INTERNATIONAL STANDARD

ISO 3977

Second edition
1991-11-15

Gas turbines — Procurement

Turbines à gaz — Spécifications pour l'acquisition

Reference number
ISO 3977:1991(E)

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.

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

International Standard ISO 3977 was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

This second edition cancels and replaces the first edition (ISO 3977:1978), which has been technically revised.

Annexes A and B form an integral part of this International Standard. Annexes C, D, E and F are for information only.

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Gas turbines — Procurement

1 Scope

1.1 This International Standard provides technical information to be used for the procurement of gas turbine systems, including combined-cycle systems, and their auxiliaries by a purchaser from a manufacturer. Because of the very widely varying operating modes for gas turbines in practice, distinct categories of operating modes are specified with which a "standard" rating can be associated. These ratings must also be made on the basis of the ISO standard ambient reference conditions.

1.2 This International Standard provides a basis for the submission of proposals to meet different environmental and safety requirements and also gives, wherever possible, criteria to establish whether these are met. It does not attempt to deal with local or national legal requirements to which the installation may be required to conform.

1.3 This International Standard defines a standard framework for dealing with questions of fuel and other matters such as the minimum information to be provided by both the purchaser and the manufacturer. It does not, however, purport to include all the necessary information for a contract and each gas turbine installation must be considered in its entirety. Attention is drawn to the need for technical consultation between the manufacturer and the purchaser to ensure compatibility of equipment being supplied, particularly where the responsibility for supply is divided.

NOTE 1 Where the term "manufacturer" is used in this International Standard, it is deemed to mean the gas turbine manufacturer or the appropriate responsible contractor.

1.4 This International Standard is applicable to open-cycle gas turbine power plants using normal combustion systems and also includes closed-cycle, semiclosed-cycle and combined-cycle gas turbine power plants. In cases of turbines using free piston gas generators or special heat sources (for example, chemical process, nuclear reactors, furnace for a super-charged boiler), this International Standard may be used as a basis but will need to be suitably modified. This International Standard excludes gas turbines used to propel aircraft, road construction and earth-moving machines, agricultural and industrial types of tractors and road vehicles.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2314:1989, *Gas turbines — Acceptance tests.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 gas turbine: Machine which converts thermal energy into mechanical work; it consists of one or several rotating compressors, a thermal device(s) which heats the working fluid, one or several turbines, a control system and essential auxiliary equipment. Any heat exchangers (excluding waste exhaust heat recovery exchangers) in the main working fluid circuit are considered to be part of the gas turbine.

Examples of gas turbine systems are shown in figure 1.

3.2 gas turbine power plant: Gas turbine and all essential equipment necessary for the production of power in a useful form (e.g. electrical, mechanical or thermal).

3.3 open cycle: Thermodynamic cycle in which the working fluid enters the gas turbine from the atmosphere and discharges to the atmosphere.

3.4 closed cycle: Thermodynamic cycle having a recirculation working fluid independent of the atmosphere.

3.5 semiclosed cycle: Thermodynamic cycle utilizing combustion in a working fluid which is partially recirculated and partially exchanged by atmospheric air.

3.6 simple cycle: Thermodynamic cycle consisting only of successive compression, combustion and expansion.

3.7 regenerative cycle: Thermodynamic cycle employing exhaust heat recovery, consisting of successive compression, regenerative heating, combustion, expansion and regenerative cooling (heat transfer from the exhaust to the compressor discharge fluid) of the working fluid.

3.8 intercooled cycle: Thermodynamic cycle employing cooling of the working fluid between stages of successive compression.

3.9 reheat cycle: Thermodynamic cycle employing the addition of thermal energy to the working fluid between stages of expansion.

3.10 combined cycle: Thermodynamic system comprising (two or more) power cycles, each using a different working fluid. In steam and air combined cycles (the most commonly used working fluids), increased thermal efficiency is achieved because the two cycles are thermodynamically complementary, since heat is rejected from the gas turbine (Brayton cycle) at a temperature such that it can be used as, or it can supplement, the energy source in the steam system (Rankine cycle).

3.11 single-shaft gas turbine: Gas turbine in which the compressor and turbine rotors are mechanically coupled and the power output is taken either directly or through gearing.

3.12 multi-shaft gas turbine: Gas turbine combination including at least two turbines working on independent shafts. The term includes cases referred to as compound and split-shaft gas turbines.

3.13 bled gas turbine: Gas turbine which has, for external use, extraction of compressed air between compressor stages and/or at the discharge of the compressor, or extraction of hot gas at the inlet of the turbine and/or between turbine stages.

3.14 gas generator: Assembly of gas turbine components which produces heated pressurized gas to a process or to a power turbine. It consists of one or more rotating compressor(s), thermal device(s) associated with the working fluid, and one or more compressor-driving turbine(s), a control system and essential auxiliary equipment.

3.15 compressor: That component of a gas turbine which increases the pressure of the working fluid.

3.16 turbine: Term which when used alone refers to the turbine action only. It is that component of the gas turbine which produces power from expansion of the working fluid.

3.17 power turbine: Turbine having a separate shaft from which output is derived.

3.18 combustion chamber (primary or reheat): Heat source in which the fuel reacts to increase directly the temperature of the working fluid.

3.19 working fluid (gas or air) heater: Heat source in which the temperature of the working fluid is increased indirectly.

3.20 regenerator/recuperator: Different types of heat-exchanger, transferring heat from the exhaust gas to the working fluid before it enters the combustion chamber.

3.21 precooler: Heat-exchanger or evaporative cooler which reduces the temperature of the working fluid before initial compression.

3.22 intercooler: Heat-exchanger which reduces the temperature of the gas turbine working fluid between stages of compression.

3.23 overspeed trip: Control or trip element which actuates the overspeed protection system when the rotor reaches the speed for which the device is set.

3.24 control system: This includes starting control systems, governor and fuel control systems, alarm and shut-down systems, speed indicator(s), gauges, electrical power supply controls and any other controls necessary for the orderly start-up, stable operation, monitoring of operation, shut-down, warning and/or shut-down for abnormal conditions.

3.25 governing system: Control elements and devices for the control of critical parameters such as speed, temperature, pressure, power output, etc.

3.26 fuel governor valve: Valve or any other device operating as a final fuel-metering element controlling the fuel input to the gas turbine.

NOTE 2 Other means of controlling the fuel flow to the turbine are possible.

3.27 fuel stop valve: Device which, when actuated, shuts off all fuel flow to the combustion system.

3.28 dead band: Total range through which an input can be varied with no resulting measurable corrective action of the fuel flow controller. In the case of speed, dead band is expressed in percent of rated speed.

3.29 governor droop: Steady-state speed changes produced by the change of output from zero to the rated output, expressed as a percentage of the rated speed.

3.30 overtemperature detector: Primary sensing element which is directly responsive to temperature and which actuates, through suitable amplifiers or converters, the overtemperature protection system when the temperature reaches the value for which the device is set.

3.31 fuel specific energy (calorific value): Gross specific energy is the total heat released per unit mass of fuel burned, expressed in kilojoules per kilogram. The net specific energy is the gross specific energy less the heat absorbed by the vaporized water formed during combustion. It is expressed in kilojoules per kilogram.

NOTES

3 The two specific energies can be obtained for constant volume or for constant pressure, respectively, the difference being rather small.

4 The gross specific energy for constant volume is obtained using a bomb calorimeter.

5 The net specific energy value for constant pressure is used in the steady-flow combustion process (see ISO 2314). Also the specific energy may be calculated according to ISO 4261 (see annex F).

3.32 heat rate: The heat consumption per unit of net power of the gas turbine (see 3.2), expressed in kilowatts of heat per kilowatt of power, based on the net specific energy of the fuel including the sensible heat above 15 °C (see also ISO 2314:1989, 8.2.3).

NOTES

6 This may apply also to the test fuel in clause 5 and can also be expressed as the reciprocal of thermal efficiency (see 3.34).

7 The net power output of the gas turbine is derived in accordance with ISO 2314:1989, 8.1.

3.33 specific fuel consumption: Mass rate of the fuel consumed per unit of power, expressed in grams per kilowatt hour, using the net specific energy specified in 6.1.2).

3.34 thermal efficiency: Ratio of the net power output to the heat consumption based on the net specific energy of the fuel [see ISO 2314:1989, 8.2.2 and 8.3.3 e)].

3.35 reference turbine inlet temperature: Mean temperature of the working fluid immediately upstream of the first stage stator vanes (as determined in ISO 2314:1989, 8.6).

3.36 self-sustaining speed: Minimum speed at which the gas turbine operates, without using the power of the starting device, under the most unfavourable ambient conditions.

3.37 idling speed: Speed designated by the manufacturer at which the turbine will run in a stable condition and from which loading or shut-down may take place.

3.38 maximum continuous speed: Upper limit of the continuous operating speed of the gas turbine output shaft.

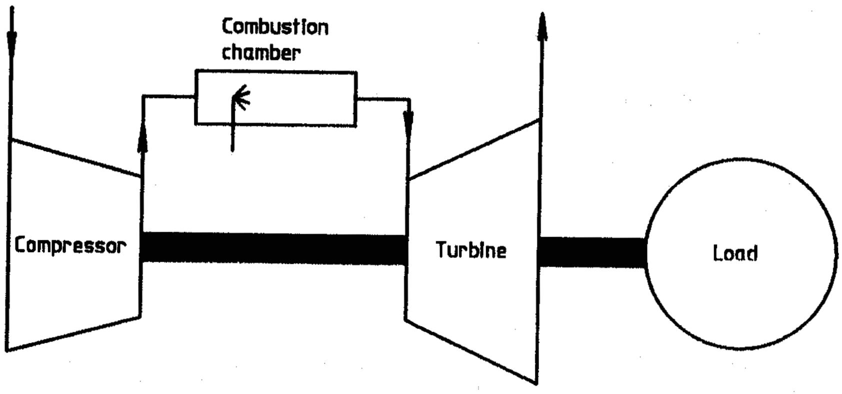
3.39 rated speed: Speed of the gas turbine output shaft at which the rated power is developed.

3.40 turbine trip speed: Speed at which the independent emergency overspeed device operates to shut off fuel to the gas turbine.

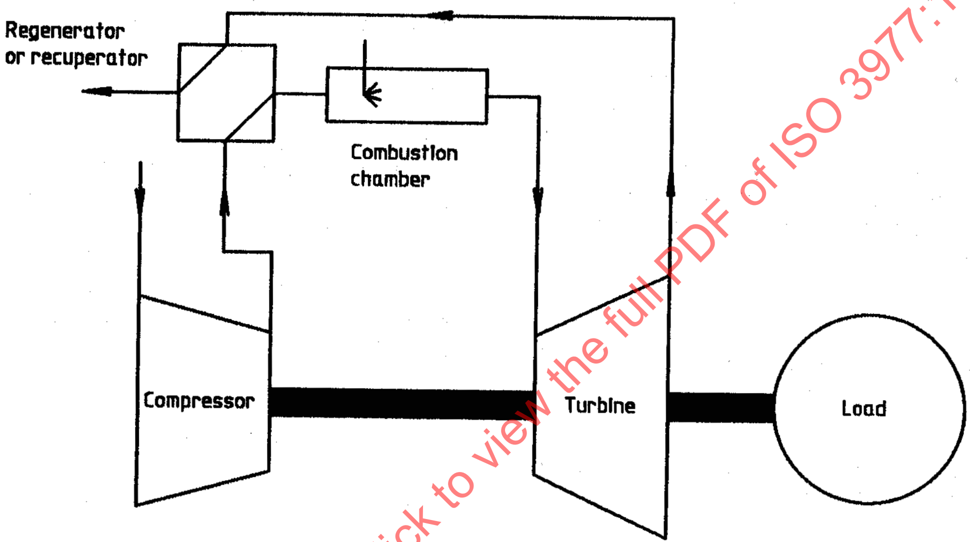
3.41 steam and/or water injection: Steam and/or water injected into the working fluid to increase the power output and/or to reduce the content of oxides of nitrogen (NO_x) in the exhaust.

