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Gas turbines — Procurement —

Part 9: Reliability, availability and maintainability

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Partie 9: Fiabilité, disponibilité, maintenance

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

This second edition cancels and replaces the first edition (ISO 3977-9:1999), which has been technically revised.

The main changes are as follows:

— safety aspects of the document were removed since this is a procurement standard.

A list of all parts in the ISO 3977 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This is a procurement standard developed for the aspects of reliability, availability and maintainability of gas turbines.

Gas turbines — Procurement —

Part 9: Reliability, availability and maintainability

1 Scope

This document provides a basis for exchange of information about reliability, availability and maintainability between gas turbine manufacturers, users, consultants, regulatory bodies, insurance companies and others. It defines terms and definitions and also describes component life expectancy, repairs and criteria for determining overhaul intervals.

This document is applicable to all elements of the gas turbine and auxiliaries.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 3977-3, *Gas turbines — Procurement — Part 3: Design requirements*

ISO 11086, *Gas turbines — Vocabulary*

ISO 19859, *Gas turbine applications — Requirements for power generation*

ISO 12100, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3977-1, ISO 3977-3, ISO 11086, ISO 12100 and ISO 19859 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
ageing
loss of *performance* (3.21) of a gas turbine due to wear and tear experienced in normal operation which is not recoverable by compressor cleaning, turbine cleaning, filter cleaning, etc.

Note 1 to entry: It is normally the result of increased seal clearances due to vibration and wear, loss of profile and increased blade surface roughness due to corrosion, erosion, etc

3.2
available
state in which a unit is capable of providing service, whether or not it is actually in service, regardless of the capacity level that can be provided

3.3
coating
in general, a consumable and generally replaceable overlay provided to protect the base material against corrosion and/or erosion and/or act as a thermal barrier.

3.4
condition monitoring
assessment of the condition of a gas turbine or its components by measuring those parameters which, over time, have been established to correlate with an incipient failure condition, and where the monitoring action is non- intrusive with respect to the equipment

Note 1 to entry: Any subsequent maintenance activity which is based upon a diagnosis of parts condition over time and executed in accordance with the monitored degree of deterioration, is referred to as "on-condition maintenance".

3.5
equivalent operating hours
weighted operating events affecting the life of the machine forming an equivalent operating time to determine inspection intervals or life expectancy

3.6
fired start
any start which achieves full ignition and applies heat to the gas path components

Note 1 to entry: For fired hours, see *service hours* (3.26).

3.7
failure
sudden and unexpected ending of the ability of a component or equipment to fulfil its function

3.8
forced outage
FO
unplanned component *failure* (3.7) (immediate, delayed, postponed) or another condition that requires the unit to be removed from service immediately or before the next planned *shutdown* (3.28)

3.9
forced outage hours
FOH
time, in hours, during which the unit or a major item of equipment was unavailable due to forced (unplanned) outages

3.10
combustion inspection
activity of determining the condition of the combustor section of the gas turbine (including the transition duct)

3.11
hot gas path inspection
activity of determining the condition of the combustion system together with the turbine components of the gas turbine

3.12
inspection
activity of determining the condition of a component or assembly and necessary replacement

3.13
major inspection
activity of determining the condition of the entire gas turbine

3.14
maintenance
sum of all measures intended to determine the actual gas turbine condition, together with the measures required to preserve/restore the specified condition

3.15
off-line
any activity whilst the machine is out of operation

3.16
on-line
any simultaneous activity whilst the machine is in operation

3.17
on-line inspection
any *inspection* (3.12) activity (e.g. of lubricating oil filter) carried out concurrent with the gas turbine being in operation

3.18
on-line maintenance
any *maintenance* (3.14) activity (e.g. of the auxiliary pump or sensing device) carried out simultaneously with the gas turbine being in operation

3.19
operating hour
accumulated period of time from *start* (3.29) initiation operation to full stop

3.20
overhaul
act of dismantling, reconditioning, renewal and/or replacement of components or sub-assemblies of a gas turbine in preparation for continued operation in accordance with the manufacturer's guidelines

3.21
performance
power output and efficiency (heat rate) of a gas turbine as stated in the manufacturer's specification

