IS 15666-9 (2006): Gas turbines - Procurements, Part 9: Reliability, availability, maintainability and safety [ETD 15: Rotating Machinery]

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*भारतीय मानक*

# गैस टरबाइन — खरीद

## भाग 9 विश्वसनीयता, उपलब्धता, रख-रखाव और सुरक्षा

*Indian Standard*

# GAS TURBINES — PROCUREMENT

## PART 9 RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY

ICS 27.040



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**Price Group 10**

Rotating Machinery Sectional Committee, ET 15

NATIONAL FOREWORD

This Indian Standard (Part 9) which is identical with ISO 3977-9 : 1999 'Gas turbines — Procurement — Part 9 : Reliability, availability, maintainability and safety' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Rotating Machinery Sectional Committee and approval of the Electrotechnical Division Council.

The text of the ISO Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma ( , ) has been used as a decimal marker while in Indian Standards, the current practice is to use a point ( . ) as the decimal marker.

In this adopted standard, reference appears to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard which is to be substituted in its respective place is listed below along with its degree of equivalence for the edition indicated:

| *International Standard* | *Corresponding Indian Standard* | *Degree of Equivalence* |
|---|---|---|
| ISO 2314 : 1989 Gas turbines — Acceptance tests | IS 15664 : 2006 Gas turbines — Acceptance tests | Identical |

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Indian Standard*

# GAS TURBINES — PROCUREMENT

## PART 9 RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY

## 1 Scope

The purpose of this part of ISO 3977 is to provide a basis for exchange of information about reliability, availability, maintainability and safety between gas turbine manufacturers, users, consultants, regulatory bodies, insurance companies and others. It defines terms and definitions used within this part of ISO 3977 and also describes component life expectancy, repairs and criteria for determining overhaul intervals.

This part of ISO 3977 is applicable to all elements of the gas turbine, especially, but not limited to, the following:

— compressor

— turbine

— combustion system

— intercooler

— regenerator or recuperator

— air ducting system

— exhaust ducting system

— air intake system

— control system

— fuel system

— lubrication system

— cooling water system

— rotor bearings

— gears

— coupling

— starting equipment

— baseplate/foundation

— enclosures and ventilation system.

## 2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this part of ISO 3977. For dated references, subsequent amendments to, or revisions of, this publication do not apply. However, parties to agreements based on this part of ISO 3977 are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

## 3 Terms and definitions

For the purposes of this part of ISO 3977, the following terms and definitions apply.

**3.1**
**actual unit starts**
**AUS**
number of times the unit was actually synchronized or run from the shut-down situation up to the required speed

**3.2**
**age**
actual number of calendar years the unit has been in commercial service

**3.3**
**ageing**
loss of performance 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 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.

**3.4**
**attempted unit starts**
number of attempts to synchronize the unit or run up to the required speed after being shut down

NOTE Repeated failures to start for the same cause within the allowable specified starting time period, without attempting corrective action, are considered a single attempt.

**3.5**
**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

**3.6**
**available hours**
**AH**
time, in hours, during which the unit is available for service

**3.7**
**availability factor**
**AF**
probability that a unit, major equipment or component will be usable at a point in time, based on the past experience with that specific gas turbine:

$$AF = 1 - \frac{FOH + POH}{PH} = \frac{AH}{PH}$$

where

FOH is forced outage hours

POH is planned outage hours

PH is period hours

**3.8**
**availability rate**
**AR**

$$AR = \frac{SH}{SH + OH}$$

where

SH is service hours

OH is outage hours

**3.9**
**average run time**
**ART**

$$ART = \frac{SH}{AUS}$$

**3.10**
**base load rated output**
normally expected or guaranteed output of the gas turbine when operating at the specified conditions and at the base-rated turbine temperature level (or other limit imposed by the manufacturer) and in a new and clean condition

**3.11**
**chemical vapour deposition**
**CVD**
method of producing a coating, based on a chemical reaction between a gaseous phase of the coating material and the heated surface of the substrate

NOTE See coating (3.13).

**3.12**
**chromizing**
coating by a chromium overlay

NOTE Also known as chromating [see coating (3.13)].

**3.13**
**coating**
in general, a consumable and generally replaceable overlay provided to protect the base material against corrosion and/or erosion

EXAMPLE The following are types of coatings which may be provided:

— chemical vapour deposition (CVD)

— chromizing

— diffusion chromizing

— physical vapour deposition (PVD)

— plasma spray

— atmospheric plasma spray (APS)

— vacuum plasma spray (VPS).

