TC 70 199..

INTERNATIONAL STANDARD ISO 3977

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Gas turbines — Procurement

Turbines à gaz — Spécifications pour l'acquisition

First edition — 1978-07-01

UDC 621.438 **Ref. No. ISO 3977-1978 (E)**

Descriptors : internal combustion engines, gas turbine engines, user-supplier relations, operating requirements, specifications, definitions, ratings, performance evaluation, control devices, safety devices, fuels, physical properties, environments, maintenance.

Price based on 33 pages

ISO 3977-1978 (E)

FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 3977 was developed by Technical Committee ISO/TC 70, *Internal combustion engines*, and was circulated to the member bodies in March 1976.

It has been approved by the member bodies of the following countries :

Australia	Japan	Switzerland
Belgium	Korea, Rep. of	Turkey
Czechoslovakia	Mexico	United Kingdom
Denmark	Netherlands	U.S.A.
France	Philippines	U.S.S.R.
Germany	Romania	Yugoslavia
India	Spain	
Italy	Sweden	

No member body expressed disapproval of the document.

CONTENTS

Page

Annexes

Gas turbines — Procurement

1 SCOPE

1.1 This International Standard provides technical information to be used for the procurement of a gas turbine and its 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 — Where the term "manufacturer" is used in this International Standard, it is deemed to mean the gas turbine manufacturer or the appropriate responsible contractor.

2 FIELD OF APPLICATION

This International Standard is applicable to open cycle gas turbine power plants using normal combustion systems and also includes closed cycle and semi-closed 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 supercharged 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.

3 REFERENCES

ISO/R 1996, *Acoustics — Assessment of noise with respect to community response.*

ISO 1999, *Acoustics — Assessment of occupational noise exposure for hearing conservation purposes.*

ISO 2041, *Vibration and shock — Vocabulary.*

ISO 2314, *Gas turbines — Acceptance tests.*

4 DEFINITIONS

For the purpose of this International Standard, the following definitions apply :

4.1 gas turbine : A 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.

4.2 gas turbine power plant : A gas turbine and all essential equipment necessary for the production of power in a useful form.

4.3 open cycle : A thermodynamic cycle in which the working fluid enters the gas turbine from the atmosphere and discharges to the atmosphere.

4.4 closed cycle : A thermodynamic cycle having a recirculation working fluid independent of the atmosphere.

4.5 semi-closed cycle : A thermodynamic cycle utilizing combustion in a working fluid which is partially recirculated and partially exchanged by atmospheric air.

4.6 simple cycle : A thermodynamic cycle consisting only of successive compression, combustion and expansion.

4.7 regenerative cycle : A 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.

4.8 intercooled cycle : A thermodynamic cycle employing cooling of the working fluid between stages of successive compression.

4.9 reheat cycle : A thermodynamic cycle employing the addition of thermal energy to the working fluid between stages of successive compression.

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

4.11 multi-shaft gas turbine : A 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.

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

4.13 gas generator : An 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 compressors, thermal device(s) associated with the working fluid, and one or more compressor driving turbines, a control system and essential auxiliary equipment.

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

4.15 turbine : This term, 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.

4.16 power turbine : A turbine having a separate shaft from which output power is derived.

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

4.18 working fluid (gas or air) heater : A heat source in which the temperature of the working fluid is increased indirectly.

