUMPTION:

COOLING WATER	____	kg/min
STEAM LEVEL	___ kPa ___ kPa ___	kPa
STEAM, NORMAL	___ ___ ___	
STEAM, MAX.	___ ___ ___	
INSTRUMENT AIR	____	m^3/min
MOTORS (AUXILIARIES)	____	kW
BATTERY CHARGES	____	kW
HEATERS	____	kW
PURGE	____	m^3/min

TURBINE AIR EXTRACTION REQUIRED:

O kg/min ____ @

O MAXIMUM PRESSURE AVAILABLE @

kPa ____ @ ____

O DISCHARGE TEMP ____ °C

O COMPRESSOR STAGE EXTRACTED ____

NOTES: ____

PURCHASE CONNECTIONS

CONNECTION	O SIZE	O FACING & RATING	O POSITION	✧ FLANGED OR STUDDED	O MATING FLG & GASKET BY VENDOR	O GAS VELOCITY m/s
INLET AIR						
EXHAUST GAS						
GAS FUEL SUPPLY						
STARTING AIR SUPPLY						
NO_x SUPPRESSION WATER						
COOLING WATER						
NO_x SUPPRESSION STEAM						
STARTING STEAM SUPPLY						

NOTES ____

Table A.3 — Data sheets — Accessory systems supplied by packager

ISO 3977 DATA SHEETS	JOB No. ________ ITEM ________ P.O. No. ________ DATE ________ INQUIRY No. ________ BY ________ REVISION ________ DATE ________
ACCESSORY SYSTEMS SUPPLIED BY PACKAGER	
STARTING SYSTEM (5.2.1)	**MOUNTING SYSTEMS (5.2.2)**
TYPE O MOTOR O TURBINE O GAS EXPANDER O IC ENGINE O HYDRAULIC O GAS TURBINE ✧ STARTER IS CLUTCHED STARTER RATING ________ kW SHAFT TURNING DEVICE REQUIRED MOTOR TYPE ________ RATING ________ kW MFR ________ MODEL ________ kW STEAM TURBINE MFR ________ MODEL kW ________ MAX. STEAM FLOW ________ kg/h TOTAL/START ________ kg O GAS EXPANDER APPLICABLE SPECIFICATION MFR ________ MODEL kW________ MAX. GAS FLOW________kg/h TOTAL/START ________ kg O GAS FOR EXPANSION TURBINE MIN. MAX. NORMAL INLET PRESSURE, kPa ________ EXHAUST PRESS, kPa ________ GAS TEMP., °C INLET ________ GAS TEMP., °C EXHAUST ________ MOLECULAR MASS ________	O TYPE OF FOUNDATION (5.2.2.1)________ O SUITABLE FOR EPOXY GROUT (5.2.2.2) ________ O BASEPLATE (5.2.2.3), SINGLE________MULTIPLE________ O LEVELLING PADS/ARGETS ________ O COLUMN MOUNTING O THERMAL ISOLATION O EXTERNAL EXCITING FORCES________ ________ O SUPPORT SYSTEM VALUE ________ ________ O DECKING/GRATING, TYPE (5.2.2.3) ________ ________ **ENCLOSURE AND FIRE PROTECTION (5.2.3)** O ENCLOSURE TYPE________ O FIRE SUPPRESSION BY CO_2 O FIRE SUPPRESSION BY WATER MIST O SPECIAL DESIGN CONSIDERATIONS ________ O VENTILATION FAN REDUNDANCY (5.2.3.4) O POSITIVE PRESSURE VENTILATION (5.2.3.4) O EXTERNAL DUCTING BY PURCHASER (5.2.3.4) D.C. FAN REQUIRED ________ kW
SPEED CONTROL O GOVERNOR O PRESSURE REGULATOR	OTHER ________

Table A.3 *(continued)*

ISO 3977 DATA SHEETS	JOB No. ________________ P.O. No. ________________ INQUIRY No. ____________ REVISION ______________	ITEM __________________ DATE __________________ BY ____________________ DATE __________________