3.42 mass to power ratio (mobile applications): Ratio of the total dry mass of the gas turbine elements, in accordance with 3.1, to the power of the gas turbine, expressed in kilograms per kilowatt, as defined in 6.3.

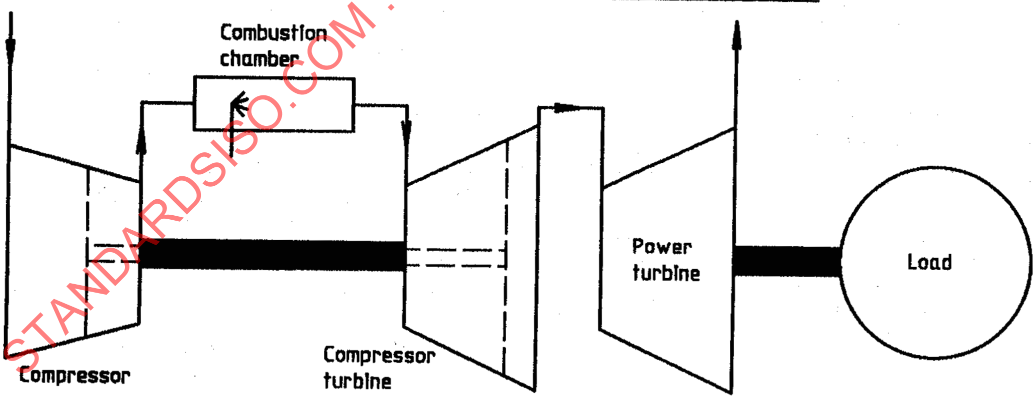
3.43 compressor surge: An unstable condition characterized by low-frequency fluctuations in mass flow of the working fluid in the compressor and in the connecting ducts.



1a) Simple cycle, single-shaft gas turbine

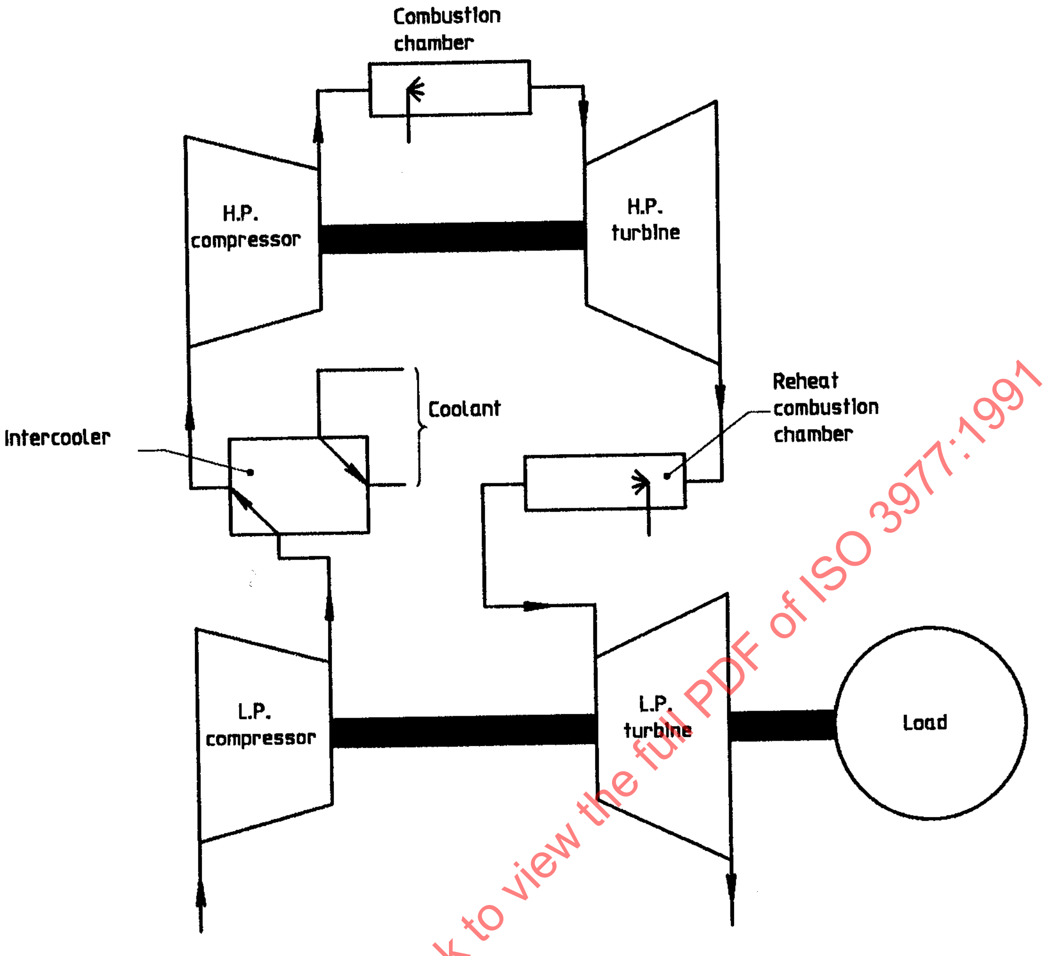


1b) Regenerative cycle, single-shaft gas turbine

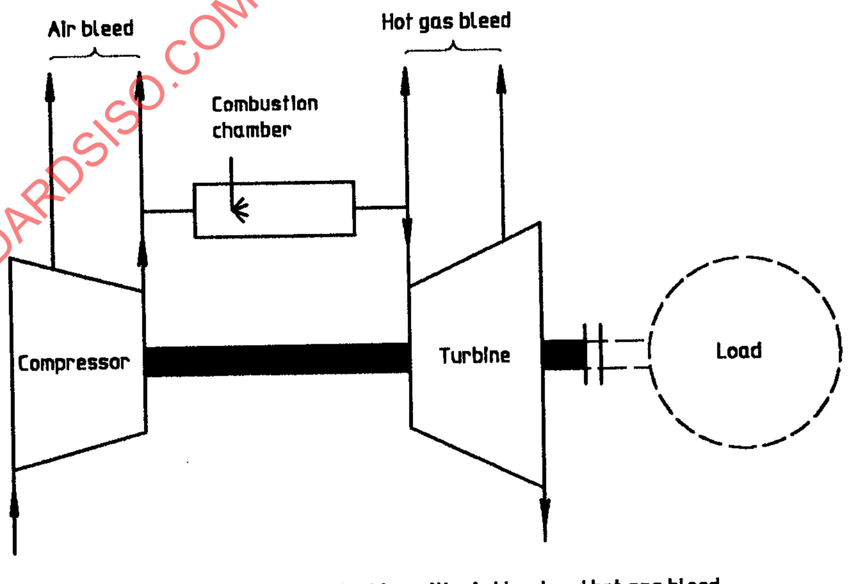


Note – Alternative twin-spool arrangement is shown in dotted lines.

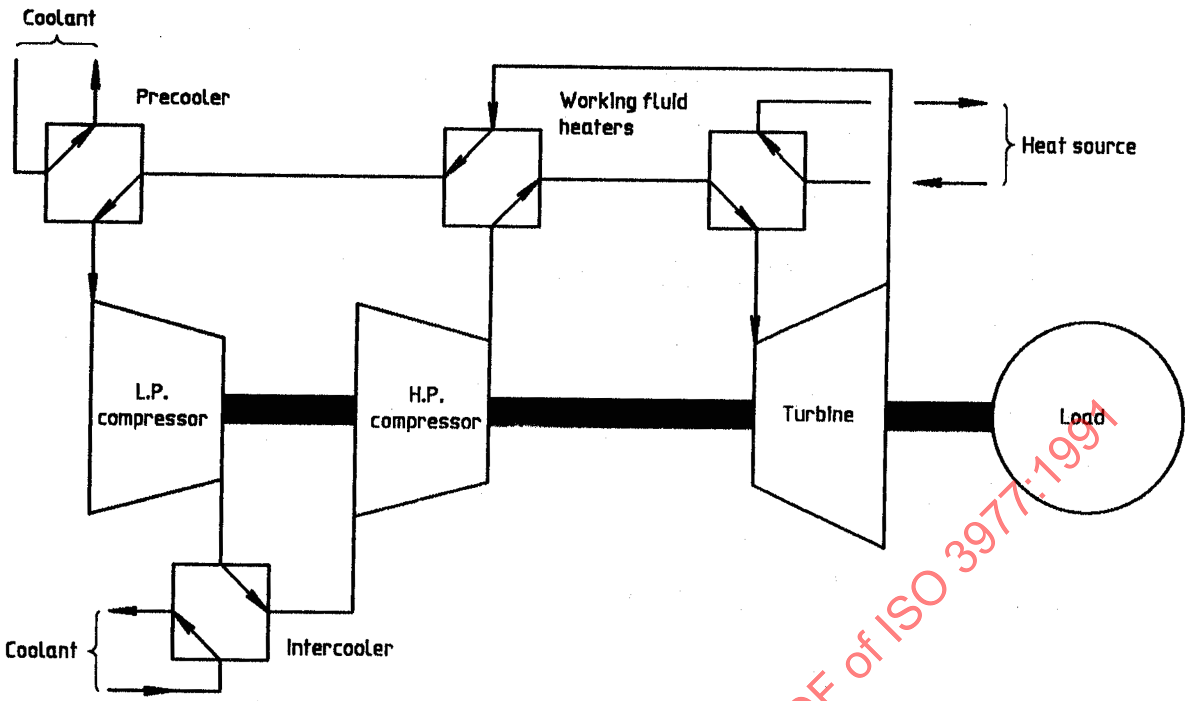
1c) Simple cycle, split-shaft gas turbine, i.e. with separate power turbine



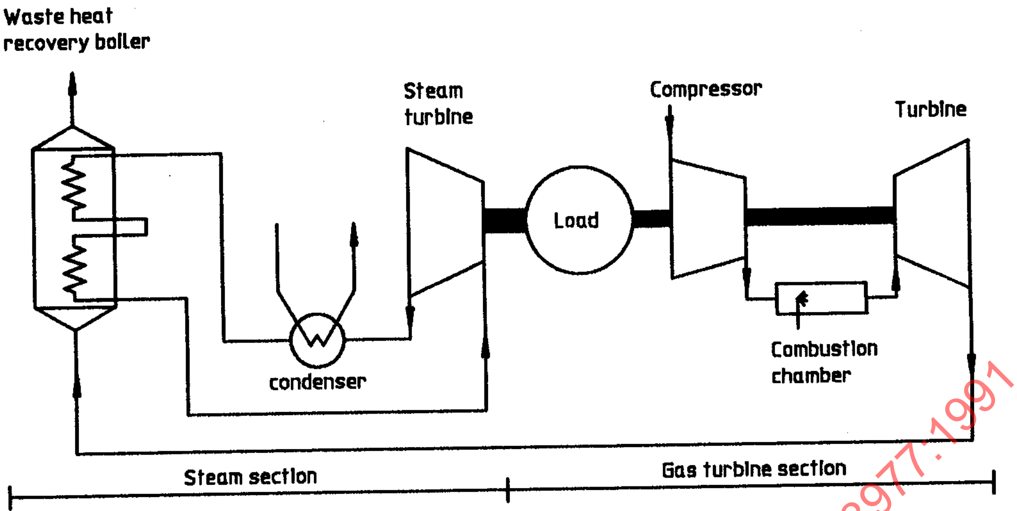
1d) Intercooled and reheat cycle (compound type), multi-shaft gas turbine with load coupled to low-pressure shaft