3.22
period hours
PH
hours in the period under consideration

3.23
fast start
starting sequence in which the load is applied to a gas turbine according to an accelerated programme

3.24
repair
any activity of correction by appropriate measures, including replacement if necessary, of any part of the gas turbine, which is damaged, destroyed or malfunctions or otherwise breaks down

3.25
scheduled maintenance
planned *maintenance* (3.14) action with preplanned shutdown of the gas turbine at a specified time

3.26
service hours
SH
accumulated period of time from main flame ignition through to flame extinction

3.27
service factor
SF
ratio of *service hours* (3.26) to *period hours* (3.22) in a period under consideration

$$F_{SF} = (t_{SH}/t_{PH}) \times 100\ \%$$

where F_{SF} is the service factor (SF)

3.28
shutdown
event in which the unit is brought from operation to a stationary condition under control of a programmed unloading and stopping sequence

3.29
start
act of getting the gas turbine and its driven equipment from the ready-to-start condition to the ready-to-load condition

Note 1 to entry: This includes synchronization with the network, breaker closure and stable running thereafter in the case of gas turbines driving alternators, and stable running of the driven equipment for mechanical drive gas turbines.

3.30
starting reliability

$$F_{SR} = \frac{n_{SS}}{(n_{SS} + n_{FS})} = \frac{n_{SS}}{n_{SA}}$$

where

F_{SR} is the start reliability (SR);

n_{SS} is the number of successful starts (SS);

n_{FS} is the number of failures to start (FS);

n_{SA} is the number of starting attempts (SA).

3.31
successful start
SS
occurrence of bringing a unit through a starting attempt to the in-service state within a specified period, as evidenced by the maintained closure of the generator to the system or stable operation of the driven equipment

3.32
trip
sudden *shutdown* (3.28) of the unit from load by stopping the fuel supply and opening the load or generator breaker

3.33
trip-to-idle
sudden reduction of the unit from load to idle on receipt of an appropriate grade of *trip* (3.32) signal

3.34
uprating
act of increasing the power output and/or efficiency of an existing gas turbine by the exchange of parts or adding/modifying auxiliary systems designed for the condition imposed by the increased *performance* (3.21)

Note 1 to entry: Uprating can sometimes be achieved by increasing the turbine inlet temperature, without physical modification after a successful field trial at a lower, i.e. introductory, rating.

4 Maintainability

4.1 General

Maintainability is the probability that an item will be retained in or restored to a specified condition within a given period of time when the scheduled maintenance is performed in accordance with the manufacturer's prescribed procedures and resources. The term is also used to denote the discipline of studying and improving the maintainability of products, primarily by reducing the amount of time required to diagnose and repair failures.

For the purposes of this document, the planned outage factor shall be used as a basic measure of maintainability.

$$F_{\mathrm{POF}} = \frac{t_{\mathrm{POH}}}{t_{\mathrm{PH}}} \tag{1}$$

where

F_{POF} is the planned outage factor (POF);

t_{POH} is the planned outage hours (POH);

t_{PH} is the period hours (PH).

NOTE 1 In IEEE 762:2023 9.2.3.4.1, The planned outage factor in Formula (1) is written as $POF = \frac{POH}{ACTH}$ where ACTH is active hours.

Values shall be supplied for

— basic maintenance and inspection: 8 760 h (1 year), and

— major service and inspection: 26 280 h (3 years) or less (using cumulated period hours).

Average forced outage period (sometimes called mean down time) for the gas turbine package, shall be used as shown in Formula (2):

$$\bar{t}_{\mathrm{FOP}} = \frac{t_{\mathrm{FOH}}}{n_{\mathrm{FO}}} \tag{2}$$

where

$\bar{t}_{\mathrm{FOP}}$ is the average forced outage period (FOP);

t_{FOH} is the forced outage hours (FOH);

n_{FO} is the number of forced outages (FO).

NOTE 2 In IEEE 762:2023, 6.10.1, the mean forced outage duration in Formula (2) is written as $r = \frac{FOH}{\text{number of forced outages}} MFOD = \frac{FOH}{NFO}$ where r is the mean forced outage duration and NFO is the number of forced outages.