**3.14**
**cold testing**
all functional tests conducted on the installation site up to and including cranking the gas turbine by means of the starter but before firing the gas turbine

**3.15**
**compressor surge**
unstable condition characterized by low-frequency fluctuations in mass flow of the working fluid in the compressor and in the connecting ducts

**3.16**
**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 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".

**3.17**
**corrosion**
chemical reaction and change of the gas turbine material due to corrosive elements in the working fluid

**3.18**
**damage**
sudden unforseen physical loss of the ability of a component or equipment to fulfil a required function

**3.19**
**design life**
usable operating life for which a component or equipment has been designed, including a safety margin against failure

NOTE Where routine repairs are designed to sustain component life, such as recoating, crack repairs, etc., the design life is the total life beyond which repairs are no longer feasible.

**3.20**
**diffusion chromizing**
enrichment of base metal with chromium by a diffusion process to increase the hot corrosion resistance

NOTE See coating (3.13).

**3.21**
**emergency start**
start of a gas turbine in any emergency with the objective of producing power in the shortest possible time, without the realms of the gas turbine operating possibilities

**3.22**
**emergency shut down**
**ESD**
shut down of a gas turbine in an emergency with the objective of taking the machine out of operation in the shortest possible time

**3.23**
**equivalent availability factor**
**EAF**

$$\mathrm{EAF} = \frac{\mathrm{PH} - (\mathrm{EUDH} + \mathrm{EPDH} + \mathrm{ESEDH})}{\mathrm{PH}} \times 100\ \%$$

**3.24**
**equivalent forced derated hours**
**EFDH**
product of the forced derated hours (FDH) and the size of hours reduction, divided by the net maximum capacity (NMC)

**3.25**
**equivalent forced derated hours during reserve shutdowns**
**EFDHRS**
output reduction factor given by the ratio of output reduction and net maximum capacity (NMC)

**3.26**
**equivalent operating hours**
$T_{eq}$
weighted operating events affecting the life of the machine forming an equivalent operating time to determine inspection intervals or life expectancy

EXAMPLE

$$T_{eq} = a_1 n_1 + a_2 n_2 + \sum_{i=1}^{n} t_i + f \times w \times (b_1 t_1 + b_2 t_2)$$

where

$a_1$ is the weighting factor for each start;

$n_1$ is the number of fired starts;

$a_2$ is the weighting factor for fast loading;

$n_2$ is the number of fast loadings;

$t_i$ is the equivalent operation hours for rapid temperature changes, e.g. due to step load changes or load rejections;

$n$ is the number of rapid temperature changes;

$t_1$ is the operating hours with output up to base-load rating;

$b_1$ is the weighting factor for base-load duty;

$t_2$ is the operating hours with output between base- and peak-load ratings;

$b_2$ is the weighting factor for peak-load duty;

$f$ is the weighting factor for contaminated, out of specification or non-specifiable fuels;

$w$ is the weighting factor for injected water or steam;

NOTE Other factors can be considered.

**3.27**
**equivalent planned derated hours**
**EPDH**
product of the planned derated hours (PDH) and the size of reduction, divided by the net maximum capacity (NMC)

**3.28**
**equivalent scheduled derated hours**
**ESDH**
product of the scheduled derated hours (SDH) and the size of reduction, divided by the net maximum capacity (NMC)

**3.29**
**equivalent seasonal derated hours**
**ESEDH**
net maximum capacity (NMC) minus the net dependable capacity derated hours (NDC), multiplied by the available hours (AH) and divided by the net maximum capacity (NMC)

**3.30**
**equivalent unplanned derated hours**
**EUDH**
product of the unplanned derated hours (UDH) and the size of reduction, divided by the net maximum capacity (NMC)

unplanned = forced + maintenance (NERC)

**3.31**
**erosion**
abrasive wear of material by mechanical impact of solid particles in the working fluid

**3.32**
**fired start**
any start which achieves full ignition and applies heat to the gas path components

NOTE For fired hours, see service hours (3.98).