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

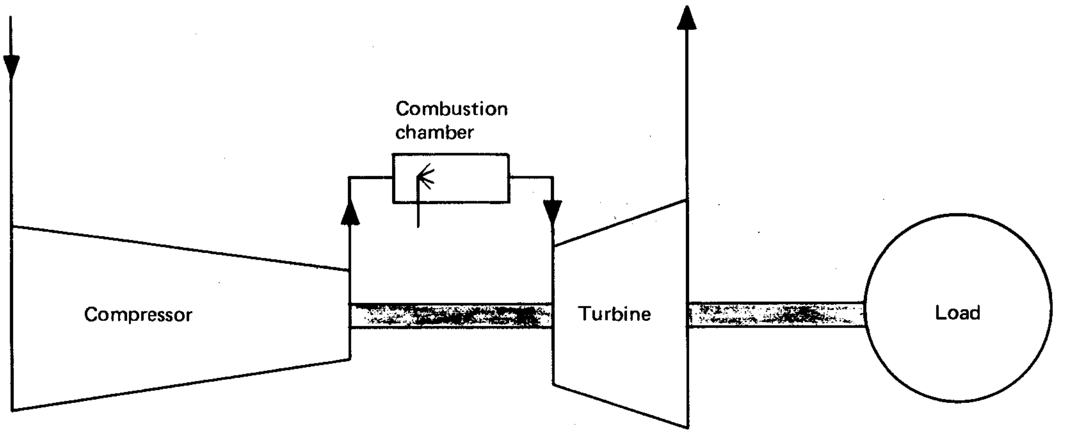
4.20 precooler : A heat exchanger or evaporative cooler which reduces the temperature of the working fluid before initial compression.

4.21 intercooler : A heat exchanger which reduces the temperature of the gas turbine working fluid between stages of compression.

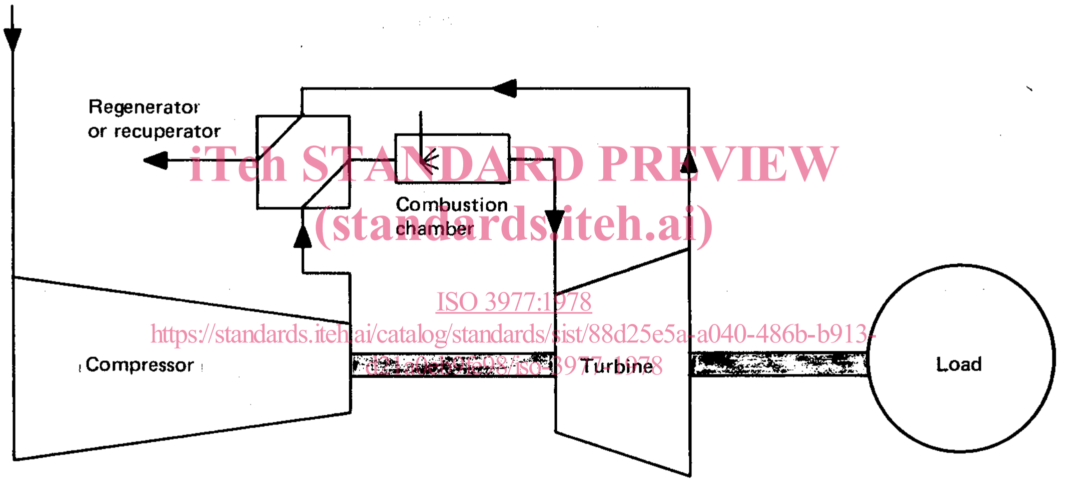
4.22 overspeed trip : A control or trip element which actuates the overspeed protection system when the rotor reaches the speed for which the device is set.

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

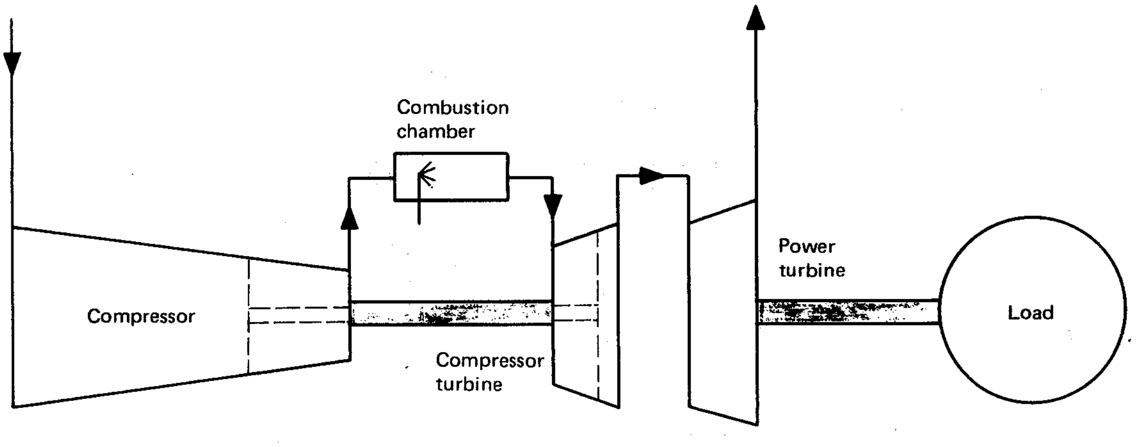
4.24 governing system : Control elements and devices for the control of critical parameters such as speed, temperature, pressure, power output, etc.