ACCESSORY SYSTEMS SUPPLIED BY PACKAGER (continued)	
YES NO INLET CONTROL VALVE FURNISHED ___________________ STAINLESS-STEEL PIPING MANIFOLD ___________________ CARBON STEEL FLANGES ___________________ Y-STRAINER W/BREAKOUT FLANGES ___________________ LOW SPEED CAPABILITY (FOR COMPRESSOR CLEANING) ____________________ RELIEF VALVE PRESSURE SET POINT ________________ kPa CASING MATERIAL ____________________________________ SEAL TYPE ____ IC ENGINE TYPE O SPARK IGNITED O DIESEL APPLICABLE SPEC. MFR MODEL kW r/min GAS TURBINE APPLICABLE SPEC ____________________________________ MFR _____________________ MODEL ___________________ kW ______________________ RPM _____________________	**COUPLINGS AND GUARDS (4.5.1)** MANUFACTURER TYPE MODEL GUARD SUPPLIED BY MAX. O.D ______________________________________ m HUB MASS _____________________________________ kg SPACER LENGTH ________________________________ m SPACER MASS __________________________________ kg O IDLING ADAPTER REQUIRED LUBRICATION REQUIREMENTS: O NON-LUBE O GREASE O CONT.OIL LUBE QUANTITY PER HUB ___________________________ kg or l/s NOTES: ____
NOTES____ ____	

AIR INLET SYSTEM (5.2.4)	**EXHAUST SYSTEM (5.2.5)**
AIR FILTER MFR ______________MODEL ___________ O TYPE O AIR PATH COMPONENT MATERIAL (5.2.4.1) LOCATION: O GROUND LEVEL O ELEVATED O PROVISIONS FOR EXTRA STAGES O DESIGN WIND VELOCITY ____________________km/h O NORMAL DUST LOADING ____________________ g/m^3 FILTRATION EFFICIENCY (5.2.4.2) _________________ ____ MAINTENANCE INTERVAL (5.2.4.2) ________ MONTHS CLEANING FREQUENCY (5.2.4.2)_____________ DAYS AIR FILTER Δp, kPa, @ 100% RATED AIR FLOW (5.2.4.2) ________ CLEAN,_________ ALARM _________SHUTDOWN	O COMPLETE EXHAUST SYSTEM REQUIRED EXPANSION JOINT MFR __________ TYPE ____________ SILENCER MFR ______________ Δp _______________ kPa DUCTING GAUGE/MATERIAL ________________________ O PERSONNEL PROTECTION INSULATION ______________ DISCHARGE FLANGE ORIENTATION: O VERTICAL O HORIZONTAL O EXTERNAL Δp BY OTHERS _________________ kPa, MAX. O HEAT RECOVERY DEVICE MFR TYPE Δp ______ kPa STEAM GEN: PRESS ___________ kPa, TEMP _________°C RATE _____________ kg/h COMPLETE EXHAUST SYSTEM RATED Δp __________ kPa

Table A.3 *(continued)*

ACCESSORY SYSTEMS SUPPLIED BY PACKAGER (continued)	
Δp INDICATOR MFR___________ MODEL ___________	**OIL SYSTEMS (5.2.7)**
O SILENCER, TYPE (5.2.4.3)	LUBE OIL VISCOSITY ___________ ISO GRADE ________
SILENCER, MFR _____________ MODEL ___________	COMMON TO GAS GENERATOR/SINGLE-SHAFT TURBINE
SILENCER Δp, kPa @ 110 % RATED AIR FLOW	FREE POWER TURBINE LOAD GEAR
DUCTING GAUGE/ATERIAL (5.2.4.4) ________________	DRIVEN EQUIPMENT AUXILIARIES
EXP JOINT MFR___________ TYPE ________________	O SYSTEM FOR SYNTHETIC LUBRICANT
OFF-LINE WASH SYSTEM, TYPE (5.2.4.7) ___________	LUBE SPECIFICATION
O ON-LINE WASH SYSTEM, TYPE (5.2.4.7) ___________	COMMON TO GAS GENERATOR
O EVAPORATIVE COOLER (5.2.4.7) EFFICIENCY ___	POWER TURBINE LOAD GEAR
EVAPORATIVE COOLER MFR ________MODEL ______	DRIVEN EQUIPMENT AUXILIARIES
ABSORBTION CHILLER MFR _________MODEL ______	✧ OIL COOLER TYPE ___________ AIR ___________WATER
EVAPORATIVE COOLER Δp, kPa @ 110 % RATED AIR FLOW	
O ANTI-ICING, TYPE (5.2.4.8)________________________	
COMPLETE AIR INLET SYSTEM Δp, kPa @ 110 % RATED AIR FLOW (5.2.4.1) ______________________________	
OTHER ____	
____	
____	
NOTES ____	
____	
____	