NOTE 3 The purpose of this clause is to provide a basis for the exchange of maintenance information between the user and manufacturer.

4.2 Manufacturer's responsibility

4.2.1 Inspection schedules

4.2.1.1 The manufacturer shall provide a schedule of inspections necessary to maintain the unit in a safe and reliable condition. The manufacturer shall state:

— component lifing;

— coating lifing;

— how intervals between the different types of inspection are to be determined;

— how the different types of inspection are influenced by the operating regime and type of fuel and water or steam injection.

As examples, two methods are suggested:

a) method based on assigning equivalent operating hours to every event in the operating history of the unit;

b) method based on a series of operating regimes to which are related inspection schedules, together with multipliers to account for different fuels and different loads (base, peak, reserve peak, etc.).

4.2.1.2 The gas turbine manufacturer and/or the user define an operating regime or a series of operating regimes as appropriate.

Examples of operating regimes which represent those found in common practice are:

— A: full-load continuous;

— B: utility-base load;

— C: utility-intermediate;

— D: alternating base and peak load;

— E: daily cycling;

— F: utility-peaking;

— G: emergency standby;

— H: user specific.

Regimes A to H are defined in terms of:

— fired hours;

— service factor;

— fired hours/start;

— fast starts;

— unit trips from full load.

The manufacturer defines inspection intervals (e.g. combustion inspection, hot gas path inspection, major inspection) based on operating hours and modified for operational regimes and various multipliers. Examples of multipliers are (but not limited to):

a) fuel effects:

— gas;

- alternative gas;
- distillate oil;
- crude oil;
- heavy residual fuel;
- user specific;

b) firing temperature effects:

- base load;
- peak load;
- reserve peak load;

c) operation effects:

- fast hot start;
- fast cold start;
- GT trip;

d) water/steam injection effects.

Together with the schedule of inspections, the manufacturer shall indicate the following for each type of inspection:

- task description;
- estimated outage time;
- estimated parts and material requirements;
- estimated personnel man-hour requirements;
- skill levels, tools, testing equipment and facility requirements;
- recommended location for task accomplishment;
- details of all components and assemblies to be removed from site to a repair centre;
- total time away from site of components and assemblies sent to a repair centre;
- mass of heaviest item to be lifted;
- access required;
- times at which meetings between manufacturer and user shall be held to review previous inspections and operating history, and to plan the next inspection/overhaul;
- times at which lubricating oil and hydraulic fluid assays should be carried out.

4.2.2 On-line inspection and on-line maintenance

The manufacturer shall state what inspection and maintenance work may be carried out with the gas turbine on-line, together with any load or speed restrictions which are imposed by these activities. The manufacturer shall also state what special equipment is required and what safety precautions shall be observed when carrying out on-line inspection and maintenance.

4.2.3 Condition monitoring

If required by the purchaser and if available, the manufacturer may offer a condition monitoring system, giving full details of the information which needs to be monitored, the frequency of monitoring, how the information is processed and any methods of forecasting and/or diagnosis of possible faults, deterioration or the need for maintenance, e.g. trend analysis.

4.2.4 Running maintenance

The manufacturer shall state all inspection and maintenance which shall be carried out as part of normal operation outside the scheduled inspections, including compressor cleaning, turbine cleaning, filter cleaning, filter changing, oil changing, etc. As part of this requirement, the manufacturer shall indicate all methods available for cleaning, without dismantling the compressor and/or turbine.

4.2.5 Fouling

The manufacturer shall state typical figures for recoverable performance loss due to compressor and/or turbine fouling, based on similar plant on similar operating regimes in similar environments. If turbine fouling is significant, it should be identified separately.

Information should be provided by the manufacturer to show typical recovery in performance from major and minor maintenance actions, compressor washing, both on-line and off-line, and air intake filter replacement.

4.2.6 Degradation

If required by the purchaser, the manufacturer shall prove predictions of long-term non-recoverable performance due to ageing, based on experience with similar plant. Information on changes to compressor mass flow, compressor efficiency, gas turbine exhaust temperature, power output and heat rate after periods of 4 000, 8 000, 16 000, 32 000 and 48 000 operating hours could be provided.