a) **Simple cycle, single-shaft gas turbine**



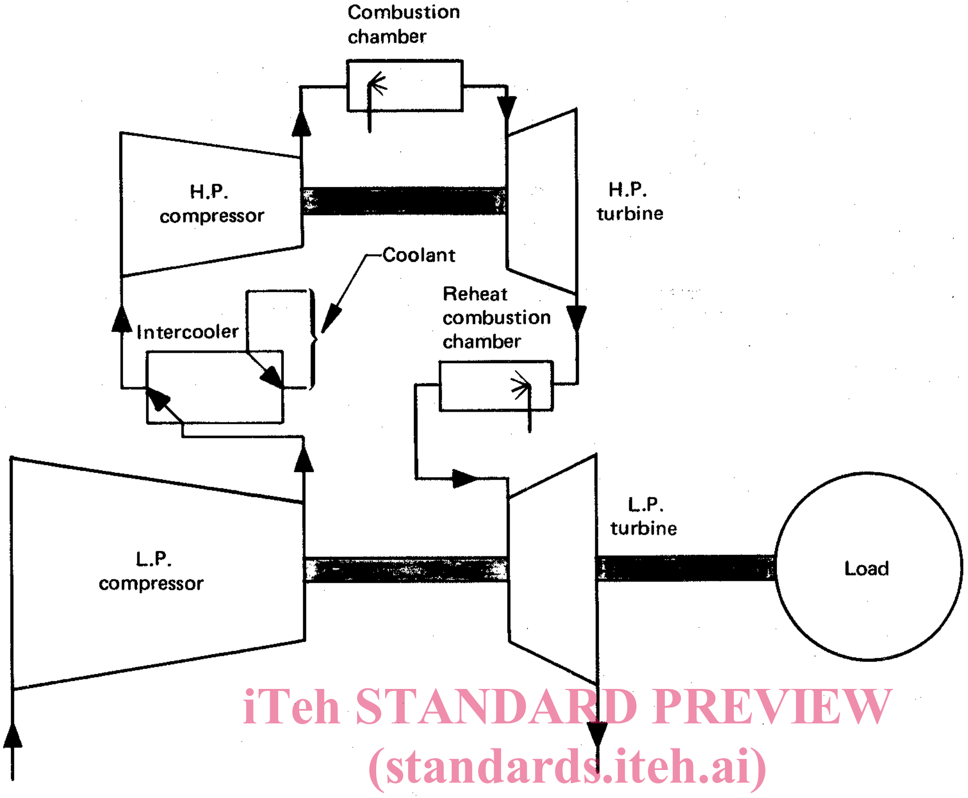
b) **Regenerative cycle, single-shaft gas turbine**