Table A.4 — Data Sheets — Fuel Systems

ISO 3977 DATA SHEETS

JOB No. ______________ ITEM ________________
P.O. No. ______________ DATE ________________
INQUIRY No. __________ BY __________________
REVISION _____________ DATE ________________

FUEL SYSTEM (5.2.8)

TYPE OF FUEL SYSTEM: O GAS O LIQUID O DUAL (GAS/GAS) O DUAL (GAS/LIQUID) O DUAL (LIQUID/LIQUID) O OTHER

DUAL FUEL SYSTEM REQUIREMENTS (5.2.8.4):
O SHUTDOWN TO TRANSFER
O (MANUAL) (AUTO) TRANSFER UNDER LOAD
O TRANSFER AFTER STARTUP
O TRANSFER AT (RATED) (_____T RATED) LOAD
O MAX TIME ALLOWED TO COMPLETE TRANSFER AT _____ s

GAS FUEL (5.2.8.2)

O FUEL ANALYSIS – MOL %

COMPOSITION	MW	MIN.	MAX.	AVERAGE
AIR	29			
OXYGEN	32			
NITROGEN	28			
WATER VAPOUR	18			
CARBON MONOXIDE	28			
CARBON DIOXIDE	44			
HYDROGEN	2			
HYDROGEN SULFIDE	34			
METHANE	16			
ETHYLENE	26			
ETHANE	30			
PROPYLENE	42			
PROPANE	44			
n-BUTANE	58			
i-BUTANE	58			
n-PENTANE	72			
i-PENTANE	72			
HEXANE	86			
HEPTANE	106			
OCTANE PLUS	114			
TOTAL				
AVG. MOL MASS.				

CORROSIVE AGENTS, mg/kg (NATURE AND CONCENTRATION)
CONTAMINANTS, mg/kg (NATURE AND CONCENTRATION)
LOW HEATING VALUE, mJ/kg

FUEL PRESS. MAX./MIN., kPa	/	/	/
FUEL TEMP MAX./MIN., °C	/	/	/
FUEL PRESS. REQUIRED	/	/	/
MAX./MIN., kPa	/	/	/

O FUEL GAS COMPRESSION SYSTEM BY PACKAGER
O FUEL GAS COMPRESSION SYSTEM BY PURCHASER
O FUEL GAS PREHEATING SYSTEM BY PACKAGER
O FUEL GAS PREHEATING SYSTEM BY PURCHASER

WATER/STEAM INJECTION (5.2.8.5)

O WATER PRESSURE REQUIRED ____________ kPa
O STEAM PRESSURE REQUIRED ____________ kPa
O STEAM TEMPERATURE REQUIRED __________ °C
O WATER/STEAM QUALITY ________________

LIQUID FUEL (5.2.8.3)

O FUEL GRADE (5.2.8.3)
LIQUID FUEL TREATMENT REQUIRED O YES O NO
TREATMENT SYSTEM SUPPL. BY O VENDOR O OTHER
HEATER REQUIRED O YES O NO
O LIQUID FUEL PRESS REQUIRED, MAX./MIN., kPa /

FUEL ANALYSIS DATA

PROPERTY	METHOD	MEASURED VALUE
VISCOSITY AT 40/100 °C, mm^2/s		
DISTILLATION DATA:		
90 % (*m/m*) RECORDED AT °C		
SULFUR CONTENT % (*m/m*)		
LOW HEATING VALUE, mJ/kg		
CARBON RESIDUE (ON 10 % BOTTOMS), % (*m/m*)		
COPPER CORROSION		
3 H AT 100 °C MAX.		
LOW TEMP. OPERABILITY, °C		
AROMATIC CONTENT		
ASH CONTENT, % (*m/m*)		
DENSITY AT 15 °C, kg/m^3		
FLASH POINT, °C		
POUR POINT, °C		
WATER, % (*V/V*)		
SEDIMENT, % (*m/m*)		
FILTERABLE DIRT, mg/100 ml		
TRACE METALS		
SODIUM, mg/kg		
POTASSIUM, mg/kg		
VANADIUM, mg/kg		
CALCIUM, mg/kg		
LEAD, mg/kg		
OTHER METALS		
OTHER		

