

Gas turbines — Acceptance tests

ICS 27.040

National foreword

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Foreword

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

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

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

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

ISO 2314 was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

This third edition cancels and replaces the second edition (ISO 2314:1989), which has been technically revised. It also incorporates the Amendment ISO 2314:1989/Amd.1:1997 and the Technical Corrigendum ISO 2314:1989/Cor.1:1997.

Introduction

This International Standard specifies guidelines and procedures for preparing, conducting and reporting thermal-acceptance tests in order to determine and/or verify electrical power output, mechanical power, thermal efficiency (heat rate), turbine exhaust gas energy and/or other performance characteristics of gas-turbine power plants and gas turbine engines, in this International Standard referred to as “gas turbines”. It is necessary that such performance test results be determined with a high level of accuracy using best engineering knowledge and industry practice in measurement technique and method.

It is necessary that a detailed, project-specific or test-equipment-specific test procedure be prepared by the party executing the performance test, based on the recommendations and guidelines given in this International Standard as well as considering contractual obligations. It is necessary that any deviations from this International Standard be mutually agreed upon by the involved parties prior to the start of the test.

Gas turbines — Acceptance tests

1 Scope

This International Standard applies to open-cycle gas-turbine power plants using combustion systems supplied with gaseous and/or liquid fuels as well as closed-cycle and semi-closed-cycle gas-turbine power plants. It can also be applied to gas turbines in combined cycle power plants or in connection with other heat-recovery systems.

In cases of gas turbines using free-piston gas generators or special heat sources (for example synthetic gas of chemical processes, blast furnace gas), this International Standard can be used as a basis but suitable modifications are necessary.

Acceptance tests of gas turbines with emission control and/or power augmentation devices that are based on fluid injection and/or inlet air treatment are also covered by this International Standard and it is necessary that they be considered in the test procedure, provided that such systems are included in the contractual scope of the supply subject to testing.

Comparative testing can be subject to many different scenarios, depending on the purpose of the conducted measures. This International Standard can also be applied to comparative tests designed to verify performance differentials of the gas turbine, primarily for testing before and after modifications, upgrades or overhaul, although no special reference is made to these topics.

This International Standard also includes procedures for the determination of the following performance parameters, corrected to the reference operating parameters:

- a) electrical or mechanical power output (gas power, if only gas is supplied);
- b) thermal efficiency or heat rate;
- c) turbine exhaust energy (optionally exhaust temperature and flow).

It is necessary that any other performance parameters defined in the contract between equipment supplier and purchaser be considered accordingly in the specific test procedure as well as in the supplier's standard manufacturing test procedure.

This International Standard describes measurement methods and corresponding instruments employed and their calibration arrangement and handling. It includes provisions for preparing and conducting a performance test, defines operating conditions of the gas turbine, boundary conditions and their limits as well as standard conditions (3.9) that should be used as a reference if no other conditions are agreed at the time of purchase. Furthermore, it contains provisions for the measurement data recording and handling, methods for the calculation and correction of the test results as well as the development of the uncertainty thereof.

Test tolerance is not addressed in this International Standard, because it is considered a commercial term not based on statistical analysis of measurement results. It is necessary that the methodology on how to apply tolerances for the demonstration of compliance with the guaranteed values be defined in the contract.

For the optional test to determine exhaust energy and/or flow, these values are determined from an energy balance around the gas turbine. Uncertainty values can be minimized by achieving the limits defined in this International Standard for the key parameters in the energy balance.

This International Standard does not apply to the following:

- a) emission testing;
- b) noise testing;
- c) vibration testing;
- d) performance of specific components of the gas turbine;
- e) performance of power augmentation devices and auxiliary systems, such as air inlet cooling devices, fuel gas compressors, etc.;
- f) conduct test work aiming at development and research;
- g) adequacy of essential protective devices;
- h) performance of the governing system and protective systems;
- i) operating characteristics (starting characteristics, reliability testing, etc.).

2 Normative references

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

ISO 2533, *Standard atmosphere*

ISO 3733, *Petroleum products and bituminous materials — Determination of water — Distillation method*

ISO 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

ISO 6245, *Petroleum products — Determination of ash*

ISO 6974-1, *Natural gas — Determination of composition with defined uncertainty by gas chromatography — Part 1: Guidelines for tailored analysis*

ISO 6975, *Natural gas — Extended analysis — Gas-chromatographic method*

ISO 6976, *Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition*

ISO 9951, *Measurement of gas flow in closed conduits — Turbine meters*

ISO 10715, *Natural gas — Sampling guidelines*

ISO 12213-2, *Natural gas — Calculation of compression factor — Part 2: Calculation using molar-composition analysis*

ISO 14596, *Petroleum products — Determination of sulfur content — Wavelength-dispersive X-ray fluorescence spectrometry*

ISO 20846, *Petroleum products — Determination of sulfur content of automotive fuels — Ultraviolet fluorescence method*

ASTM D4629, *Standard Test Method for Trace Nitrogen in Liquid Petroleum Hydrocarbons by Syringe/Inlet Oxidative Combustion and Chemiluminescence Detection*

ASTM D5291, *Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants*

DIN 51451, *Testing of petroleum products and related products — Analysis by infrared spectrometry — General working principles*

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1

degradation

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 1 This can also be referred to as ageing.