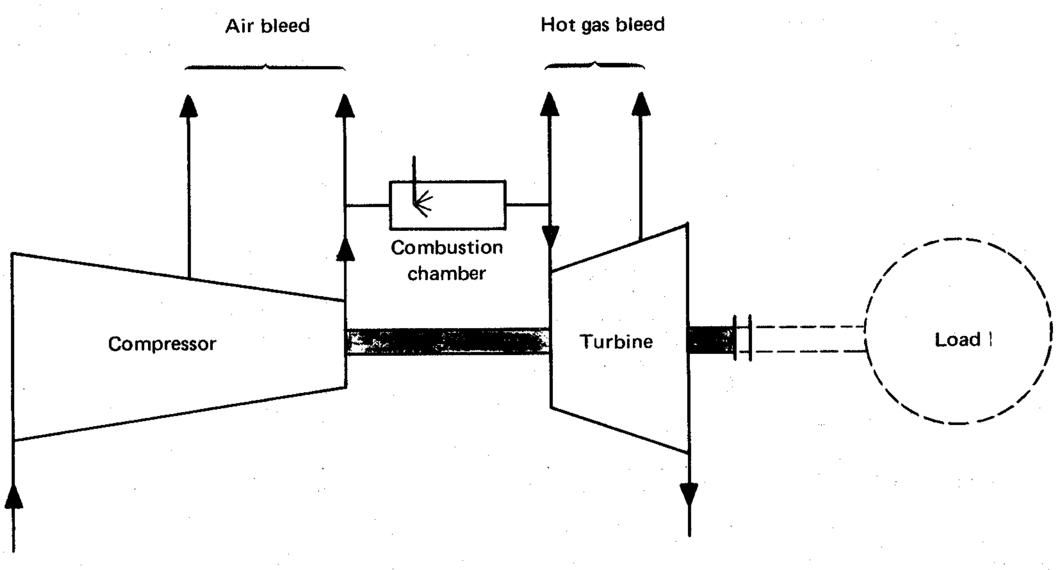
c) **Simple cycle, split shaft gas turbine, i.e. with separate power turbine**

(Alternative twin spool arrangement shown in dotted lines)

FIGURE 1 — **Examples of gas turbine systems**

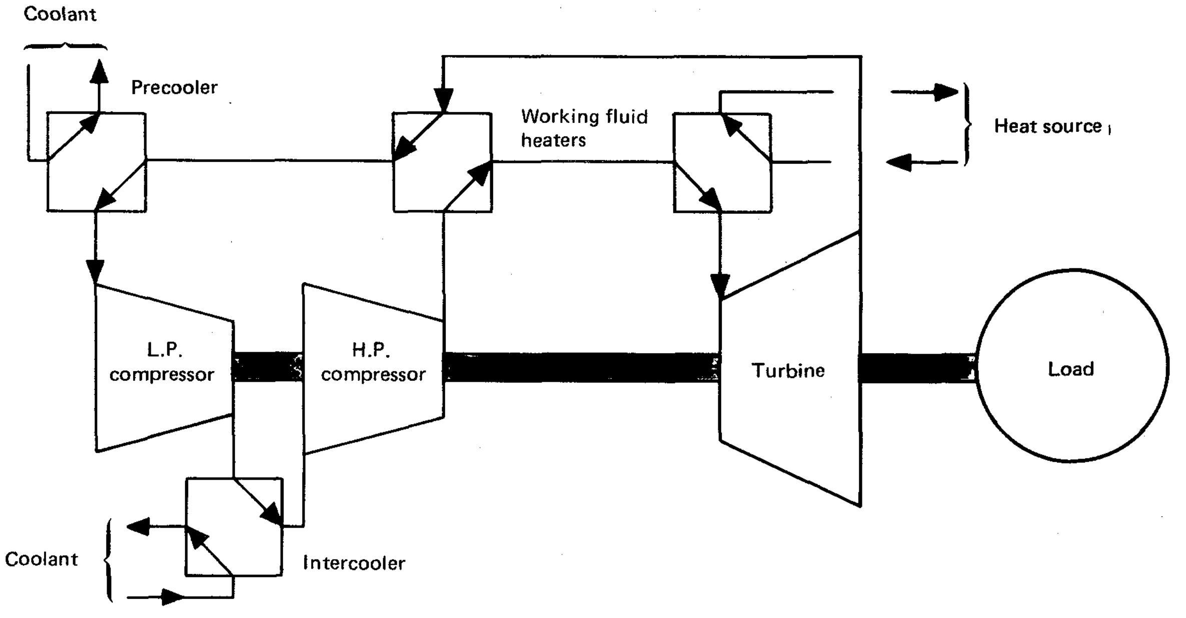


d) **Intercooled and reheat cycle (compound type), multi-shaft gas turbine with load coupled to low-pressure shaft**