**3.33**
**failure**
sudden and unexpected ending of the ability of a component or equipment to fulfil its function

**3.34**
**failure to start**
**FS**
inability to bring a unit through a qualifying starting attempt to the in-service state within a specified period due to equipment supplied in the contract

NOTE 1 Repeated failures within the specified period are to be counted as a single starting failure. Test starts and failures to start due to equipment not furnished under the contract shall not be counted as starting attempts, failures or successes.

NOTE 2 As a general assurance of readiness, if a unit has not experienced a successful start during the prior 30 days, then the starting attempt is considered as a "test start" and is not counted.

NOTE 3 Procedural errors that do not constitute equipment failure involving repair are not counted as failures-to-start.

NOTE 4 For calculation, FS = number of failures to start.

**3.35**
**forced derating**
unplanned component failure (immediate, delayed, postponed) or another condition that requires the load on the unit be reduced immediately or before the next weekend

**3.36**
**forced derated hours**
**FDH**
sum of all hours experienced during forced deratings

**3.37**
**forced outage**
**FO**
unplanned component failure (immediate, delayed, postponed) or another condition that requires the unit to be removed from service immediately or before the next planned shut down

**3.38**
**forced outage factor**
**FOF**
percentage of forced outage hours (FOH) to the period hours (PH):

$$\mathrm{FOF} = \frac{\mathrm{FOH}}{\mathrm{PH}} \times 100\ \%$$

**3.39**
**forced outage hours**
**FOH**
time, in hours, during which the unit or a major item of equipment was unavailable due to forced (unplanned) outages

**3.40**
**forced outage rate**
**FOR**

$$\mathrm{FOR} = \frac{\mathrm{FOH}}{\mathrm{FOH} + \mathrm{SH}} \times 100\ \%$$

**3.41**
**combustion inspection**
activity of determining the condition of the combustor section of the gas turbine (including the transition duct)

**3.42**
**gross actual generation**
**GAG**
actual amount of energy supplied

**3.43**
**gross available capacity**
**GAC**
greatest capacity at which a unit can operate with a reduction imposed by a derating

**3.44**
**gross capacity factor**
**GCF**

$$\mathrm{GCF} = \frac{\mathrm{GAG}}{(\mathrm{PH} \times \mathrm{GMC})} \times 100\ \%$$

**3.45**
**gross dependable capacity**
**GDC**
gross maximum capacity modified for seasonal limitations over a specified period of time

**3.46**
**gross maximum capacity**
**GMC**
maximum capacity a unit can sustain over a specified period of time when not restricted by seasonal or other deratings

**3.47**
**gross output factor**
**GOF**

$$GOF = \frac{GAG}{(SH \times GMC)} \times 100\ \%$$

**3.48**
**hot isostatic pressing**
**HIP**
heat treatment process with simultaneous application of a high isostatic pressure

**3.49**
**hot corrosion**
accelerated oxidation of metals in the presence of salts, e.g. sodium sulfate, leading to degradation

NOTE The salts tend to dissolve the protective oxides on the metal, thus continuously consuming the base metal. Hot corrosion occurs mainly in the metal temperature range between 700 °C and 900 °C. In the presence of vanadium the hot corrosion will occur at even lower temperatures, down to 565 °C, by forming very corrosive and low melting phases of sodium vanadates.

**3.50**
**hot section inspection**
activity of determining the condition of the combustion system together with the turbine components of the gas turbine

**3.51**
**hot testing**
all functional tests commencing with firing leading to the gas turbine being regarded as operational

**3.52**
**inhibition**
avoiding vanadium hot corrosion by treating the fuel with additives, such as magnesium compounds, thus forming the magnesium vanadate phase with melting points higher than the metal temperature

NOTE Inhibition can lead to severe fouling of the turbine.

**3.53**
**inspection**
activity of determining the condition of a component or assembly and necessary replacement

**3.54**
**invalid outage hours**
**IOH**
includes all outage time not due to preserve, forced outage, planned outage and maintenance outage

EXAMPLES The following come under this category.

— force majeure events such as flood, storm, lightning strikes, externally caused fire, labour disputes, severe sandstorms, etc.;

— system problems, problems with the system to which the driven equipment is connected, excessive frequency and voltage swings and fuel pressure and flow.