FUEL SYSTEM PIPING (5.2.8.1)

O BY PASS CONTROL VALVE
O Y STRAINER ____________ MESH
O FINAL FILTER ____________ MICRON
O ISOLATION BLOCK VALVES ____________
O BLOW DOWN OR VENT VALVE O OTHER ____________

NOTES: ____

Table A.5 — Data Sheets — Generator

Basic Details	
Manufacturer	....
Model	....
Type	....
Basic Data	
Rated Output	............kW
Power Factor	....
No. of Poles	....
Phases	....
Voltage	 V
Frequency	.... Hz
Synchronous Speed	............r/min
Enclosure Type	....
Total Temperature	.... F/B
Overspeed	............r/min
Maximum Stator Temperature	............°C
Maximum Field Temperature	............°C
Stator Isolation System	....
Cooling System	....
Performance Data	100 % 75 % 50 % 25 %
Output Power	............kW
Stator Current	.... A
Efficiency	.... %
Power Factor	....
Reactance	
Synchronous Reactance	....
Transient Reactance	....
Sub-transient Reactance	....
Negative Sequence Reactance	....
Zero Sequence Reactance	....
Armature Winding	
Transient Field Time Constant	....
Sub-transient Time Constant	....
Armature DC Time Constant	....
Short Circuit Ratio	....
Mechanical Data	
Base Torque	.... N·m
Full Load Torque	.... N·m
Rotor Inertia	............kg·m^2
Dimensions	
Length	............mm
Width	............mm
Height	............mm
Net Height	.... Dry .... Operating............kg
Heaviest Component	............kg
Utility Requirements	
AC	.... Phase(s)............ V............ Hz
Water/Glycol	.... litres/s
Bearing Oil Flow Rate (each)	.... litres/s
Oil Viscosity Grade	....

Table A.6 — Data Sheets — Controls and Instrumentation

ISO 3977 DATA SHEETS	JOB No. ______ P.O. No. ______ INQUIRY No. ______ REVISION ______	ITEM ______ DATE ______ BY ______ DATE ______	

DATA SHEET

INFORMATION TO BE COMPLETED BY

O PURCHASER O PACKAGER ✧ PACKAGER IF NOT BY PURCHASER

UNIT CONTROL PANEL POWER SUPPLY (6.12.10)

O UNINTERRUPTABLE POWER SUPPLY (UPS) BY PURCHASER

O UNINTERRUPTABLE POWER SUPPLY (UPS) BY PACKAGER

✧ ______ AC ______ DC (SPECIFY VOLTAGE)

O TIME FOR UPS TO BE MAINTAINED ______ hours

INSTALLATION (6.13)

UNIT CONTROL PANEL LOCATION

O CABLE LENGTH FROM TURBINE BASE ______ (metres) O CABLE SEGREGATION REQUIRED (SPECIFY)

______

HAZARDOUS AREA CLASSIFICATION ______

O SAFE ENVIRONMENT O ZONE I O ZONE II

O DUSTY O AMBIENT TEMPERATURE RANGE ______ °C to ______ °C

O HUMIDITY O ANTI-VIBRATION MOUNTS REQUIRED

SYSTEM ARCHITECTURE (DIGITAL SYSTEMS) (6.12.1)

✧ SIMPLEX ✧ FAULT TOLERANT DESIGN ✧ OTHER (SPECIFY)

STARTING/LOADING (6.2, 6.3)

O BLACK START CAPABILITY

O MANUAL LOADING O AUTOMATIC LOADING

STARTING INITIATION

O AUTOMATIC (CLOSING CONTACT)

O LOCAL AT UNIT PANEL (MANUAL)

O OTHER LOCATIONS (SPECIFY) ______

______

FIRE DETECTION MONITORING (6.4.4, 6.10.7)