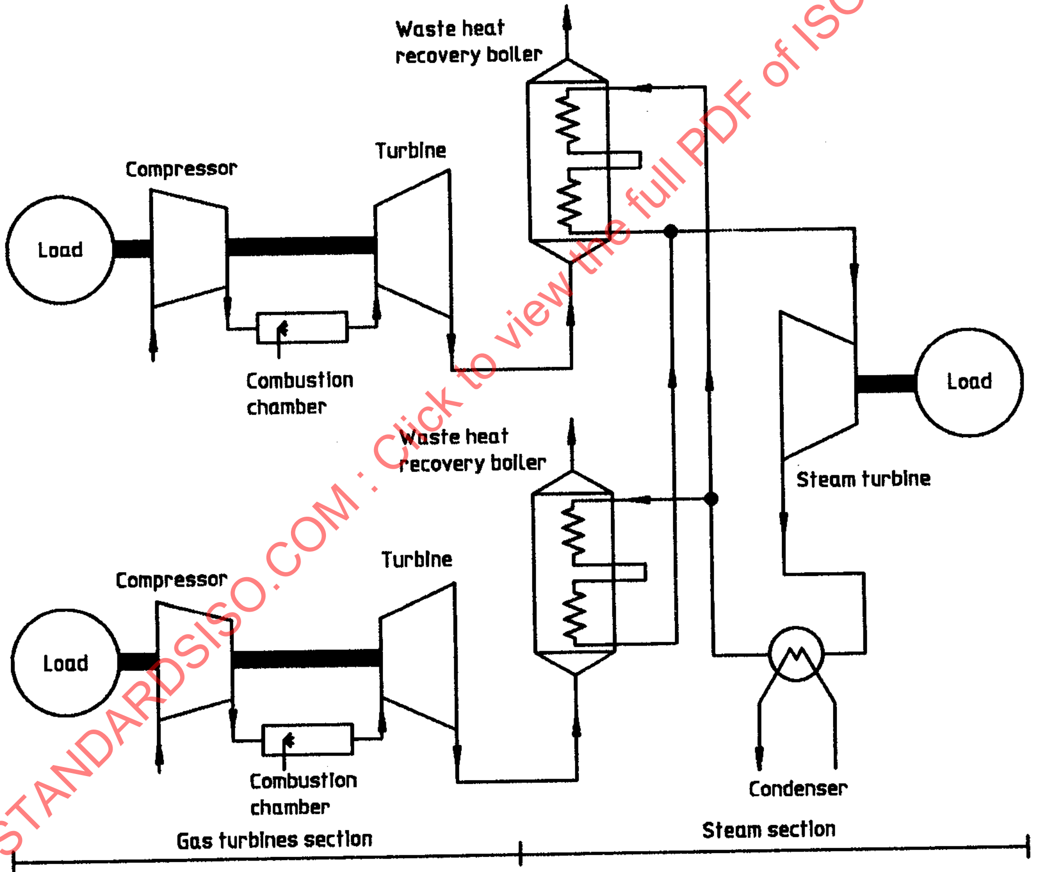
1e) Single-shaft gas turbine with air bleed and hot gas bleed



1f) Single-shaft closed-cycle gas turbine

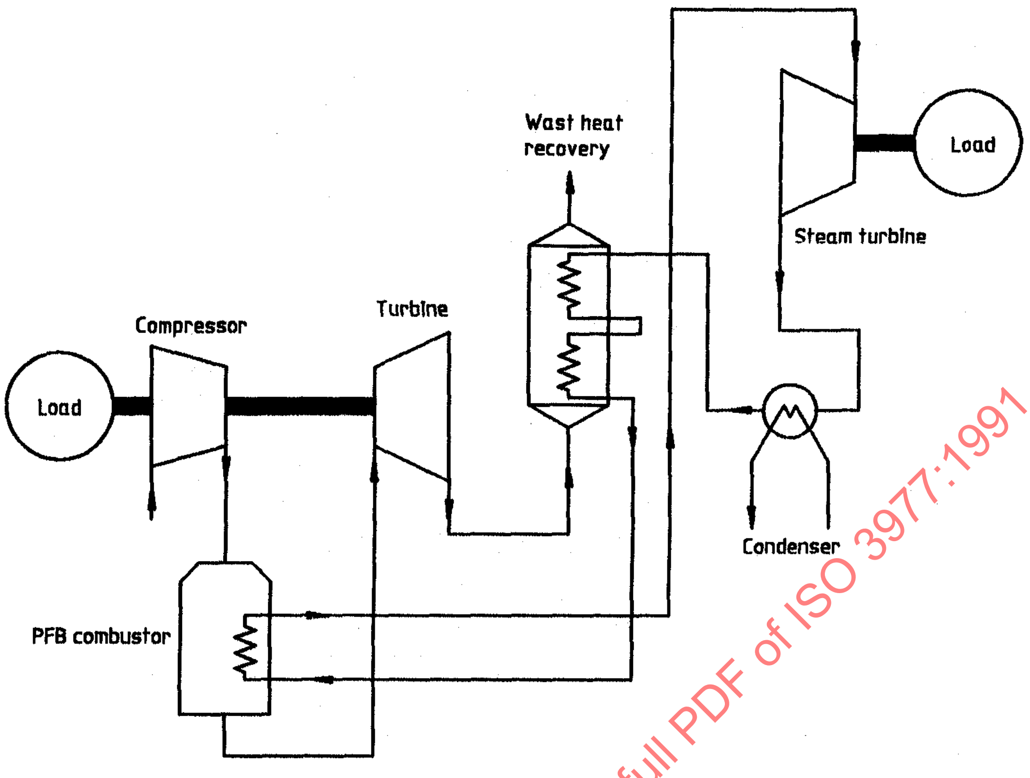


Steam and gas turbine on the same shaft



Configuration with two gas turbines and one steam turbine

1g) Combined-cycle gas turbine



1h) Combined-cycle gas turbine with pressurized fluidized bed combustor

Figure 1 — Examples of gas turbine systems

4 Standard reference conditions

The standard reference conditions on which ISO power, efficiency, heat rate or specific fuel consumption are based are as given in 4.1 to 4.4.

4.1 Air intake conditions

For the intake air at the compressor flange (alternatively, the compressor intake flare), as described in ISO 2314:1989, 6.6.2:

— a total pressure of 101,3 kPa;

— a total temperature of 15 °C;

— a relative humidity of 60 %.

4.2 Exhaust conditions

For the exhaust at turbine exhaust flange (or regenerator outlet, if a regenerative cycle is used):

— a static pressure of 101,3 kPa.

4.3 Cooling water conditions (if applicable)

An inlet water temperature of 15 °C applies if cooling of the working fluid is used.

4.4 Working fluid heater or cooler

Where a heater or a cooler is employed and uses ambient air, the standard reference conditions of the ambient air shall be 15 °C and 101,3 kPa.

5 Test fuels

If the fuel to be used for testing the gas turbine is different from that agreed between the purchaser and the manufacturer for service operation (see 10.7), a test fuel of a mutually agreed specification shall be used.

6 Ratings

6.1 General

6.1.1 The output power of a given gas turbine at a given reference turbine inlet temperature is, in general, proportional to the absolute ambient pressure and is also greatly dependent on air intake temperature (normally outside dry bulb temperature). Likewise, the output at a given air intake temperature is dependent on the reference turbine inlet temperature. To achieve a rating it is necessary to adopt standard conditions of ambient temperature and pressure, but gas turbine ratings will nevertheless vary considerably owing to the differing operational modes demanded of them as well as the varying criteria used in the design of the basic elements. ISO standard ratings neglect pressure drop at the inlet and exhaust but site ratings allow for these losses.

NOTE 8 Steam or water injection may be used to increase the power output and to reduce the NO_x emissions (see 3.41).

6.1.2 The performance ratings of gas turbines shall be assessed on the net specific energy of the fuel used as follows:

a) turbines intended for use on liquid fuel (DST 2, see table E.2): 42 000 kJ/kg;

b) turbines intended for use on gaseous fuel (100 % methane): 50 000 kJ/kg.

The specific energy at constant pressure of the fuel, whether liquid, gaseous or solid, is based on a pressure of 101,3 kPa and a temperature of 15 °C.

6.2 Operational modes

Unless special circumstances apply, and these must be specially agreed between the purchaser and the manufacturer, the net power rating of a gas turbine shall be specified under a combination of one of the classes in 6.2.1 together with one of the ranges of average number of starts per annum in 6.2.2.

EXAMPLE

B II refers to operation of up to 2 000 h per annum associated with any number of starts up to 500 per annum.

The manufacturer shall state the type, frequency and degree of inspection and/or maintenance required for the relevant operational mode [see 11.1 c)].

NOTE 9 It should be recognized that some gas turbine applications will operate with a combination of the classes given in 6.2.1. In such cases, the purchaser should specify the anticipated number of annual hours of operation at the specified net power ratings in each class. Operation outside these specified net power ratings/operational modes could materially affect the inspection intervals and maintenance required.

6.2.1 Classes

Class A: operation up to and including 500 h per annum at reserve peak power rating;

Class B: operation up to and including 2 000 h per annum at peak power rating;

Class C: operation up to and including 6 000 h per annum at semi-base power rating;

Class D: operation up to and including 8 760 h per annum at base power rating.

6.2.2 Ranges

Range I: over 500 starts per annum average;

Range II: up to 500 starts per annum average;

Range III: up to 100 starts per annum average;

Range IV: up to 25 starts per annum average;

Range V: continuous operation without planned shut-down for inspection and/or maintenance within a specified period.

6.3 ISO standard ratings

The manufacturer shall declare standard ratings, based on electrical power at the generator terminals or on turbine output shaft power under the standard reference conditions defined in clause 4, associated with the following operational modes:

a) ISO standard peak load rating (2 000 h and 500 starts per annum average) Class B: Range II.

b) ISO standard base load rating (8 760 h and 25 starts per annum average) Class D: Range IV.

In each case, the manufacturer shall state the type, frequency and degree of inspection and/or maintenance required.

6.4 Site ratings

The site power rating shall be specified by the manufacturer as follows.

a) Generating plant: the net electrical power at the generator terminals, with adjustment for auxiliary power as given in ISO 2314:1989, 8.1.2.

b) Mechanical drives: the net shaft power, adjusted for any auxiliaries not driven directly by the turbine (as defined in ISO 2314:1989, 8.1.1).

In either case, the site power rating shall relate to specified site conditions of the installation (such as ambient pressure and temperature, and pressure losses, steam and water injection, etc.) and operating modes under which the plant is intended to run in service.

Where the gas generator is supplied separately, its site power shall be expressed as the gas power arising from the isentropic expansion of the gas generator exhaust flow (using total pressure and temperature) to the ambient atmospheric pressure when it is operated under the specified site conditions of the installation and operating modes under which the plant is intended to run in service (see ISO 2314:1989, 6.3.5).

7 Controls and protection devices

7.1 Starting

The starting control system, including any pre-start requirements such as barring, may be manual, semi-automatic or automatic, as defined in 7.1.1, 7.1.2 and 7.1.3 respectively.

7.1.1 Manual start shall require the operator to start the auxiliary equipment, initiate, hold and advance the starting sequence (crank, purge, fire) and accelerate to minimum governor setting or ready for synchronizing in the case of generating sets.

7.1.2 Semi-automatic sequence start may require manual starting of the auxiliaries and shall permit the operator to commit the turbine by a single action to the complete starting sequence up to minimum governor setting or ready for synchronizing in the case of generating sets.