**3.55**
**load factor**
mean value of the load during a time period under consideration, expressed as a percentage of the base load output of the gas turbine at actual site conditions

**3.56**
**load rejection**
sudden loss or significant reduction of system load causing the turbine unit to momentarily increase speed, thus coming under the influence of the speed governer or overspeed trip system to avoid undesirable overspeed

**3.57**
**major inspection**
activity of determining the condition of the entire gas turbine for a major overhaul

**3.58**
**maintenance derating**
derating of the gas turbine as the result of the removal of a component for scheduled repairs that can be deferred beyond the end of the next planned shut down, but requires a reduction of capacity before the next planned shut down

**3.59**
**maintenance derated hours**
**MDH**
sum of all hours experienced during maintenance deratings and scheduled derating extensions of any maintenance deratings

**3.60**
**maintenance outage**
**MO**
removal of a unit from service to perform work on specific components that can be deferred beyond the end of the next weekend, but requires the unit be removed from service before the next planned outage

**3.61**
**maintenance outage extension**
**SE or MO**
extension of a maintenance outage

**3.62**
**maintenance outage hours**
**MOH**
sum of all hours experienced during maintenance outages and maintenance outage extensions

**3.63**
**major overhaul**
thorough overhaul that repairs or replaces those parts deemed necessary to allow the gas turbine to have a reasonable expectation of being able to operate for a specified period of time

**3.64**
**maintenance**
sum of all measures intended to determine the actual gas turbine condition, together with the measures required to preserve/restore the specified condition

**3.65**
**maintenance cost**
financial expenditure in terms of labour and materials for undertaking maintenance

**3.66**
**maintenance cycle**
time period after which a maintenance schedule is repeated

**3.67**
**mean time between failures**
**MTBF**
average time between failures which initiate a forced outage, i.e. the ratio of attempted operating hours to the number of forced outages:

$$\text{MTBF} = \frac{\text{PH} - (\text{RSH} - \text{FOH} - \text{POH})}{\text{FO}} = \frac{\text{SH}}{\text{FO}}$$

where

PH is the period hours

POH is the planned outage hours

RSH is the reserve shutdown/service hours

SH is the service hours

FOH is the forced outage hours

FO is the number of forced outages

NOTE This index is sometimes referred to as the mean time between unplanned outages (MTBO).

**3.68**
**mission reliabilty**
**MR**

$$\text{MR} = e^{-\lambda t}$$

where

e is the base of the natural logarithm;

$\lambda$ is the failure rate in events per hour;

$t$ is the mission time in hours.

**3.69**
**net actual generation**
**NAG**
actual amount of energy (in megawatt hours) supplied by the unit during the period being considered, minus any energy supplied by the unit for that unit's own station services or utilities

**3.70**
**net availability capacity**
**NAC**
gross available capacity minus the unit capacity utilized for that unit's station services or auxiliaries

**3.71**
**net capacity factor**
**NCF**

$$\text{NCF} = \frac{\text{NAG}}{(\text{PH} \times \text{NMC})} \times 100\ \%$$

**3.72**
**net dependable capacity**
**NDC**
gross dependable capacity minus the unit capacity utilized for that unit's station services or auxiliaries

**3.73**
**net maximum capacity**
**NMC**
gross maximum capacity minus the unit capacity utilized for that unit's station services or auxiliaries

**3.74**
**net output factor**
**NOF**

$$\text{NOF} = \frac{\text{NAG}}{(\text{SH} \times \text{NMC})} \times 100\ \%$$

**3.75**
**off line**
any activity whilst the machine is out of operation

**3.76**
**on condition maintenance**
concept of maintenance activities to be planned and executed in accordance with the degree and trend of deterioration of specific parts, components and assemblies of the gas turbine depending on the diagnosis of their condition by the monitoring of performance parameters during operation

NOTE This kind of maintenance activity may be scheduled during planned or maintenance outages (see condition monitoring).

**3.77**
**on line**
any simultaneous activity whilst the machine is in operation

**3.78**
**on-line inspection**
any inspection activity (e.g. of lubricating oil filter) carried out concurrent with the gas turbine being in operation

**3.79**
**on-line maintenance**
any maintenance activity (e.g. of the auxiliary pump or sensing device) carried out simultaneously with the gas turbine being in operation

**3.80**
**on-line monitoring**
monitoring activities, previously scheduled and to be executed periodically, simultaneously with the gas turbine being in operation

**3.81**
**operating hour**
accumulated period of time from start initiation operation to full stop

**3.82**
**overhaul**
act of dismantling, reconditioning, renewal and/or replacement of components or sub-assemblies of a gas turbine in preparation for continued operation up to the next scheduled inspection or overhaul in accordance with the manufacturer's guidelines

**3.83**
**ownership cost**
sum of annual fuel, operation and maintenance financial expenditures, to which is added an amortized proportion of the capital cost of the installation

NOTE This may also include an element for loss or profit, where appropriate.