PACKAGE INSTRUMENTS

O SUPPLIED BY PURCHASER

O SUPPLIED BY PACKAGER

✧ SPECIFY NUMBER & TYPE No. ______ TYPE ______

MONITORS

O SUPPLIED BY PURCHASER

O SUPPLIED BY PACKAGER

Table A.6 *(continued)*

GAS DETECTION MONITORING (6.4.4 and if applicable 6.10.8)
PACKAGE INSTRUMENTS
O SUPPLIED BY PURCHASER
O SUPPLIED BY PACKAGER
✧ SPECIFY NUMBER & TYPE No. ____________ TYPE ____________
MONITORS
O SUPPLIED BY PURCHASER
O SUPPLIED BY PACKAGER
VENTILATION and PURGING (6.5)
O NATIONAL REGULATION APPLICABLE
(SPECIFY) ____________
FUEL CONTROL (6.6)
O GAS FUEL O LIQUID FUEL O DUAL FUEL (GAS/GAS) O DUAL FUEL (GAS/LIQUID) O DUAL FUEL (LIQUID/LIQUID)
DUAL FUEL (OTHER) SPECIFY ____________
BI-FUEL OPERATION – METHOD OF CONTROL, e.g. MANUAL, GAS SUPPLY PRESSURE (SPECIFY) ____________
O LOW NET SPECIFIC ENERGY GAS FUEL OPERATION
O STARTING GAS FUEL/LIQUID FUEL AVAILABLE
O VARIABLE NET SPECIFIC ENERGY GAS FUEL OPERATION
SPECIFY NET SPECIFIC ENERGY RANGE ____________
SPECIFY WOBBE INDEX RANGE ____________
SPEED CONTROL MECHANICAL DRIVE APPLICATIONS (6.7.1.2)
O PROCESS CONTROL SIGNAL INPUT ____________
O GOVERNOR SPEED RANGE REQUIRED (SPECIFY) ____________
ALARM/SHUTDOWN ANNUNCIATION (6.12.3)
✧ MONITOR BASED (SEE 6.12.3)
✧ ALARM LAMP BOX ANNUNCIATOR
✧ SHUTDOWN LAMP BOX ANNUNCIATOR
TURBINE SPEED & TEMPERATURE INDICATION (6.12.5)
✧ MONITOR BASED
✧ ANALOG METERS
✧ DIGITAL METERS

Table A.6 *(continued)*

VIBRATION MONITORING (6.10.6)			
GAS TURBINE			
O	SEISMIC TYPE	O	SHAFT DISPLACEMENT
GEAR BOX		DRIVEN UNIT	
✧	SEISMIC (velocity or acceleration)	✧	SEISMIC (velocity or acceleration)
✧	SHAFT DISPLACEMENT	✧	SHAFT DISPLACEMENT
PERFORMANCE MONITORING (6.12.6)			
O	PERFORMANCE INSTRUMENTS AND MONITORING REQUIRED		
EMISSIONS MONITORING (6.8)			
O	EMISSIONS INSTRUMENTS AND MONITORING REQUIRED		
MAN MACHINE INTERFACE (MMI) (6.12.2)			
TYPE			
O	MONOCHROME MONITOR		
O	COLOUR MONITOR (SPECIFY SIZE) ____________		
LOCATION			
O	DESKTOP		
O	PANEL MOUNTED		
O	BOTH		
O	COLOUR MONITOR (SPECIFY SIZE)		
FEATURE REQUIRED			
O	UNIT MIMICS		
O	TREND DISPLAYS (GENERAL)		
O	TREND DISPLAYS (PERFORMANCE) O TREND DISPLAYS (VIBRATION) O TREND DISPLAYS (EMISSIONS)		
O	ALARM ANNUNCIATOR		
O	OTHERS (SPECIFY) ____________		
ELECTROMAGNETIC COMPATIBILITY (6.12.8)			
O	SPECIFY ANY LOCAL, NATIONAL OR INTERNATIONAL STANDARD APPLICABLE		
____________			
____________			
____________			
DATA COMMUNICATION (6.15)			
O	REQUIRED		
O	TYPE e.g. SERIAL RS232 (MODBUS RTU PROTOCOL) (SPECIFY) ____________		
FEATURES			
O	DATA ONLY		
O	DATA PLUS CONTROL		