7.1.3 Automatic sequence starts require only a single action (manual or otherwise) to start the required auxiliary equipment and initiate the complete starting sequence up to minimum governor setting or ready for synchronizing in the case of generating sets.

7.2 Loading

Subsequent loading of the set may be manual, semi-automatic or automatic up to a specified power level. Automatic loading may follow directly the starting sequence without any additional action of the operator.

In any mode of loading, periods of dwell at specific loads may be introduced to provide for warm-up requirements.

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

7.3 Shut-down

This may be achieved by manual, semi-automatic or automatic means. In each case, however, the principal sequence of operations is essentially as given in 7.3.1, 7.3.2 or 7.3.3.

7.3.1 Generator drives

a) Controlled unloading to zero output at synchronized speed.

b) Opening the circuit breaker.

c) Reduction to idling speed and period of cooling where applicable.

d) Fuel cut-off and shut-down of auxiliaries not required for barring.

e) Barring period, if necessary.

f) Shut-down of remaining auxiliaries, for example lubricating oil pumps.

g) Return to starting conditions.

7.3.2 Mechanical drives

a) Controlled unloading to minimum load conditions.

b) Cooling period where applicable.

c) Fuel cut-off followed by shut-down of auxiliaries not required for barring.

d) Barring period, if necessary.

e) Shut-down of remaining auxiliaries, for example lubricating oil pumps.

f) Return to starting conditions.

7.3.3 Emergency shut-down

a) Emergency shut-down shall be capable of manual selection and shall also occur automatically as a result of automatic operation of plant protection devices. The system shall operate directly on the fuel stop valve to cut off the turbine fuel supply.

b) Except where otherwise specified, automatic means shall be provided for isolating upon shut-down the driven equipment from the system it supplies in order to prevent motoring or reverse flow.

c) It may also be necessary to operate venting systems for the release of stored energy.

d) Normal barring and shut-down sequences, as appropriate, shall subsequently take place, but where automatic restart is included, means shall be provided to prevent automatic restart without manual reset.

7.4 Purging

7.4.1 Where gaseous fuels are used, the starting control system shall provide an automatic purge period (whether the starting sequence is manual or automatic) of sufficient duration to ensure safe operation of the gas turbine.

Where national regulations do not exist, the purging cycle shall displace 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.

7.4.2 Where liquid fuels of a highly volatile nature are used, special precautions may be necessary. Special precautions should include, but are not limited to, the inclusion of automatically operated fuel dump valves.

7.5 Fuel control

Fuel supply shall be under a controlled opening sequence which shall be over-ridden by the turbine temperature or other protective devices.

7.6 Constant speed

Gas turbines which are to be regulated to a substantially constant speed (in particular, those driving an electric generator where, in some cases, isochronous speed control is necessary), shall be fitted with a governor sensing the output shaft speed. Unless otherwise agreed between the purchaser and the manufacturer, 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 typically, when held synchronized, be capable of reducing the output from maximum site rated output to zero in not more than 40 s, but the operating time taken shall be specified by the purchaser to be compatible with other speed changers on units running in parallel.

7.7 Variable speed

For gas turbines which are required to run over a range of speeds, for example as in ship propulsion, suitable control equipment shall be provided.

7.8 Governor

The governor for mechanical-drive applications shall limit the output speed at 105 % of the rated speed under all conditions of steady load. Unless otherwise specified by the purchaser, governor systems for electric generator drive shall prevent the gas turbine from reaching the turbine trip speed with an instantaneous loss of load when the turbine is operating under conditions within the limits of capability set by specified ambient conditions with design fuel pressures, temperature and fuel calorific values, and with the speed changer set and controlling at the rated speed.

7.9 Fuel governor valve

The fuel governor valve (see 3.26) shall return to minimum position under any turbine shut-down condition.

7.10 Fuel shut-off

7.10.1 In addition to the fuel governor valve or control valve, the fuel control system shall include a separate stop valve or "shut-off valve" which stops all fuel flow to the turbine in any shut-down condition and which will not open until all permissible firing conditions are satisfied.

7.10.2 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 is specified, these requirements may be operationally over-ridden.

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

7.11 Overspeed control

Each separate line of shaft shall be fitted with either an overspeed governor or an overspeed trip unless it can be shown that dangerous overspeeding is not a practical possibility.

7.12 Manual check on overspeed controls

Facilities shall be available for the operator to check manually the overspeed governor/overspeed protective devices.

NOTE 10 It is desirable that this should be done as far as is practicable without trip shut-down and without temporary loss of protection.

7.13 Overspeed settings

The overspeed governor or overspeed trip shall be set to operate at a level which will not allow the transient speed to exceed the maximum safe limit for the line of shafting under any sudden loss of load. Their main functions are respectively to cause the fuel to be reduced or to be cut off near the burner(s) by means independent of the main governor.

7.14 Transient speeds

In a gas turbine, particularly a multi-shaft unit, where a line of shafting may be subject to high acceleration on loss of load, speed may continue to rise after the operation of the overspeed trip. Hence, transient speeds significantly greater than the cut-off speed may be attained. The turbine shall be capable of subsequent normal operation without the need for inspection. Attention is drawn to the necessity of ensuring also that all coupled equipment, including auxiliaries, etc., electrically, mechanically or hydraulically coupled, withstands the corresponding overspeed.

7.15 Additional overspeed 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, load resistors, actuated by the main governor or overspeed trip, or both.

7.16 Flame failure

Where installation requirements indicate, consideration shall be given to providing a device to shut off the fuel in the event of flame failure.

7.17 Fuel override control

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

7.18 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.

7.19 Stability of the speed governing system

7.19.1 The speed governing and fuel control systems, with the turbine operating between zero and its maximum turbine capability, shall be capable of stable control of

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

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

In certain cases the control is obtained by a combination of a) and b) above. Stability of operation is also required in these cases.

7.19.2 The speed governing and fuel control systems shall be considered stable when

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 $\pm$ 0,12 % of the 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 $\pm$ 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.

For gas turbines of large output, the permissible magnitude of oscillations is expected to be generally lower.

7.20 Stability of the temperature control system

The temperature control and fuel control systems shall be capable of controlling with stability the temperatures of the gas turbine when the 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.

7.21 Overall system stability

In certain installations where the driven equipment and its associated system exercise an overriding influence, the criteria of stability given in 7.19 and 7.20 may not be achievable.

7.22 Lubricating oil system

Gas turbines with main shaft bearings of the hydrodynamic type shall be equipped with at least two oil pumps driven from independent power sources. One of the pumps shall be automatically actuated if the oil pressure is below the safe minimum value specified by the manufacturer.

7.23 Bearing temperature

Gas turbines with main shaft bearings of the hydrodynamic type shall be equipped with temperature monitors which shall measure the bearing metal and/or return-oil temperatures and which shall actuate alarms and/or trips.

7.24 Pressure fluctuations and excessive pressure drop in air intake

The design of the air intake system shall take into account pressure differentials due to fouling or icing of the air intake filters and fluctuations arising from abnormal operating conditions due to a transient compressor surge.

7.25 Fuel leakage

Consideration shall be given to the need for fuel leakage detection.

7.26 Vibration monitoring system

Where requested by the purchaser, a suitable vibration monitoring system may be supplied.

7.27 Other safety aspects

Information on other aspects of safety which shall be considered at the tender stage is given in annex A.

8 Fuels

8.1 General

As gas turbines may be designed to burn gaseous, liquid and/or solid fuels with or without change-over while under load, the following information shall be supplied by the purchaser (see 10.7):

a) the full specification and chemical analysis of the proposed available fuel(s), including expected concentrations of contaminants and possible variations of fuel composition;

b) any proposed treatment of the fuel(s) and the resulting specification;

c) where change-over from one fuel to another is required, the load and speed change-over conditions, the fuel change sequence and any other relevant operational requirement.

If the purchaser's fuel specification is not acceptable to the turbine manufacturer, the latter shall advise the purchaser of acceptable limits of contaminants and acceptable variations of fuel composition.

8.2 Gaseous fuels

8.2.1 Properties

The fuel shall be completely gaseous at the turbine manufacturer's termination point and at all points downstream to the fuel nozzle(s) where liquid might be harmful to the gas turbine; liquid eliminators or other special features, such as heaters, may be necessary to achieve this.

The manufacturer shall advise the purchaser of the minimum and maximum acceptable temperatures and pressures of the fuel gas.

The manufacturer shall advise on the degree of fuel cleaning required in respect of solids.

8.2.2 Corrosive agents

Special attention shall be given in the analysis to the presence of known corrosive agents, such as hydrogen sulfide, sulfur dioxide, sulfur trioxide, total sulfur, alkaline metals, chlorides, carbon monoxide and carbon dioxide, which may be present in the fuel gas.

8.2.3 Specific energy (calorific value)

The purchaser shall notify the manufacturer of the composition and the net specific energy of the gaseous fuel, or information whereby the value may be calculated. If it is anticipated that during steady-state operation the net specific energy will differ from the specified value, both the extent and the rate of change shall be stated by the purchaser in order that special equipment which may be required for proper gas turbine control may be fitted. If the variations in net specific energy are unacceptable, the manufacturer shall advise the purchaser of acceptable limits.

Annex E gives further information on the specific energy of gaseous fuels.

8.2.4 Supply pressure and temperature

The purchaser shall notify the manufacturer of the fuel gas supply pressure and temperature. The amplitude rate of change and period of pressure and temperature fluctuations shall be stated by the purchaser. In the event that these fluctuations are unacceptable, the manufacturer shall advise the purchaser of acceptable limits.

Annex E gives supplementary information on gaseous fuels.

8.3 Liquid fuels

8.3.1 Properties

Liquid fuels ranging from the highest aviation grades to the heaviest boiler fuels are burned in gas turbines. However, not all gas turbines are designed to operate on such a wide range of liquid fuels, and the properties of a liquid fuel to be used may seriously affect the operation and maintenance as well as the capital cost of a gas turbine installation.

Therefore, agreement on the fuel oil specifications between the purchaser and manufacturer should be sought, depending on the availability of the fuel and the duty of the gas turbine. The manufacturer shall advise on the degree of fuel treatment required in respect of solids.

8.3.2 Liquid fuel grades

Liquid fuels in accordance with specifications recognized locally or authorized by other organizations and being suitable for gas turbines may be used with the mutual agreement of the purchaser and manufacturer.

Recognizing the necessity for additional or more stringent requirements for certain types of gas turbines and applications, more restrictive specifications, additional properties and/or necessary fuel treatment may be specified.

ISO 4261 presents the requirements for petroleum fuels for gas turbines. Annex E reproduces table 1 of ISO 4261 which presents detailed requirements for gas turbine fuels.

8.4 Solid fuels

8.4.1 General information

Solid fuels can be applied to gas turbines in several forms, as follows.

a) Direct combustion by injection of pulverized coal or coal/solvent.

b) Direct combustion through use of a pressurized fluidized bed combustion (PFBC) system.

NOTE 11 Both a) and b) will require control of particulate matter to prevent erosion.

c) Indirect heat input through an externally fired air heater.

d) Gasification of coal or other solid fuels, by oxygen or air blown processes.

There are many opportunities for integrating the gas turbine and its combined cycle into the gasification process to optimize overall thermal efficiency.

The characteristics of the fuel as supplied to the gas turbine shall be agreed upon by the turbine manufacturers and fuel supplier.

Problems to be dealt with in such an application are similar if not identical to those occurring in steam boilers. Taking into consideration the complexity of the problem due to the influence of the vast variations in physical and chemical characteristics on the fuels, it is impracticable to give specific requirements. It is therefore left to the purchaser and the manufacturer to reach agreement on the type of solid fuel to be used.

NOTE 12 A technical report on solid fuels and derivatives for gas turbine use is being developed.