**3.84**
**pattern factor**
**PF**
maximum deviation of the hot gas temperature from the average temperature, divided by the temperature increase in the combustion chamber:

$$PF = \frac{TIT_{max} - TIT_{average}}{TIT_{average} - TVII}$$

where

$TIT_{max}$ is the maximal value of the turbine inlet temperature

$TIT_{average}$ is the average value of the turbine inlet temperature

TVII is the average value of the compressor outlet temperature

**3.85**
**peak rating**
normally expected or guaranteed output of the gas turbine when operating at the specified conditions and at the peak rated turbine temperature level and in a new and clean condition

NOTE The standard ISO peak rating is for up to 2 000 h of operation per year at peak rated temperature level and 500 starts.

**3.86**
**performance**
power output and efficiency (heat rate) of a gas turbine as stated in the manufacturer's specification

**3.87**
**period hours**
**PH**
hours in the period under consideration

**3.88**
**physical vapour deposition**
**PVD**
method of producing a coating, based on a physical reaction between a gaseous phase of the coating material and the heated surface of the substrate

NOTE See coating (3.13).

**3.89**
**plasma spray coating**
**APS or VPS**
overlay of a base metal with a special compound of materials basically on the basis of Co-Cr-Al-Y or Ni-Cr-Al-Y to protect the base metal from hot corrosion

NOTE The coating material is normally added to a hot plasma jet in the form of a powder and sprayed onto the surface of the component in the molten phase. The process may take place under atmosphere (APS = atmospheric plasma spray) or under vacuum (VPS = vacuum plasma spray) [see coating (3.13)].

**3.90**
**rapid start**
fast loading
starting sequence in which the load is applied to a gas turbine according to an accelerated programme

NOTE This is also referred to as an emergency start.

**3.91**
**rebuilds**
complete or substantially complete overhaul of products without any redesigning

**3.92**
**reconditioning**
refurbishment and/or repair of parts to obtain the approximate original design condition

**3.93**
**redesign**
conversion or replacement of any components and/or systems to achieve enhanced operational characteristics

**3.94**
**reliability factor**
**RF**
probability that a unit, major equipment, or component will not be in a forced outage condition at a point in time; i.e. the complement of the ratio of forced outage time (FOH) to total time (PH):

$$RF = 1 - \frac{FOH}{PH}$$

**3.95**
**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

**3.96**
**retrofit**
exchange of major assemblies of a gas turbine by components of a changed design

NOTE See also uprating (3.111) and upgrading (3.110).

**3.97**
**scheduled maintenance**
planned maintenance action with preplanned shut down of the gas turbine at a specified time

**3.98**
**service hours**
**SH**
accumulated period of time from main flame ignition through to flame extinction

**3.99**
**service factor**
**SF**
ratio of service hours to period hours in a period under consideration

$$SF = \frac{SH}{PH} \times 100\ \%$$

**3.100**
**shut down**
event in which the unit is brought from operation to a stationary condition under control of a programmed unloading and stopping sequence

**3.101**
**special tools**
all/any special tools, equipment and systems required for the operation, maintenance and repair of the gas turbine, which normally are supplied by the manufacturer and are not available in any reasonably equipped tool shop

**3.102**
**start**
act of getting the gas turbine and its driven equipment from the ready-to-start condition to the ready-to-load condition

NOTE 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.

**3.103**
**starting attempt**
**SA**
action intended to bring a unit from the shutdown to the in-service state within a specified time

NOTE Repeated initiations of the starting sequence within the allowable specified starting time period without carrying out any corrective repairs are counted as a single attempt. For calculation SA = number of starting attempts.

**3.104**
**starting reliability**
**SR**

$$SR = \frac{SS}{SS + FS} = \frac{SS}{SA}$$

where

SS is the number of successful starts

FS is the number of failures to start

SA is the number of starting attempts

**3.105**
**starting success**
**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

NOTE For calculation SS = number of successful starts.