Table A.6 *(continued)*

UNIT CONTROL PANEL TESTING

O WITNESS HARDWARE FACTORY ACCEPTANCE TEST O WITNESS FUNCTIONAL FACTORY ACCEPTANCE TEST

CONTROL INSTRUMENT LIST

⊗ = Indicates that the specification defines a mandatory requirement

O = Optional – this must be completed by the purchaser if required

(1) refers to adjacent to the gas turbine (2) refers to control panel location

DESCRIPTION		MANDATORY REQUIREMENT	INDICATOR		CONTROL	
			(1)	(2)	(1)	(2)
1.	Start selector, 2 position	O	n/a	n/a	O	O
2.	Start sequence, enable	⊗	O	⊗	O	⊗
3.	Stop sequence, enable	⊗	O	⊗	O	⊗
4.	Emergency shutdown	⊗	O	O	⊗	⊗
5.	Ready to load	⊗	O	⊗	n/a	n/a
6.	Hour meter	⊗	O	⊗	n/a	n/a
7.	Peak hours meter	O	O	O	n/a	n/a
8.	Fired start counter	⊗	O	⊗	n/a	n/a
9.	Start attempt counter	O	O	O	n/a	n/a
10.	Speed selector, auto/manual	⊗	O	O	O	⊗
SELECT 11a *plus* 11b *or* 11c						
11.a	Speed, gas generator	⊗	O	⊗	n/a	n/a
11.b	Speed, power turbine	⊗	O	⊗	n/a	n/a
11.c	Speed, gas turbine (single shaft)	⊗	O	⊗	n/a	n/a
12.	Speed, raise/lower	⊗	n/a	n/a	O	⊗
13.	Speed demand, set point	O	O	O	n/a	n/a
14.	Hot gas path temperature	⊗	O	⊗	n/a	n/a
15.	Hot gas path temperature spread	O	O	O	n/a	n/a
16.	Bearing temperature	O	O	O	n/a	n/a
17.	Fuel supply pressure	⊗	⊗	O	n/a	n/a
18.	Fuel supply temperature	O	O	O	n/a	n/a
19.	Wash system, compressor	O	O	O	O	O
20.	Lub. oil supply pressure	⊗	⊗	⊗	n/a	n/a
21.	Lub. oil heater	O	O	O	O	O
22.	Lub. oil pump running, standby	⊗	O	⊗	O	O
23.	Lub. oil pump running, emergency	⊗	O	⊗	O	O
24.	Reset/lamp test	⊗	n/a	⊗	O	⊗
25.	Horn silence	⊗	n/a	n/a	O	⊗