4.3 User's responsibility

It is the user's responsibility to carry out the following.

a) Establish a fuel purchasing, handling and storage policy to ensure that only as-specified fuel is delivered to the gas turbine.

   This may include (but not limited to)

   — monitoring of fuel quality as delivered and stored,

   — the use of a calibrated gas/liquid chromograph,

   — use of magnetic plugs,

   — the cleaning and examination of fouled filters,

   — the maintenance of fuel storage breathing apparatus to restrict the entry of liquids and solids,

   — the periodic cleaning of fuel storage facilities, and

   — centrifuging as appropriate and the logging of fuel quality.

b) Maintain competency of staff.

c) Observe manufacturer´s operating and maintenance instructions.

d) Use only manufacturer-recommended spare parts and consumables.

e) Keep inspection and maintenance records.

f) Plan major maintenance. This would also apply to major refurbishment or uprating.

g) Store and care maintenance equipment.

4.4 Spares parts

The manufacturer shall provide a list of recommended parts required:

a) installation and commissioning consumable and contingency spares;

b) operational consumable spares which include the spares to cater for the random failure of minor components during normal operation between inspections such as:

- gaskets;
- "O" rings;
- thermocouples;
- temperature switches;
- pressure switches;
- filter elements;

c) maintenance/overhaul spares;

These are spares needed at the various types of scheduled inspection.

d) operational contingency spares.

These are spares to cater for unpredictable failures of components, and could include bearings, auxiliary pumps, sets of compressor blades, complete rotors or gas generators.

4.5 Operating log sheets

The manufacturer shall provide, by agreement with the user, operating log sheets in which to record the operating history of the gas turbine and driven unit. Alternatively, automatic data recording may be provided. The following is a typical list of data which requires to be logged/recorded.

a) Performance:

- pressure drop across intake air filter;
- compressor inlet pressure;
- compressor inlet temperature;
- compressor discharge pressure;
- compressor discharge temperature;
- compressor mass flow;
- turbine entry pressure;
- turbine exhaust pressure;
- turbine exhaust temperature;
- fuel flow(s);
- turbine speed (s);

- system frequency;
- load;
- throttle opening;
- guide vane position(s);
- water/steam injection flow;
- fuel calorific value.

b) Mechanical:

- vibration levels;
- oil pressures;
- oil temperatures;
- oil tank level(s);
- cooling air flow(s);
- cooling air pressures;
- cooling air temperatures;
- cooling air control valve position(s);
- cooling water pressure(s);
- cooling water temperature(s);
- acceleration time(s);
- run-down time(s).

c) Emissions:

- NO_x
- CO
- O_2
- CO_2

} at intervals or continuously as required by regulatory authorities or others

- SO_2;
- C as soot;
- unburnt hydrocarbons (UHC).

d) Availability and reliability:

- number of attempted normal starts;
- number of attempted fast starts;
- number of successful normal starts;
- number of successful fast starts;

- operating hours up to base load;
- operating hours up to peak load;
- operating hours as synchronous condenser;
- alarms:
  - date and time;
  - reason;
- trip-to-idle:
  - date and time;
  - reason;
- trips fuel shut-off:
  - date and time;
  - reason;
- outage events:
  - date and time of outage;
  - date and time of end of outage;
  - location;
  - mode;
  - cause;
  - consequence;
  - measures;
- shutdown:
  - date, time and reason;
  - energy generated.

5 Reliability and availability

5.1 Reliability acceptance tests

Reliability acceptance tests are short-duration tests that do not accurately measure long-term inherent equipment reliability or availability, but rather serve to screen for the acceptability (or thoroughness) of manufacturing and installation. The remedy for failure of a reliability acceptance test shall be to apply a generic correction to the observed deficiencies and then re-attempt the test.

One form of acceptance test is a starting reliability acceptance test. Starting reliability acceptance tests require a number of consecutive successful starts performed in accordance with operating instructions supplied with the unit.

Another common form of a reliability acceptance test is the 15-day or 30-day demonstration test, for which success is defined as not exceeding X forced outage events or Y equivalent plant outage hours over the duration of the test. If the user requests this type of reliability acceptance test, the supplier shall provide values for both X and Y appropriate to the plant configuration and normal operating expectations. As a