**3.106**
**trip**
sudden shut down of the unit from load by stopping the fuel supply and opening the load or generator breaker

**3.107**
**trip to idle**
sudden reduction of the unit from load to idle on receipt of an appropriate grade of trip signal

**3.108**
**turbine inlet temperature**
**TIT**
general term indicating the flow-weighted mean total temperature before the turbine

NOTE 1 Depending on the section, there exist different definitions:

— combustor outlet temperature;

— nozzle inlet temperature;

— firing temperature;

— ISO inlet temperature.

Combustor outlet temperature is the flow-weighted mean total temperature of the combustion gas at the combustor outlet section after being diluted by the secondary air. Nozzle inlet temperature is the flow-weighted mean total temperature of the hot gas entering the first stage stationary blades after cooling air from the inlet casing has been added downstream of the combustor outlet. Firing temperature is the flow-weighted mean total temperature of the hot gas before the first stage of rotating blades after cooling and sealing air from the first stage nozzles and turbine disc has been added to the hot gas after it has entered the first stage stationary blades. ISO inlet temperature is a flow-weighted mean temperature before the first stage stationary blades calculated from an overall heat balance of the combustion chamber with the total compressor air mass flow and the total fuel mass flow.

NOTE 2 Generally the temperature of the hot gas is never even but there are deviations from the average value to higher and lower temperatures. The maximum deviation is defined by the pattern factor.

**3.109**
**turbine outlet temperature**
**TOT**
total temperature of the hot gas leaving the turbine

**3.110**
**upgrading**
exchanging of components on an existing installation to those of improved design, which may also achieve an improvement in any or all functions except performance

**3.111**
**uprating**
act of increasing the power output and/or efficiency of an existing gas turbine by the exchange of parts designed for the condition imposed by the increased performance

NOTE 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. See also retrofit (3.96).

## 4 Maintainability

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

### 4.1 Manufacturer's responsibility

#### 4.1.1 General

The manufacturer shall state how the component lives, coating lives and intervals between the different types of inspection are to be determined and how they are influenced by the operating regime and type of fuel.

#### 4.1.2 Inspection schedules

**4.1.2.1** The manufacturer shall provide a schedule of inspections necessary to maintain the unit in a safe and reliable condition. The manufacturer shall state how the component lives, coating lives and intervals between the different types of inspection are to be determined and how they are influenced by the operating regime, 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; and

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.).

**4.1.2.2** Equivalent operating hours, $T_{eq}$, may be defined as:

$$T_{eq} = a_1 n_1 + a_2 n_2 + \sum_{i=1}^{n} t_i + f \times w \times (b_1 t_1 + b_2 t_2)$$

where

$n_1$ is the number of fired starts;

$a_1$ is the weighting factor for each start;

$a_2$ is the weighting factor for each fast loading;

$n_2$ is the number of fast loading procedures;

$t_i$ is the equivalent operating hours for a rapid temperature change, e.g. due to step load changes or trips;

$n$ is the number of rapid temperature changes;

$t_1$ is the operating hours at up to base-load rating;

$b_1$ is the weighting factor for base-load duty;

$t_2$ is the operating hours between base- and peak-load ratings;

$b_2$ is the weighting factor for peak-load duty;

$f$ is the weighting factor for contaminated, out of specification or non-specifiable fuels;

$w$ is the weighting factor for injected water or steam.

The manufacturer states lifetimes and inspection intervals in equivalent operating hours.

**4.1.2.3** With different operating regimes the gas turbine manufacturer and/or the user define an annual operating regime or a series of operating regimes as appropriate. The gas turbine manufacturer then provides a recommended inspection schedule with multipliers for different fuels and load limits. The proposed 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 G are defined in terms of:

— fired hours;

— service factor;

— fired hours/start;

— fast starts;

— unit trips from full load.

These are as shown in Table 1. Regime H is defined by the user for his/her specific application. Based on the agreed operating regime, the gas turbine manufacturer lists the inspection intervals and multipliers appropriate to maximum operating load (to account for the firing temperature) and the type of fuel, as shown in Tables 2 and 3.