8.5 Nuclear fuels

The application of a nuclear reactor as the heat source for a direct closed-cycle gas turbine may be economically advantageous. This will involve the use of an inert gas such as helium as working fluid in the cycle.

Depending upon the design and the working principle of the reactor, special caution shall be taken regarding contamination of the machines and heat-exchangers as well as the possible influence of even small amounts of gases such as water vapour, hydrogen, carbon monoxide and carbon dioxide on the corrosion of the cycle elements.

Therefore, when designing a nuclear closed-cycle gas turbine plant, the fuel requirements shall be thoroughly investigated jointly by the manufacturers of the reactor and the power equipment and the purchaser.

9 Environment

9.1 General

This clause deals with vibration and other environmental factors which affect gas turbine operating personnel and people in inhabited areas adjacent to the gas turbine power plant. These other factors include sound (noise), atmospheric pollution, thermal pollution and site contamination. Locally recognized or mutually agreed upon standards or regulations shall take precedence over the criteria described in this clause, which shall be considered where no such standards or regulations are applicable.

9.2 Vibration

9.2.1 Vibration affects availability and safety. Measurement of vibration and its interpretation is presented in ISO 7919-1 and ISO 7919-4 (see annex F). ISO 7919-1 provides a method for measuring and evaluating vibration characteristics which are more clearly indicated by vibration measurements on their rotating shafts. ISO 7919-4 presents the special features required for measuring shaft vibrations on the coupled rotor systems of gas turbine sets.

ISO 2372 (see annex F) establishes an alternative basis for the evaluation of mechanical vibration of machines by measuring the vibration response on stationary members only, i.e. bearing houses.

The gas turbine train shall be shut down immediately if the vibration level exceeds predetermined safety limits.

9.2.2 Vibration measurements are made on shafts, bearing housings or casings. The design details, including mass, stiffness and accessibility of these parts, determine the most significant locations for vibration measurement. This International Standard does not specify numerical limits for vibration. The manufacturer shall ensure that vibration limits are compatible with the intended service (see 11.1).

9.2.3 The suitability of a gas turbine system to perform its intended function is often determined by detailed knowledge of vibration characteristics of system components. The components include shafts, bearings, housings, casings, enclosures, piping, accessories and particularly the internal blading and rotor discs, drums, etc. Obviously such knowledge is vital to the manufacturer. However, when system components are to be supplied by more than one manufacturer, the purchaser is advised to obtain an analysis of the lateral and torsional vibration characteristics of the complete system. A component consultant or one of the manufacturers can usually supply this service at a time that permits corrective action in the event the analysis predicts a troublesome natural mode of vibration within the range of expected operating conditions.

It is well established that rotating machinery can encounter severe vibration when components are coupled by their shafts and foundations even though they each operate satisfactorily uncoupled (as during factory tests for example).

9.2.4 Intolerably severe levels of vibration can cause serious damage to equipment and structures. Vibration is also a source of sound.

9.3 Sound

NOTE 13 ISO 10494 (see annex F) relates to noise emission of near-field inlet and exhaust. In the interim period, the information given in 9.3.1 to 9.3.3 may be used for guidance.

9.3.1 General

Different people perceive a given sound level with varying degrees of sensitivity. Factors such as frequency, intensity, directivity and duration influence tolerance to objectionable sound. Too high a sound level may be damaging to human beings, and lower levels, while not damaging, may constitute a nuisance to nearby occupied structures. It is, therefore, important to the user to determine the acceptable sound level both in the gas turbine enclosure (if operating personnel are normally or frequently present) and also in the vicinity of the gas turbine power plant. It should be recognized that sound can be due to equipment other than the gas turbine, for example such associated equipment as fans, diesel starting engines, transformers, generators, etc. Since sound reduction equipment and station design concepts which reduce the sound level add cost to the overall power plant, the objective should be to achieve an acceptable sound level satisfactory for the health of the operator, operator communication considerations, and for nearby occupied structures.

The formulation of the sound requirements to be fulfilled by the gas turbine manufacturer shall be adapted to the part of the total plant included in the delivery.

In order to meet the design objectives, both the user and the manufacturer shall integrate their design of the total sound contributors while recognizing environmental factors that affect the overall sound level. The arrangements for sound reduction shall be coordinated.

9.3.2 Sound level inside the gas turbine enclosure

If the operator is to be inside the gas turbine enclosure, the degree and amount of acoustical treatment shall be based on reducing the sound level in the immediate working vicinity of the gas turbine installation to a level in accordance with the relevant national standard. If no such standard exists, ISO 10494 gives guidance in determining the appropriate sound level.

If the plant normally is unmanned, the use of ear-protectors is acceptable in engine rooms. Normal conversation shall be feasible in control rooms.

9.3.3 Sound level outside the gas turbine plant

The sound generation shall be limited to prevent disturbing noise in the vicinity. Local authority demands shall be fulfilled.

The purchaser shall specify the required sound level and indicate if possibilities are provided for extending the sound reduction equipment, for example for settlement that may arise in the vicinity. The durability of the sound reduction equipment shall be taken into account.

The influence that surrounding country, settlement, etc. has on shielding and reverberation shall be taken into account.

The requirements for the sound level may be formulated as a fixed maximum sound level not to be exceeded at any point at a specified distance from the plant. The requirements may also be specified for certain points or certain directions.

The requirements for the sound level shall be formulated to enable verification. The distance between the point of measurement and the plant should be not greater than that permitting easy correction for the background sound.

The requirements shall include the maximum sound level in dB(A) or the allocation of frequencies, for example the *NR*-graph according to International Standards and/or any criterion that protects against interfering tones.

The method of sound measurement shall be agreed before the contract is finalized.

The background sound should be measured before the specified value is fixed, and possible time-variations should be taken into consideration.

Meteorological factors seriously affect the sound extension. In view of this, considerations shall be taken, for example by detailed description in the contract, of the weather conditions expected at the location where the sound requirements are verified.

Measuring tolerances should also be stated.

Guidance for acceptable sound levels outdoors are indicated in ISO 10494 where certain instructions regarding sound measurements are also given.

9.4 Atmospheric pollution

9.4.1 Smoke

Tests shall be made in accordance with a recognized and mutually agreed test method for stack emission. Information on existing methods is given in annex B.

If a limit on exhaust smoke is required by the purchaser, it shall be specified in the Bacharach scale or a mutually acceptable equivalent under

a) steady-state conditions, or

b) a specified condition of load or loads, 5 min after reaching these conditions.

NOTE 14 Other suitable methods of smoke measurement are under development and consideration will be given to their inclusion at a later date.

9.4.2 Chemical pollution

Local codes and standards shall be consulted to determine the acceptable level of chemical pollution from gas turbine exhausts independent of light-reflective characteristics.

Gas turbine power plants generally generate less noxious gases than gasoline engines or diesel engines.

Unburned hydrocarbons and oxides of nitrogen and sulfur, however, can cause severe atmospheric pollution, especially in smog-prone areas.

Particles are typically of submicron size but are smog producers by providing condensation sites or nuclei.

In the event that fuel additives are used for either smoke reduction or inhibiting corrosion with residual fuel oils, then there is greater possibility of stack emissions containing deleterious chemicals. This shall be checked against local codes.

9.4.3 Total content of nitrogen oxides

The method for determining the total content of nitrogen oxides in gas turbine exhausts shall be made in accordance with a recognized and mutually agreed test method (see annex C). Water or steam injection is one way to reduce nitrogen oxides emissions, in which case the rate of water consumption shall be indicated.

9.4.4 Atmospheric thermal effects

In the simple-cycle gas turbine without exhaust heat recovery, the exhaust stack temperature is normally higher than for other types of fossil fuel power plants with resultant greater buoyancy and faster dissipation of the exhaust. The rapid mixing with surrounding air reduces the temperature of the mixture substantially in a distance of a few exhaust duct diameters. In the event that a large number of gas turbines are to be located near an airport flight path, possible deleterious effects of turbulence induced by exhaust gas shall be analysed.

9.5 Water thermal effects

Most gas turbines use little, if any, cooling water and therefore there is little heating of rivers, lakes, etc. Cooling water is frequently used for cooling lubricating oil for the power plant, but for self-contained units water-to-air heat-exchangers are used to dissipate this heat. If compressor precoolers or intercoolers are used, then more cooling water is needed.

9.6 Site pollution

Design of civil engineering features of a power plant site shall provide protection for plant environs in the event of abnormal operation, fire, or failure of plant equipment. Potential spillages from fuel storage and handling facilities shall be contained by means of compounds in accordance with the appropriate standards or regulations.

A method for disposing of waste materials shall be provided. Waste materials include fuel from false start drains, lubricating oil contaminated with fuel oil or water, such as accidental leakage and spillage. Site selection shall give consideration to prevailing winds and the possibility of stack gases being drawn into neighbouring structures.

10 Technical information to be supplied by the purchaser with the enquiry

The particulars given in 10.1 to 10.10 shall be supplied to the manufacturer with the enquiry. If it is convenient, the information required in clause 10 may be presented by the purchaser in the form of data sheets.

10.1 Driven equipment

Electric generator, pump, compressor, etc.

10.2 Application

Stationary, portable, marine, locomotive, etc.

10.3 Extent of supply

The purchaser shall state the manufacturer's total responsibilities and define the extent of supply, including the interfaces between the manufacturer's supply and supply by others. Typical examples of the manufacturer's total responsibility and extent of supply may, for instance, include equipment supply and delivery time, erection, testing and guarantees, etc.

10.4 Environment

a) Elevation referred to sea level or normal barometric pressure, coincident wet and dry bulb air temperature and cooling water inlet temperature including average and extreme values and daily time/temperature air curves under the hottest and coldest conditions.

Mean wet bulb temperature and range of variation experienced or relative humidity shall be furnished. The former is preferred.

b) Nature of surroundings as affecting purity of the air and possible fouling by dirt, dust or salt and any other environmental conditions, for example whether the site is an industrial district, rural or near the sea, or a region liable to dust storms or freezing fog.

c) Nature of surroundings as affecting exhaust emissions and suppression of sound, for example smoke-free zone, proximity to residential property, whether the gas turbine has to comply with any special requirements, for example statutory regulations, electricity requirements or standards, sound and smoke levels, etc. (see clause 9).

d) Particulars of any special conditions relative to fire risks, for example installation in an oil refinery, gas works or explosives works.

10.5 Details of site

a) Whether the installation will be outdoors or in a new or existing building and whether heating exists or is to be supplied; also whether the manufacturer will be required to supply the building or enclosure.

b) Space available for the installation, including limitations in regard to size of engine room, depth of basement, etc.

c) Maximum size and mass (weight) of parts which can be transported to site and handled there.

d) Information required for foundation design, nature of ground, soil bearing capacity, sub-soil conditions and transmission of vibration.

e) Expected wind loads or levels, snowfall, rainfall, earthquake zone, and "G" loads for portable, marine and locomotive applications.

f) Details of access to site, i.e. waterway, railway or road; distance of unloading point to final location.

g) Required sound level in the control room and other designated areas within the station.

h) Properties and conditions of preferred cooling media (see 10.8).

10.6 Expected duty

a) Site rating and ambient conditions at which this is required.

b) Ambient temperature (and, if relevant, coolant inlet temperature) at the time when maximum output is required.

c) Expected number of running hours per annum, duration of runs and the number of starts. If known, average load to be carried and extent and duration of peaks (see 6.2.1 and 6.2.2).

d) Any other information regarding the required duty, for example black start, minimum time required for reaching full load from standstill in normal and emergency conditions, and the power required over the proposed range of operating speeds.

e) Particulars of any other machines with which the drive machine is to run in parallel.

f) Where an electrical generator is to be included, the number of phases, the preferred method of generator cooling, whether required to operate as synchronous compensator and relevant data under normal and abnormal operating conditions, such as voltage, frequency and duration of operation at abnormal frequencies.