Table A.6 *(continued)*

CONTROL INSTRUMENT LIST

⊗ = Indicates that the specification defines a mandatory requirement

O = Optional – this must be completed by the purchaser if required

(1) refers to adjacent to the gas turbine (2) refers to control panel location

DESCRIPTION	MANDATORY REQUIREMENT	WARNING	SHUTDOWN	LOCATION OF ALARM FUNCTION INDICATOR	
				(1)	(2)
1. Emergency shutdown	⊗		⊗	O	⊗
2. Fail to turn	O	O	O	O	O
3. Fail to start	⊗		⊗	O	⊗
4. Fail to ignite	⊗		⊗	O	⊗
SELECT 5a *and* 5b *or* 5c					
5.a Underspeed, gas generator	O	O	O	O	O
5.b Underspeed, power turbine	O	O	O	O	O
5.c Underspeed, gas turbine (single shaft)	O	O	O	O	O
6. Overspeed starter	O	O	O	O	O
SELECT 7a *and* 7b *or* 7c					
7.a Overspeed, gas generator	O	O	O	O	O
7.b Overspeed, power turbine	⊗		⊗	O	⊗
7.c Overspeed, gas turbine (single shaft)	⊗		⊗	O	⊗
8. Overspeed, backup	O		O	O	O
9. Hot gas path temperature gas turbine	⊗	⊗	⊗	O	⊗
10. Hot gas path temperature spread	O	O	O	O	O
11 Governor failure	O	O	O	O	O
SELECT 12a *and* 12b *or* 12c					
12.a Vibration, gas generator	⊗	⊗	⊗	O	⊗
12.b Vibration, power turbine	⊗	⊗	⊗	O	⊗
12.c Vibration, gas turbine (single shaft)	⊗	⊗	⊗	O	⊗
13. Vibration monitor failure	O	O	O	O	O
14. Axial displacement high	O	O	O	O	O
15. Bearing temperature	O	O	O	O	O
16. Fuel supply pressure low	O	O	O	O	O
17. Fuel supply pressure high	O	O	O	O	O
18. Fuel supply temperature low	O	O	O	O	O
19. Fuel valve failure	O	O	O	O	O
20. Lub oil supply pressure low	⊗	⊗	⊗	O	⊗
21. Lub oil reservoir level, low	O	O	O	O	O
22. Lub oil discharge temperature high	⊗	⊗	⊗	O	⊗
23. Lub oil supply temperature high	⊗	⊗	⊗	O	⊗
24. Lub oil filter differential pressure high	O	O	O	O	O
25. Inlet air filter differential pressure high	⊗		O	O	O
26. Gas detection level, high	⊗	O	⊗	O	⊗
27. Fire/gas monitor failure	⊗	⊗	O	O	⊗
28. Enclosure temperature, high	O	O	O	O	O
29. Fire extinguishant system disabled	⊗	⊗	O	O	⊗
30. Fire detected	⊗	O	⊗	⊗	⊗
31. Fire extinguishant system discharged	O	O	O	O	O
32. Control voltage, low	O	O	O	O	O
33. Battery voltage, low	O	O	O	O	O
34. Battery charger failure	O	O	O	O	O
35. Trip to minimum self-sustaining speed	O	O	O	O	O
36. Trip to minimum governor speed	O	O	O	O	O
37. Rotor over temperature	O	O	O	O	O
38. Enclosure heat detectors	⊗	O	⊗	O	⊗

Annex B
(informative)

List of national or International Standards applicable in context

APPLICATION	INTERNATIONAL (ISO or IEC)	USA	GERMANY (DIN)	UK (BSI)	FRANCE (AFNOR)	JAPAN (JIS)
Practice for helical and Herringbone gear speed reducers and increasers		AGMA 420				
Practice for high speed helical and herringbone gear units		AGMA 421				
Steel and alloy pipe flanges	ISO 7005-1	ASME B 16.5	DIN 2543 DIN 2544 DIN 2545 DIN 2546 DIN 2547 DIN 2548 DIN 2549 DIN 2550 DIN 2551	BS 4504	NF E29-203 NF E29-204	B 2220 B 2239
Forged fittings		ASME B 16.11	DIN 910	BS 3799	N E29-600	
Code for pressure piping		ASME B 31.1 ASME B 31.3		BS 1600		B8270
Lubrication systems	ISO 10438-1, -2, -3, -4	API STD 614 ASTM D4241-83	DIN 24425	BS 4807		
Gas turbines for refinery services		API STD 616				
Special purpose couplings		API STD 671				
General purpose pipe threads	ISO 228-1	ASME B1.20.1		BS 2779 (seal on gasket) BS 21 (seal on thread)		B0202 B0203
Boiler and pressure vessel code welding and brazing		ASME Section IX	DIN EN 288-3	BS EN 288-3	NF EN 288-3	Z3040 Z3801 Z3881 Z3891
Zinc (hot galvanized) coatings on products fabricated from rolled, pressed and forged steel shapes, plates, bars and strips		ASTM A 123				
Carbon and alloy steel nuts for bolts for high-pressure and high-temperature service		ASTM A 194	DIN 17440	BS 4882 BS 1506		G4051 G4303
Cupola malleable iron		ASTM A 197				G5702
Carbon steel externally threaded standard fasteners		ASTM A 307				
National electric code	IEC 60079	NFPA 70				
Automatic fire detectors		NFPA 72E				
Sulfide stress cracking resistant metallic materials oilfield equipment		NACE MR 0175				

Bibliography

[1] ISO 228-1:2000, *Pipe threads where pressure-tight joints are not made on the threads — Part 1: Dimensions, tolerances and designation*

[2] ISO 1940-2:1997, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 2: Balance errors*