**Table 1 — Operating regime (annual operation)**

| | Basis | Range |
|---|---|---|
| **Regime A** | | |
| Fired hours | 8 200 | 8 000 to 8 600 |
| Service factor (%) | 90,6 | 90 to 100 |
| Fired starts | 20 | 3 to 40 |
| Fired hours/start | 410 | Greater than 200 |
| Fast starts | 0 | — |
| Unit trips (from load) | 4 | 0 to 8 |
| **Regime B** | | |
| Fired hours | 7 000 | 6 000 to 8 000 |
| Service factor (%) | 80 | 70 to 90 |
| Fired starts | 50 | 20 to 80 |
| Fired hours/start | 140 | 60 to 400 |
| Fast starts | 0 | — |
| Unit trips (from load) | 4 | 1 to 8 |
| **Regime C** | | |
| Fired hours | 5 000 | 3 000 to 6 000 |
| Service factor (%) | 57 | 35 to 70 |
| Fired starts | 40 | 10 to 60 |
| Fired hours/start | 125 | 60 to 400 |
| Fast starts | 0 | — |
| Unit trips (from load) | 3 | 1 to 6 |
| **Regime D** | | |
| Fired hours | 2 500 | 2 000 to 3 000 |
| Service factor (%) | 34,2 | 20 to 50 |
| Fired starts | 85 | 40 to 120 |
| Fired hours/start | 35 | 30 to 60 |
| Fast starts | 1 | 0 to 5 |
| Unit trips (from load) | 3 | 1 to 6 |
| **Regime E** | | |
| Fired hours | 3 000 | 200 to 4 000 |
| Service factor (%) | 34,2 | 20 to 50 |
| Fired starts | 240 | 250 to 300 |
| Fired hours/start | 12,5 | 10 to 18 |
| Fast starts | 3 | 0 to 10 |
| Unit trips (from load) | 3 | 1 to 6 |

**Table 1** (*continued*)

| | Basis | Range |
|---|---|---|
| **Regime F** | | |
| Fired hours | 400 | 200 to 800 |
| Service factor (%) | 4,5 | 2,2 to 10 |
| Fired starts | 100 | 60 to 150 |
| Fired hours/start | 4 | 3 to 8 |
| Fast starts | 5 | 0 to 20 |
| Unit trips (from load) | 2 | 1 to 6 |
| **Regime G** | | |
| Fired hours | 48 | 20 to 80 |
| Service factor (%) | 0,5 | 0,2 to 0,9 |
| Fired starts | 30 | 10 to 120 |
| Fired hours/start | 1,6 | 0,5 to 2 |
| Fast starts | 10 | 0 to 20 |
| Unit trips (from load) | 0 | 0 to 2 |

The manufacturer shall provide a schedule of inspections indicating the data shown in Tables 2 and 3.

**Table 2 — Gas turbine manufacturer's recommended inspection intervals**

| | | Months between inspections | | |
|---|---|---|---|---|
| | **Operating regime** | **Combustion** | **Hot gas path** | **Major** |
| A | Full-load continuous | | | |
| B | Utility-base load | | | |
| C | Utility-intermediate | | | |
| D | Alternating, base and peak | | | |
| E | Daily cycling | | | |
| F | Utility-peaking | | | |
| G | Emergency standby | | | |
| H | User specific | | | |

**Table 3 — Multipliers to inspection intervals shown in Table 2**

| | | Combustion | Hot gas path | Major |
|---|---|---|---|---|
| **1** | **Fuel effects** | | | |
| 1 a | Gas | | | |
| 1 b | Alternative gas | | | |
| 1 c | Distillate oil | | | |
| 1 d | Crude oil | | | |
| 1 e | Heavy residual fuel | | | |
| 1 f | User specific | | | |
| **2** | **Firing temperature effects** | | | |
| 2 a | Base load | | | |
| 2 b | Peak load | | | |
| 2 c | Reserve peak load | | | |
| **3** | **Water/steam injection effects** | | | |
| 3 a | Water | | | |
| 3 b | Steam | | | |

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.

### 4.1.3 On-line inspection and 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.

#### 4.1.4 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.

#### 4.1.5 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.

#### 4.1.6 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.

#### 4.1.7 Degradation

If required by the purchaser, the manufacurer 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.