NOTE 15 Where extremes of temperature are encountered, consideration should be given to specifying a larger generator to make use of the extra capacity available from the gas turbine at low ambient temperature.

g) If the driven machine is not supplied by the turbine maker, its nature, characteristics (for example, fault conditions, speed in revolutions per minute, direction of rotation, if significant, range of required variation of speed and end thrust imposed), together with breakaway torque, low speed torque and polar moment of inertia of the driven unit. In addition, details of any special control requirements (for example where the speed of a gas turbine driving a compressor or pump may require to be controlled so as to give a constant delivery pressure) and requirements for lubricating oil, if this is to be supplied from the main turbine oil system.

h) Where the gas turbine exhausts to a waste-heat boiler not supplied by the gas turbine manufacturer, the pressure drop across the boiler including ducting, and whether arrangements will be made for bypassing the boiler.

10.7 Fuel

a) Complete specifications of available fuels shall be submitted (see clause 8).

b) Cost of proposed fuel may be stated, if required, to assist in discussions on the most economical fuel and cycle for intended duty, balancing capital and operating cost.

10.8 Cooling water

Type, quantity, temperature and chemical analysis of water available (for example clear fresh water, sea water, abundant, restricted, available only for make up to recooling circuit), also pressure head and price where applicable and any restrictions on return temperature.

NOTE 16 Water may be required for precoolers, intercoolers, generator cooler, lubricating oil cooler, compressor and turbine washing, or for treatment of crude and residual oil fuels.

10.9 Auxiliary power supply

Details of electric, hydraulic or pneumatic power available on site for auxiliaries, for example starter motor, lubricating oil pump, etc.

10.10 Special requirements

a) Whether the gas turbine is to be

1) attended, unattended, or

2) controlled locally, remotely or automatically.

b) Whether the gas turbine is required to function over a range of inclinations.

c) Preferred lubricating oils.

d) Details of optional tests required in accordance with ISO 2314.

e) Expected maximum duration of operation without external services and/or power supplies.

11 Technical information to be supplied by the manufacturer when tendering

The particulars given in 11.1 to 11.6 shall be supplied to the purchaser when tendering. If it is convenient, the information required in clause 11 may be supplied by the manufacturer in the form of data sheets.

11.1 General information

a) A detailed list of any and all exceptions taken to the procurement specification. In the absence of such a list, it shall be understood and agreed that the manufacturer's proposal is in complete conformity to the procurement specification. Particular note shall be given to proposed deviations from standards quoted in the procurement specification.

b) Performance: information supplied shall include, but not necessarily be limited to, the following:

   1) site rating: power output under clearly stated ambient conditions [see 11.1 j)];

   2) expected thermal efficiency or specific fuel consumption, based on the net specific energy of the fuel, at site rating and at three-quarters and half site rating; also, data on power losses and heat consumption during operation as a synchronous compensator and spinning reserve under the conditions specified by the purchaser in 10.6 f);

   3) compressor air inlet flow or turbine exhaust flow;

   4) turbine inlet or exhaust gas temperature.

c) An indication of the anticipated replacement frequency of major components and type, frequency and degree of inspection and/or maintenance required for the relevant operational mode (see 6.2 and 6.3).

   NOTE 17 The life expectancy of major components is difficult to assess and may vary with operating patterns, site conditions, fuel used, etc.

d) Other factors include the following:

   1) rotational speed of each shaft;

   2) direction of rotation of the output shaft(s);

   3) minimum continuous idling speed;

   4) critical speeds or combined resonance speeds, if known.

e) Leading particulars, for example cycle arrangement, reference turbine inlet temperature, pressure ratios, mass flow and number of compressors, number of turbines, whether separate power turbine, intercooling, reheat or heat-exchanger.

f) Method of starting, peak starting demand, time to reach rated speed and time to reach rated output, time on barring gear before start and after shut-down.

g) If fuel is gas, the pressure required.

h) Speed variation:

   1) transient and permanent speed rise of output shaft on sudden loss of full load;

   2) transient and permanent speed variations resulting from the changes of load notified by the purchaser following 10.6 d).

i) Curves showing the effect on output of ambient temperature and any limitations, including that of maximum power; also, if appropriate, corrections for ambient pressure, different external pressure losses and variation of thermal efficiency of fuel consumption with ambient temperature, any restriction in operating the machine over the full power and speed range, and, where relevant, a curve relating output power and output shaft speed.

j) Sufficient information, including heat rejection rates where required by the purchaser, to enable the plant ventilation and cooling requirements to be determined.

k) If a waste-heat recovery system is part of the installation, the manufacturer shall state his tolerances on exhaust temperatures and/or gas flow, related to a stated back-pressure.

   If the installation is to include turbine exhaust heat-recovery equipment not supplied by the manufacturer, the manufacturer shall include details of exhaust flow, temperature and pressure at stated ambient conditions and details of the variations with ambient pressure, temperature and exhaust back-pressure.

l) Type of lubricating oil recommended and consumption rate if significant.

m) Quantity of cooling water required, and any other auxiliary services, for example compressed air.

n) Statement of all contractors' terminating points.

o) Painting and any special protection required for start-up, operation and periods of idleness under site conditions as specified by the purchaser in 10.4.

p) If the driven equipment is supplied by the turbine manufacturer, he shall provide leading particulars, including description, performance, size, mass (weight), lubrication system, etc.

q) Where the purchaser provides his own starting device, the starting torque/speed characteristics of the gas turbine should be provided by the manufacturer.

r) The manufacturer should, if possible by agreement with the purchaser, state the sequence of delivery of the components and the extent of packing.

11.2 Mass (weight) and dimensions

a) Dry mass (weight) [defined as the mass (weight) without liquid, including all accessories essential to running or any drives incorporated for non-essential accessories].

b) Other factors include the following:

1) mass (weight) of heaviest part to be lifted during erection;

2) mass (weight) of heaviest part to be lifted during overhaul;

3) dimensions of the largest part;

4) maximum hook height required during erection (underside of base to crane hook);

5) maximum hook height required during overhaul (underside of base to crane hook).

11.3 Drawings

11.3.1 The following drawings shall be supplied with the tender.

a) Preliminary plant layout and associated descriptive literature.

b) Outline drawing of the gas turbine giving overall dimensions and draw-out space.

c) An outline dimension drawing showing the location of the inlet and exhaust openings and such information needed by the purchaser to recognize what specific supports and supporting services are required.

d) Preliminary foundation requirements.

11.3.2 The following drawings should be supplied with the tender.

a) Cross-section of the gas turbine.

b) Piping and instrumentation diagram of lubricating oil, fuel oil, cooling water, control air, etc.

c) Diagram of the control system.

11.4 Environmental considerations

a) Where required by the purchaser, the tender shall list the expected sound pressure level data for the gas turbine installation in accordance with clause 9.

b) Where required by the purchaser, the tender shall list the expected exhaust gas composition and smoke emission in accordance with clause 9.

11.5 Auxiliary equipment

a) A tabulated list of auxiliaries for which a power allowance has been made in the maker's site rating and which are necessary for the running of the turbine, for example:

- main lubricating oil pump;
- fuel pump;
- air blast oil cooler fan;
- water circulating pump, etc.

b) A list of other auxiliaries stating the power and voltage (where applicable) required for each (whether driven by the turbine or independently), for example:

- auxiliary lubricating oil pump;
- auxiliary fuel pump;
- stand-by air blast oil cooler fan;
- stand-by water circulating pump;
- battery charger;
- barring gear and jacking oil pump;
- starting equipment, etc.

c) Statement of other equipment and materials supplied by the maker and included with the turbine, for example:

- main speed reduction or increasing gear;
- sole plate, bedplate supports, foundation bolts;
- normal exhaust ducting;
- normal intake ducting;
- control cabinet and instrumentation;
- fuel filters;
- lubricating oil filters;
- lubricating oil tanks;
- lubricating oil cooler;
- lubricating oil purifier;

- tools, lifting gear;
- piping;
- batteries;
- essential spare parts, for example igniter;
- spares list;
- instruction manual;
- external insulation;
- list of essential protection devices, including controls, etc.

d) Statement of additional equipment available from or through the maker, for example:

- exhaust silencer;
- air filters or silencers, or both;
- house generator;
- extra ducting and cascade elbows;
- fuel and lubricating oil tanks, pumps, heaters, treatment plant and piping;
- turbine or compressor washing or cleaning equipment;
- platform, handrailing;
- additional spare parts recommended;
- supervisory, etc.;
- fuel gas compression equipment;
- fire-fighting system;
- utility requirements such as compressed air, water, etc.

11.6 Maintenance

Where requested by the purchaser, the manufacturer shall give information on the anticipated maintenance requirements for the proposed gas turbine system. Typical maintenance information is given in annex D for guidance purposes.

Annex A
(normative)

Safety

WARNING — Compressor surge is a dangerous mode of operation, so the surge condition shall be avoided for all anticipated operating conditions.

Safety is of paramount importance in any power plant including the gas turbine power plant[1]. Protection from both human and equipment safety hazards is required. Careful attention shall be given to the following safety elements:

a) minimization of fire hazards and provisions for appropriate fire control;

b) control systems designed to prevent unsafe conditions (speeds, temperature, vibrations, etc.) (see clause 7);

c) alarms to warn of unsafe operating conditions (see clause 7);

d) suitable safety trips to protect operating personnel and/or equipment (see clause 7);

e) if operators will be near the gas turbine while it is operating, guards, insulation, handrails, etc., shall be provided to protect personnel from accidental contact with dangerous elements;

f) proper handling equipment and tools shall be available to maintenance personnel; particular attention is required for safe handling of heavy equipment including rigging or blocking tools, slings, hoists and cranes;

g) power plant design shall minimize the possibility of a fire fed by lubricating oil, hydraulic oil and fuel oil leaks (localizing any potential leaks shall be given careful attention);

h) adequate ventilation and means of escape shall be provided for any station personnel who will be near the power plant when it is operating; recognition shall be given to the fact that fire protection systems using CO_2 in a confined area can be dangerous to operating personnel;

i) manufacturer's recommendations relative to occupancy of the gas turbine enclosure during operation shall be followed;

j) if operators are to be exposed to abnormal sound levels, suitable protective ear devices shall be worn;

k) operating and maintenance personnel shall be provided with instructions to promote safe operation and maintenance of the power plant;

l) the inter-relationship of the gas turbine protective equipment and its possible effect on other power plant or system equipment (see clause 7).

1) In most countries there are national or local safety regulations which must be observed.

Annex B
(normative)

Exhaust smoke measurement[2)]

B.1 General

B.1.1 Smoke intensity

With proper maintenance, there should be no visible smoke from the exhaust of gas turbines burning gaseous fuel. Smoke in the exhaust of oil-burning gas turbines can be deceptive as only 0,1 %, or even less, of unburned carbon can result in extremely dense smoke. Techniques have been developed to measure smoke content, quantitatively, that extend into the invisible range. Specifications and codes for controlling smoke intensity should recognize transient as well as steady requirements. Smoke intensity can be most critical at

- light off;
- idle;
- full load;
- shut-down.

B.1.2 Smoke spot number

The degree of smoke intensity for a gas turbine may be specified using the smoke spot number, also known as the Bacharach number, where the smoke scale ranges from 0 to 9, with the lower values corresponding to a logarithmically lower value of smoke. The smoke spot number provides a fine discrimination in the vicinity of the threshold visibility.

Information on the Bacharach method of exhaust smoke measurement is given in B.2.