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

FIGURE 1 (*continued*)



f) Single-shaft closed cycle gas turbine

FIGURE 1 *(concluded)*

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

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

4.26 fuel stop valve : A device which, when actuated, shuts off all fuel flow to the combustion system.

4.27 dead band : The total range through which an input can be varied with no resulting measurable corrective action of the fuel flow controller. In case of speed, dead-band is expressed in per cent of rated speed.

4.28 governor droop : The steady state speed changes produced by the change of output from zero to the rated output, expressed as a percentage of the rated speed.

4.29 overtemperature detector : The 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.

4.30 fuel calorific value : The higher calorific value is the total heat released per unit mass of fuel burned, expressed in kilojoules per kilogram. The lower calorific value is the higher calorific value less the heat absorbed by the vaporized water formed during combustion, expressed in kilojoules per kilogram.

The two calorific values can be obtained for constant volume or for constant pressure respectively, the difference being rather small.

The higher calorific value for constant volume is obtained using a bomb calorimeter. The lower calorific value for constant pressure is used in the steady flow combustion process (see ISO 2314).

4.31 heat rate : The heat consumption per unit of net power of the gas turbine, expressed in kilowatts of heat per kilowatt of power, based on the lower calorific value of the fuel including the sensible heat above 15 °C (see also 8.2.3 in ISO 2314). This may apply also to the test fuel in clause 6. This can also be expressed as the reciprocal of thermal efficiency (see 4.33).

4.32 specific fuel consumption : The mass rate of the fuel consumed per unit of power, expressed in grams per kilowatt hour, using the lower calorific value specified in 7.1.2.

4.33 thermal efficiency : The ratio of the net power output to the heat consumption based on the lower calorific value of the fuel [see 8.2.2 and 8.3.3 e) in ISO 2314].

4.34 turbine inlet temperature : The mean temperature of the working fluid immediately upstream of the first stage stator vanes (as determined in 8.6 in ISO 2314).

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

4.36 idling speed : The speed designated by the manufacturer at which the turbine will run in a stable condition and from which loading or shutdown may take place.

4.37 maximum continuous speed : The upper limit of the continuous operating speed of the gas turbine output shaft.

4.38 rated speed : The speed of the gas turbine output shaft at which the rated power is developed.

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

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

4.41 mass to power ratio (mobile applications) **:** The ratio of the total dry mass of the gas turbine elements, in accordance with 4.1, to the power in 7.3 of the gas turbine, expressed in kilograms per kilowatt.

4.42 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. Since this is a dangerous mode of operation, the surge condition must be avoided for all anticipated operating conditions.

5 STANDARD REFERENCE CONDITIONS

The standard reference conditions on which ISO power, efficiency, heat rate or specific fuel consumption are based are as follows :

5.1 Air intake conditions

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

— a total pressure of 101,3 kPa[1)];

— a total temperature of 15 °C;

— a relative humidity of 60 %.

5.1.2 Except in the case where intercooling is involved or where water spray coolers are used, the effect of humidity may generally be ignored.

5.2 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.

5.3 Cooling water conditions (if applicable)

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

5.4 Working fluid heater or cooler

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

6 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 11.7), a test fuel of a mutually agreed specification shall be used.

7 RATINGS

7.1 General

7.1.1 The output power of a given gas turbine at a given 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 turbine inlet temperature. To achieve a rating it is necessary to adopt a standard condition 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.