### 4.2 User's responsibility

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

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

   This may include monitoring of fuel quality as delivered and stored, the installation of an accurate, calibrated atomic mass spectograph, the use of a gas/liquid chromograph, 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, the use of stainless-steel fuel piping after filtration, off- or on-line centrifuging as appropriate and the logging of fuel quality.

b) The selection of a suitable grade of operating, maintenance, engineering, store keeping, clerical and managerial staff.

c) Periodic training of staff by attendance at manufacturers training courses and international gas turbine maintenance seminars and congresses.

d) The maintenance of air filtration equipment to ensure only clean air enters the compressor.

e) The strict observation of manufacturer's operating and maintenance instructions, including:

   1) the regular logging/recording of agreed readings as recommended by the gas turbine manufacturer,

   2) the periodic calibration of control devices,

   3) lubrication as recommended by the manufacturer and care of lubricating oil.

f) The anticipation of developing faults from log readings, machine response, leaks, vibration noise, etc.

g) The use only of manufacturer-recommended spare parts and consumables (e.g. air filter media).

h) Maintaining a continuous liaison with the manufacturer, keeping him/her informed of machinery performance, carrying out field maintenance recommendations, etc.

i) Keeping inspection and maintenance records and providing the gas turbine manufacturer with ready access to these and operational records, as necessary.

j) Planning major maintenance with the manufacturer. This would also apply to major refurbishment or uprating.

k) Proper care and storage of maintenance equipment.

l) The avoidance of rapid load changes and trips and other potentially harmful operating events such as over-load, over-torque, under frequency, malsynchronizing, short circuit, etc.

### 4.3 Spares holding

The manufacturer, by arrangement with the user, shall provide a list of spare parts required and their usage rate, taking into account:

- the optimum required unit availability and security of power supply;
- the proposed unit operating regime;
- lead time for spare part;
- method of delivery of spares to sit;
- proximity and availability of spares pool;
- proximity and availability of qualified refurbishing facilities;
- access to site;
- facilities available on site.

The spare parts shall be classified into the following categories.

a) Consumable spares

These 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, etc.

b) Overhaul spares

These are spares needed at the various types of scheduled inspection, and could include such components as combustion chamber flame tubes, transition pieces, cross-fire tubes, turbine blades, turbine vanes, etc.

c) 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.

### 4.4 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 $t_1$, $t_2$, $t_3$, $t_4$, $t_5$, ... $t_i$ etc.
- — 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

- $NO_x$ (at intervals or continuously as required by regulatory authorities or others)
- CO (at intervals or continuously as required by regulatory authorities or others)
- $O_2$ (at intervals or continuously as required by regulatory authorities or others)
- $CO_2$ (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
- shut down
  - 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 generic correction to the observed deficiencies and then re-attempt the test.

ISO 2314:1989, subclause 7.2.3.2, specifies a starting reliability acceptance test which reads as follows: "Starting reliability shall have been attained when ten consecutive successful starts are 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 reasonable guideline, the $X$ value should yield at least 70 % probability (Poisson) for individual test success based on the life-cycle expected forced outage event rate. The $Y$ value should correspond to the expected life-cycle plant equivalent availability. The remedy for failure is to re-try the test.

### 5.2 Reliability and availability, calculating and reporting

Availabilty and reliability information should be calculated and reported using the terms and definitions shown in clause 3. Additional availability and reliability information may be found in definitions from standards institutes such as ISO, IEC, DIN, VDE, NERC, IEEE, CEI, ANSI, etc.

# 6 Safety

## 6.1 General

This clause is confined to those aspects of safety that are controllable by adequate design and implementation of the design. It does not cover such safety considerations as personnel training, procedures, and usage of personnel protective equipment.

## 6.2 Safety elements

Safety is of paramount importance in any power plant including a gas turbine power plant. Protection from both human and equipment safety hazards is required. Design and its implementation shall be in accordance with applicable mandatory regulations, standards, etc. 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, vibration, etc.).

c) Alarms to warn of unsafe operating conditions.

d) Suitable safety trips to protect operating personnel and/or equipment.

e) If operators will be near the gas turbine while it is operating, guards, insulation, handrails, etc., should be provided to protect personnel from accidental contact with dangerous elements. Where appropriate, warning signals shall also be supplied.

f) Proper handling equipment and tools shall be available to maintenance personnel; particular attention is required for the 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 personnel who will be near the power plant when it is operating; recognition shall be given to the fact that fire protection systems operating in a confined area can be dangerous to personnel.

i) Manufacturers' 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.

m) Power plant design shall minimize the possibility of fuel gas leakage and gas explosion by provision of suitable arrangements for venting, gas detection, cell/building ventilation, equipment spark suppression, pipework earthing/bonding, etc.

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