[3] ISO 3977-5:2001, *Gas turbines — Procurement — Part 5: Applications for petroleum and natural gas industries*

[4] ISO 7005-1:1992, *Metallic flanges — Part 1: steel flanges*

[5] ISO 10438-1:2003, *Petroleum, petrochemical and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 1: General requirements*

[6] ISO 10438-2:2003, *Petroleum, petrochemical and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 2: Special-purpose oil systems*

[7] ISO 10438-3:2003, *Petroleum, petrochemical and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 3: General-purpose oil systems*

[8] ISO 10438-4:2003, *Petroleum, petrochemical and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 4: Self-acting gas seal support systems*

[9] ISO 10439:2002, *Petroleum, chemical and gas service industries — Centrifugal compressors*

[10] ISO 10816-3:1998, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*

[11] ISO 11342:1998, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*

[12] AGMA 420, *Practice for helical and herringbone gear speed reducers and increases*

[13] AGMA 421, *Practice for high speed helical and herringbone gear units*

[14] API STD 614, *Lubrication, Shaft-sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services*

[15] API STD 616, *Gas Turbines for the Petroleum, Chemical and Gas Industry Services*

[16] API STD 671, *Special Purpose Couplings for Petroleum, Chemical and Gas Industry Services*

[17] ASME B16.5, *Piped Flanges and Flanged Fittings*

[18] ASME B16.11, *Forged Fittings, Socket-Welding and Threaded*

[19] ASME B31.1, *Power Piping*

[20] ASME B1.20.1, *Pipe Threads, General Purpose (Inch)*

[21] ASTM A 123, *Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

[22] ASTM A 197, *Standard Specification for Cupola Malleable Iron*

[23] ASTM D 4241, *Standard Practice for Design of Gas Turbine Generator Lubricating Oil Systems*

[24] BS 21, *Specification for pipe threads for tubes and fittings where pressure-tight joints are made on the threads (metric dimensions)*

[25] BS 1600, *Specification for dimensions of steel pipe for the petroleum industry*

[26] BS 2779, *Specification for pipe threads for tubes and fittings where pressure-tight joints are not made on the threads (metric dimensions)*

[27] BS 3799, *Specification for steel pipe fittings, screwed and socket-welding for the petroleum industry*

[28] BS 4504-3.3, *Circular flanges for pipes, valves and fittings (PN designated). Specification for copper alloy and composite flanges*

[29] BS 4807, *Recommendation for centralized lubrication systems*

[30] BS EN 288-3, *Specification and approval of welding procedures for metallic materials — Welding procedure tests for the arc welding of steels*

[31] DIN 910, *Destructive test on welds in metallic materials — Bend tests*

[32] DIN 2543, *Cast steel flanges, nominal pressure 16*

[33] DIN 2544, *Cast steel flanges, nominal pressure 25*

[34] DIN 2545, *Cast steel flanges, nominal pressure 40*

[35] DIN 2546, *Cast steel flanges, nominal pressure 64*

[36] DIN 2547, *Cast steel flanges, nominal pressure 100*

[37] DIN 2548, *Cast steel flanges, nominal pressure 160*

[38] DIN 2549, *Cast steel flanges, nominal pressure 250*

[39] DIN 2550, *Cast steel flanges, nominal pressure 320*

[40] DIN 2551, *Cast steel flanges, nominal pressure 400*

[41] DIN 24425, *Oil (supply) systems; description, selection, requirements classes*

[42] JIS B 0202, *Parallel pipe threads*

[43] JIS B 0203, *Taper pipe threads*

[44] JIS B 2220, *Steel pipe flanges*

[45] JIS B 2239, *Cast iron pipe flanges*

[46] JIS B 8270, *Pressure vessels (General standard)*

[47] NF E29-203, *Industrial pipework — Non alloy, alloy, austenitic stainless steel flanges and collars — Terminology — Specifications*

[48] NFE29-204, *Industrial pipeworks — Forged steel flanges and collars — Materials — Mechanical properties — Fabrication — Test*

[49] NF E29-600, *Industrial pipework — Steel fittings and plugs — Socket welding fittings*

[50] NFPA 70, *National electrical code (softbound)*

ICS 27.040

Price based on 63 pages