7.1.2 The performance ratings of gas turbines shall be assessed on the lower calorific value of the fuel used as follows :

a) turbines intended for use on liquid fuel : 42 000 kJ/kg;

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

The calorific value 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.

1) 100 kPa = 1 bar = 750,1 mmHg

7.2 Operational modes

Unless special circumstances apply, and these must be specially agreed between the purchaser and the manufacturer, the rating of a gas turbine shall be specified under a combination of one of the classes in 7.2.1 together with one of the ranges of average number of starts per annum in 7.2.2 (for 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 12.1 c)).

NOTE — It should be recognized that some gas turbine applications will operate with a combination of the classes in 7.2.1. In such cases the purchaser should specifiy the anticipated number of annual hours of operation at the specified power ratings in each class. Operation outside these specified power ratings/operational modes could materially affect the inspection intervals and maintenance required.

7.2.1 *Classes*

Class A : operation up to and including 500 h per annum (Reserve peak);

Class B : operation up to and including 2 000 h per annum (Peak-load);

Class C : operation up to and including 6 000 h per annum (Semi-base-load or mid-range);

Class D : operation up to and including 8 760 h per annum (Base-load).

7.2.2 *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.

7.3 ISO standard ratings

The manufacturer shall declare standard ratings, based on net shaft power adjusted for any auxiliaries not driven directly by the turbine as defined in 8.1 in ISO 2314, under the standard reference conditions in clause 5, 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.

NOTE — For gas turbines used for generation, the above ratings are known as "ISO peak load" and "ISO base load" respectively.

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

7.4 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 loads as given in 8.1.2 in ISO 2314.

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

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, 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 6.3.5 in ISO 2314).

8 CONTROLS AND PROTECTION DEVICES

8.1 Starting

The starting control system, including any pre-start requirements, such as barring, may be manual, semi-automatic or automatic as defined below :

8.1.1 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.

8.1.2 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.

8.1.3 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.

8.2 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.

8.3 Shutdown

This may be achieved by manual, semi-automatic or automatic means. In all cases, however, the principal sequence of operations is essentially as follows :

8.3.1 *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 shutdown of auxiliaries not required for barring.

e) Barring period, if necessary.

f) Shutdown of remaining auxiliaries, for example lubricating oil pumps.

g) Return to starting conditions.

8.3.2 *Mechanical drives*

a) Controlled unloading to minimum load conditions.

b) Cooling period where applicable.

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

d) Barring period, if necessary.

e) Shutdown of remaining auxiliaries, for example lubricating oil pumps.

f) Return to starting conditions.

8.3.3 *Emergency shutdown*

a) Emergency shutdown 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 shutdown the driven equipment from the system which it is supplying 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 shutdown sequences, as appropriate, shall subsequently take place, but where automatic restart is included, means shall be provided to prevent automatic restart without manual reset.

8.4 Purging

8.4.1 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 permit the gas turbine to displace at least three times the volume of the entire exhaust system (including the stack) at least three times before firing the unit. In cases where alternative precautions are taken, this may not be necessary.

8.4.2 Where liquid fuels of a highly volatile nature are used, special precautions may be necessary.

8.5 Fuel control

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

8.6 Constant speed

Gas turbines which are to be regulated to a substantially constant speed (in particular those driving 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.

8.7 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.

8.8 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 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.

8.9 Fuel governor valve

The fuel governor valve (see 4.25) shall return to minimum position under any turbine shutdown condition.

8.10 Fuel shut-off

8.10.1 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 shutdown condition and which will not open until all permissible firing conditions are satisfied.

8.10.2 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.

8.10.3 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.

8.11 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.

8.12 Manual check on overspeed controls

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

NOTE — It is desirable that this should be done as far as is practicable without trip shutdown and without temporary loss of protection.

8.13 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.

8.14 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.

8.15 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.

8.16 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.

8.17 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.

8.18 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. However, for large output generator applications the dead band will be expected to be generally lower.

8.19 Stability of the speed governing system

8.19.1 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 isolated;

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.

8.19.2 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 ± 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 ± 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.