B.1.3 Von Brand reflective smoke number

Another method of specifying smoke is the Von Brand reflective smoke number. The Von Brand method allows for continuous sampling and hence permits observation of engine transients. A correlation between the Von Brand and smoke spot number is shown in table B.1.

The estimated public response to gas turbine stack plumes is given in table B.2.

B.2 Smoke spot (Bacharach) method for gas turbine exhaust smoke measurement

B.2.1 Introduction

This sub-clause gives information on test equipment and procedures based on the smoke spot method for the measurement of smoke emission from gas turbines having exhaust pressures ranging from sub-atmospheric to high positive pressures, for example gas generators. The procedures included are for determining and reporting the amount of smoke emission and to enable a uniform approach to be established.

The information is presented as follows:

- terms and definitions;
- equipment;
- test procedures;
- information and data to be recorded.

B.2.2 Definitions

B.2.2.1 smoke: Small gas-borne particles, including but not limited to black carbonaceous material from the burning of fuel in sufficient concentration to create visible opacity.

B.2.2.2 sampling: Collection of an exhaust gas sample under controlled conditions for the purpose of analysis.

B.2.2.3 test filter paper: Particular filter material used to collect smoke particles from the exhaust gas sample.

2) May become the subject of a future separate standard.

Table B.1 — Approximate comparison of Von Brand and smoke spot numbers

Smoke spot No.	Von Brand reflective smoke No.	
0	100	
1	99	
2	97	
3	93	
4	89	
5	82	
6	74	Perceptible range
7	67	
8	56	
9	0	

NOTE — For the comparison in this table to be valid, the sampling rate for the Von Brand reflective smoke number is 4,74 m^3 of gas flow per square metre of filter paper area and for the smoke spot number 57,2 m^3 of gas flow per square metre of filter paper. See ASTM D2156-80[1)] for definition of smoke spot number.

1) ASTM D 2156-80:1988, *Standard test method for smoke density in flue gases from burning distillate fuels.*

Table B.2 — Estimated public response to gas turbine stack plumes

Smoke spot No.	Von Brand reflective smoke No.	Public response
0 — 3	100 — 90	None — invisible smoke
4 — 5	90 — 80	Acceptable — may satisfy local codes
6	80 — 70	Sporadic complaints
7 — 8	70 — 60	Many complaints leading to community action
9	Below 60	Immediate vigorous community action

NOTE — For the comparison in this table to be valid, the sampling rate for the Von Brand reflective smoke number is 4,74 m^3 of gas flow per square metre of filter paper area and for the smoke spot number 57,2 m^3 of gas flow per square metre of filter paper. See ASTM D2156-80[1)] for definition of smoke spot number.

1) ASTM D 2156-80:1988, *Standard test method for smoke density in flue gases from burning distillate fuels.*

B.2.3 Equipment

A schematic illustration of the sampling system is shown in figure B.1.

B.2.3.1 Sampling probe, having an internal diameter between 9 mm and 10 mm. It shall have at least five 2,54 mm diameter holes spaced along its length such that each hole samples an equal area of the exhaust stream when placed across the exhaust duct.

Ideally the probe should be uncooled but if cooling is necessary to make the probe mechanically sound, the coolant flow shall be controlled so that the temperature of the sample gas does not fall below 100 °C.

Probe material shall be stainless steel or nickel-base alloy.

B.2.3.2 Sampling line, straight through with no kinks or loops, and no bends of less than ten line diameters. The sampling line inside diameter shall be between 9 mm and 10 mm. The sampling line section from the probe exit to valve A shall be as short as practicable and not greater than 30 m. Line material shall be stainless steel or copper. The line and sampling box shall be heated (electrically or by steam) and lagged to ensure that the sample gas is maintained within the range of 100 °C and 150 °C to prevent condensation of the sample at any position in the line, and overheating of the filter paper.

B.2.3.3 Valving, valves A and B of which shall be throttling valves used to establish the sampling pressure in the smoke sampling box. Valve A shall be adjusted to produce minimum impingement in the sampling box.

B.2.3.4 Smoke sampling box, serving as plenum chamber in order to stabilize flow conditions. A schematic illustration of the sample box is shown in figure B.1 and detailed requirements are shown in figure B.2.

B.2.3.5 Device for temperature measurement, enabling the temperature of the gas sample to be measured at the entry to the sampling box.

B.2.3.6 Vacuum pump (if required), capable of producing between 1,2 kPa and 2,5 kPa pressure in the smoke sampling box when valve A is fully open and valve B closed. The pump shall be of the oil-free variety to avoid the possibility of contamination of the sample.

B.2.3.7 Bacharach pump, providing a total volume of 5 680 $cm^3 \pm 250\ cm^3$ at 15 °C and 100 kPa for each square centimetre of effective surface area of filter paper.

B.2.3.8 Bacharach oil burner smoke scale, consisting of 10 spots numbered consecutively from 0 to 9, ranging in equal photometric steps from white through neutral shades of grey to black, imprinted or otherwise processed on white paper or plastics stock having an absolute surface reflectance of between 82,5 % and 87,5 %, determined photometrically. The smoke spot number is defined as the percentage reduction (due to smoke) in reflected incident light divided by 10.

B.2.3.9 Test filter paper, white, having an absolute surface reflectance of 82,5 % to 87,5 %, determined by photometric measurement. When making this reflectance measurement, the filter paper shall be backed by a white surface having an absolute surface reflectance of not less than 75 %. When clean air at standard conditions is drawn through clean filter paper at a rate of 47,6 $cm^3 \cdot min^{-1} \cdot cm^{-2}$ effective surface area of filter paper, the pressure drop across the filter paper should fall between the limits 1,73 kPa and 8,55 kPa.

B.2.4 Cleaning and leak checks

The probe and sampling line shall be thoroughly cleaned prior to taking a smoke sample if more than 5 h running has taken place since they were last cleaned. It is recommended that the probe and line be cleaned by passing a suitable solvent through them, and then blowing clean, dry compressed air through for about 5 min to remove any remaining solvent in the line. While the air is being blown through the line, the line heaters shall be switched on.

The sampling line and probe connections shall be checked for leaks before any smoke samples are taken.

B.2.5 Test procedures

B.2.5.1 Precautions

The sample being measured is composed of low micron and/or sub-micron size agglomerated particles. Precautions shall be taken to ensure that steady-state engine conditions have been achieved prior to taking a sample.

To prevent material accumulation in the sampling system, the probe shall be removed when not in use.

B.2.5.2 Probe orientation

The probe shall be located across the centre of the engine exhaust with its holes facing upstream. It shall be located at least two exhaust diameters downstream of the power turbine and not within two exhaust diameters of any bends in the exhaust.

B.2.5.3 Preparation for sampling at each power setting

The leak checks and cleanliness requirements in B.2.4 shall be confirmed. The following procedure shall then be carried out at each power setting to prepare the system for sampling

a) Open valve A fully and adjust valve B as necessary to give between 1,2 kPa and 2,5 kPa pressure in the sampling box, with or without the vacuum pump, depending on available exhaust pressure.

b) Ensure that the temperature of the sample entering the sampling box is within the range 100 °C to 150 °C.

c) Allow sample to flow for 5 min.

d) Clamp a strip filter paper in the Bacharach pump and ensure that it is firmly secured, i.e. cannot be pulled out.

e) Connect the Bacharach pump to the smoke sampling box and adjust valve B as necessary to maintain between 1,2 kPa and 2,5 kPa pressure in the smoke sampling box.

B.2.5.4 Sampling procedure

a) Draw the required sample through the test filter paper, using a Bacharach pump, over a period of approximately 1 min.

b) Having the sample, loosen the clamp on the Bacharach pump, move the filter paper along 10 mm and reclamp it firmly in position.

c) Repeat a).

d) Compare the smoke stains on the filter material (backed with a piece of white paper) with the Bacharach oil burner smoke standard scale. If they are not the same smoke spot number, repeat a), b) and c) until two consecutive stains are the same smoke spot.

e) Samples shall be taken at engine conditions as agreed between the manufacturer and the purchaser.

B.2.5.5 Obtaining the smoke spot number

The smoke stain on the filter paper shall be compared with the standard smoke spot smoke scale by viewing the stain through the holes in the smoke scale. When the smoke stain and the smoke scale number are the same colour, then the number corresponding to the smoke stain is the smoke spot.

The comparison shall be carried out in daylight, not artificial light, within 1 h of taking the sample.

B.2.6 Test data

For each Bacharach number measured, the following data shall be recorded:

a) gas turbine power, speed fuel flow and power turbine entry temperature;

b) ambient conditions (pressure, temperature and humidity);

c) fuel type and additives, if used.

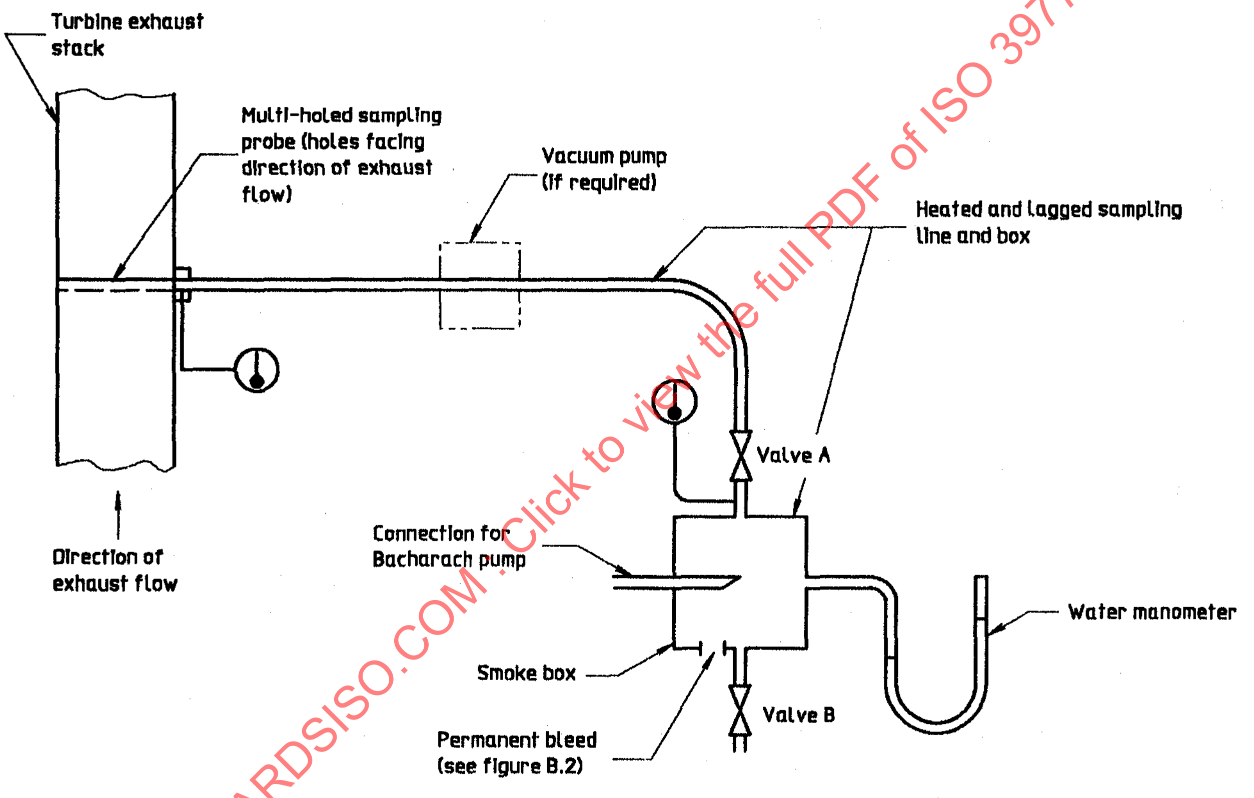
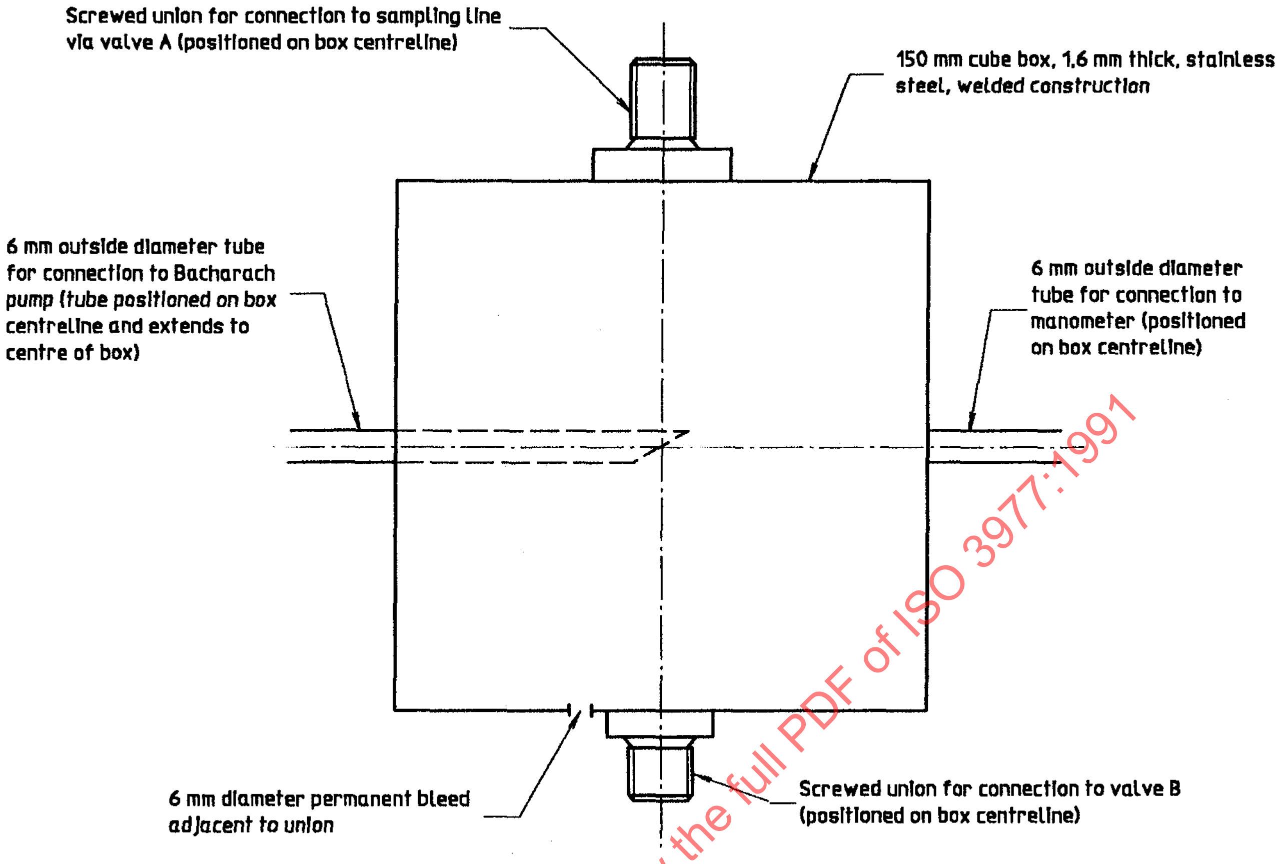


Figure B.1 — Schematic illustration of smoke spot smoke sampling system



NOTE — All dimensions are approximate.

Figure B.2 — Smoke spot sampling box

Annex C
(informative)

Determination of total content of nitrogen oxides in gas turbine exhausts

C.1 General

One of the difficulties in measuring the content of nitrogen oxides (NO_x) is that of measuring a low concentration of NO ($<$ 10 ppm), because it is a relatively inert gas, by straightforward physical or wet-chemical techniques. However, if NO is deliberately converted to NO_2, numerous methods exist, but then information on the original NO/NO_2 ratio is lost, and doubts must exist regarding the completion of the oxidation to NO_2. Measurement of NO_2 in low or high concentrations is relatively easy by a number of physical or chemical methods, but handling the gas sample can be a problem. NO_2 attacks metals, oils, rubber or plastics compounds; it is absorbed by chemical drying agents such as silica gel and alumina, and the presence of water can lead to high losses from the gas stream by solution. In the following summary of different methods, a distinction is made between batch methods and continuous methods.

NOTE 18 The references quoted in brackets are listed in C.6.

C.2 Batch methods

a) Phenoldisulfonic acid method (PDSA)[1]. This standard wet-chemical ASTM method[2] measures total nitrogen oxides in the form of nitrates. The method is applicable over a very wide range of concentrations (1 ppm to several thousand ppm) and is a method which can reliably be used as a primary standard[3]. The method is reliable but slow and is not particularly susceptible to the presence of contaminants.

b) Saltzman's method[4]. This wet-chemical method is a sensitive technique and since it is specific for NO_2, it can in principle distinguish between NO and NO_2. Concentration range is 1 ppm to 5 000 ppm. Accuracy is good if calibrated. The method is fast but interference from SO_2 and water vapour is a drawback.

c) Detector tubes. Crystal-filled detector tubes can be used to measure ($NO + NO_2$) and NO_2 quite quickly (10 s) but the method is somewhat imprecise and inaccurate and can therefore only be used as a rough check.

C.3 Continuous methods

All these methods are secondary ones and require calibration with primary blends.

a) Non-dispersive infrared (NDIR) spectroscopy. This method is only applicable to NO and is widely adopted throughout the motor industry and is specified in current US Test procedures[5]. Currently, the range is 100 ppm to 5 000 ppm but future trends toward dilution sampling will stretch the method somewhat. The method is susceptible to water vapour and therefore the samples need careful drying.

b) Non-dispersive ultraviolet (NDV) spectroscopy[6]. This method measures NO_2 only. In some cases it has been used in conjunction with a total oxidizer to achieve a measurement of NO. Concentration range is 20 ppm to 500 ppm. A general drawback is loss of NO_2 in sampling, as condensed water very effectively will remove NO_2 from the gas stream.

c) Chemiluminescent methods[7]. These methods are currently being developed and seem to be coming into favour rapidly. The main advantage is the wide concentration range: 0,001 ppm to 3 000 ppm.

d) Two wavelength absorption spectroscopy (ultraviolet absorption method) [8],[9]. This method measures total nitrogen oxides, and is fast and convenient because no reagent is necessary. Concentration range is 1 ppm to 500 ppm.

e) Correlation spectroscopy (ultraviolet absorption method) [8],[9]. This method measures NO and NO_2 more accurately compared with two wavelength absorption spectroscopy. Since no reagent is necessary, this method is convenient and fast. Concentration range is 1 ppm to 100 ppm.

f) Coulometric method (constant potential coulometry) [8],[10]. This method measures precisely NO_2 only using the reaction of nitrogen dioxide and bromide ions. Concentration ranges are optionally selected 0 ppm to 5 ppm and 0 ppm to 5 000 ppm.

g) Electrochemical transducer (constant potential electrolysis method) [8],[11]. This method measures nitrogen oxides by a constant potential electrolytic analyser with a gas-permeable membrane. It is possible to select measurement ranges of 0 ppm to 5 ppm and 0 ppm to 5 000 ppm. The method is slightly inaccurate and interference from SO_2 is to be considered, but the method is very convenient because of a portable analyser.

NOTE 19 A summary of the methods described in C.2 and C.3 is given in table C.1.

C.4 Sampling problems

A number of problems exist in direct sampling of neat exhaust, in its storage in bags, and in the entry into the analytical instruments themselves. Thus the choice of sampling-bag material is of prime importance. There is no way of preventing the oxidation of NO to NO_2 so both pollutants need to be measured simultaneously and in all cases reasonably rapid analysis of the whole bag sample is preferred.

It is important to dry the exhaust gases carefully prior to NO measurement. However, for NO_2 measurements the gases must not be dried at all, either chemically or by cooling, because some NO_2 will be removed with the water; nor must the gases be allowed to contact fresh metal on which the NO_2 is readily absorbed.

C.5 Future methods

Future methods should be remotely controlled and avoid physical sampling of the gases. An electro-optical method utilizing the Raman effect is under development in the USA. This method is expected to be very sensitive and can handle practically all types of pollutants in exhaust gases. The method requires expensive and stationary equipment.

C.6 References

[1] Tentative method of analysis for total nitrogen oxide as nitrate (phenoldisulphonic acid method), *Health Lab. Sci.*, 1970, Vol. 7, No. 3, pp. 190-193.

[2] ASTM D 1608-77:1985, *Standard test method for oxides of nitrogen in gaseous combustion products (phenol-disulfonic acid procedure).*

[3] MOR 627 F, *The measurement of nitrogen oxides from the gasoline engine,* Shell International Petroleum Company Limited.

[4] BODENSTEIN, M.Z. *Electrochem.*, 1918, Vol. 24, p. 183.

[5] Federal Register, 15 July 1970, Vol. 35, p. 136.

[6] BECKMAN, G. RIIC Ldt. S.E. 26.

[7] FONTIGU, A., SABADELL, A.J. and RONCO, R. *J. Anal. Chem.*, 1970, Vol. 42, p. 575.

[8] JIS-K0104: 1974, *Methods for determination of oxides of nitrogen in exhaust gases* (Japanese Industrial Standard).

[9] HANST, P.L. Spectroscopic method for air pollution measurement, *Advances in environmental science and technology,* Wiley Interscience, USA, Vol. 2, pp. 91-214.

[10] *Mast Analyzer Catalog*, Mast Development Co., Iowa, USA.

[11] *Dynasciences NO_x Monitor Catalog*, Dynasciences Corp., California, USA.

Table C.1 — Summary of methods for measurement of nitrogen oxides

Method	Nitrogen oxide	Concentration range ppm (*V/V*)	Nature	Accuracy	Instrument response time s	Ease of use	Interference from contaminant	Comments
Phenoldisulfonic acid	$NO + NO_2$	1 to 5 000	B	G	—	E	—	Very slow (12 h to 24 h) development time
Saltzman's	NO_2, $NO + NO_2$	1 to 5 000	B	G	—	E	SO_2	Fast chemical method; not a primary method
Draeger tubes	NO_2, $NO + NO_2$	Wide	B	P	—	VE	—	Only useful as a rough check
Non-dispersive infrared	NO	10 to 5 000	C	G	1	E	H_2O, CO, CO_2	A widely used instrument; gases need careful drying
Non-dispersive ultraviolet	NO_2	20 to 500	C	G	1	E	—	Loss of NO_2 in sampling is a problem
Ozone chemiluminescence	NO	0,001 to 3 000	C	G	1	M	—	Rapidly coming into favour
Oxygen atom chemiluminescence	NO_x	10^{-6} to 3 000	C	M	1	M	—	Still under development
Two wavelength absorption spectroscopy	$NO + NO_2$	1 to 500	C	M	1	E	—	No reagent is necessary
Correlation spectroscopy	NO, NO_2	1 to 100	C	G	1	E	—	No reagent is necessary
Coulometric	NO_2	0 to 5 0 to 5 000	C	G	10 to 60	E	—	Indirect method still under development
Electrochemical transducer	NO_x, NO, NO_2	0 to 50 0 to 5 000	C	M	3	VE	SO_2	Slightly inaccurate, but portable and convenient. Requires a NO concentrator

KEY
B = Batch
C = Continuous
G = Good
P = Poor
M = Medium
E = Easy
VE = Very easy