NOTE 2 Adapted from ISO 3977-9:1999, 4.1.7.

3.2

equivalent operating hours

weighted operating events affecting the life of the gas turbine forming an equivalent operating time to determine inspection intervals of life expectancy

NOTE Adapted from ISO 3977-9:1999, 4.1.2.2.

3.3

gas generator

assembly of gas turbine components that produces heated, pressurized gas and provides it to a process or to a power turbine

NOTE Adapted from ISO 3977-1:1997, 2.14.

3.4

gas turbine

machine that converts thermal energy into mechanical work

NOTE 1 It consists of one or several rotating compressors, thermal device(s) that heat 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 as part of the gas turbine.

NOTE 2 Adapted from ISO 3977-1:1997, 2.1.

3.5

heating value

calorific value

specific energy

amount of heat released by the complete combustion in air of a specific quantity of gas or liquid fuel when the reaction takes place at constant pressure

NOTE If the combustion products accounted for are only in the gaseous state, the value is called lower heating value, LHV, or inferior calorific value or net heating value. If the combustion products are gaseous with the exception of water, which is in liquid state, the value is called higher heating value, HHV, or superior calorific value or gross heating value at 15 °C for natural gas fuel.

See ISO 6976.

3.6

power

quantity that may be expressed in terms of mechanical shaft power at the turbine coupling, electrical power of the turbine-generator or gas power in the case of a gas turbine or gas generator producing gas or compressed air

3.7

random error

result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions

See ISO/IEC Guide 99:2007, 2.19.

3.8

reference standard

standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements are derived

See ISO/IEC Guide 99:2007, 5.6.

3.9

standard reference conditions

conditions as defined in ISO 2533, equal to the following:

a) for the ambient air or intake air at the compressor flange (alternatively, the compressor intake flare):

- absolute pressure of 101,325 kPa (1,013 25 bar; 760 mm Hg),
- temperature of 15 °C,
- relative humidity of 60 %;

b) for the exhaust at turbine exhaust recuperator outlet, if a recuperator cycle is used:

- static pressure of 101,325 kPa

NOTE 1 In the case of the closed cycle, the standard conditions for the air heater are 15 °C and 101,325 kPa for the ambient atmospheric air.

NOTE 2 An inlet water temperature of 15 °C applies if cooling of the working fluid is used.

3.10

systematic error bias

mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand

See ISO/IEC Guide 99:2007, 2.17.

3.11

thermal efficiency

ratio of the power output to the heat consumption based on the lower heating value, LHV, or net heating value of the fuel

NOTE Adapted from ISO 3977-1:1997, 2.3.4.

3.12

heat rate

ratio of the fuel energy supplied per unit time to the power produced

NOTE 1 The heat rate is expressed in units of kilojoules per kilowatt hour.

NOTE 2 It is widely used in the power generation industry.

See ISO 11086.

3.13

tolerance

allowed deviation from a specific requirement

3.14

traceability

property of the result of a measurement or the value of the standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

NOTE Adapted from ISO/IEC Guide 99:2007, 2.41.

3.15

turbine inlet temperature

TIT

defined arbitrarily as a theoretical flow-weighted mean temperature before the first-stage stationary blades calculated from an overall heat balance of the combustion chamber with the gas mass flow from combustion mixed with the turbine cooling air mass flows prior to entering the first stage stationary blades

3.16

turbine outlet temperature

TOT

temperature of the hot gas leaving the turbine

3.17

type A evaluation

(of uncertainty) method of evaluation of uncertainty by the statistical analysis of series of observations

See ISO/IEC Guide 98-3.

3.18

type B evaluation

(of uncertainty) method of evaluation of uncertainty by means other than the statistical analysis of series of observations

See ISO/IEC Guide 98-3.

3.19

uncertainty

(of measurement) shortened form of “uncertainty of measurement”, a parameter associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand

NOTE 1 The determination of the quality of a measurement that can be expressed with the uncertainty of the test result is of fundamental importance in any field of measuring and testing. A measure to quantify such quality is the uncertainty of measurement. The shortened term “uncertainty” is used for simplicity in this International Standard.

NOTE 2 The expression “accuracy of measurement” (closeness of the agreement between the result of a measurement and the value of the measurand), commonly abbreviated as “accuracy,” is not associated with numbers and is not used as a quantitative term.

See ISO/IEC Guide 99:2007, 2.26.

3.20

working standard

standard that is used routinely to calibrate or check material measures, measuring instruments or reference materials

See ISO/IEC Guide 99:2007, 5.7.

4 Test boundary

The test boundary concept encompasses the hardware scope of the gas turbine subject to performance testing considering the reference conditions for the given guaranties. It provides the basis for the definition and layout of instrument number, range and location required to determine the energy streams crossing the test boundary as well as to determine the actual conditions during testing for correcting the test results to reference conditions.

Figure 1 shows a typical test boundary for the scope of an open cycle gas turbine for electrical output application with the measurement stations needed for the performance determination. The measurement stations within the test boundary may be used for energy balance calculation as demonstrated in Chapter 8.

The given nomenclature is used for the example calculations in this International Standard.

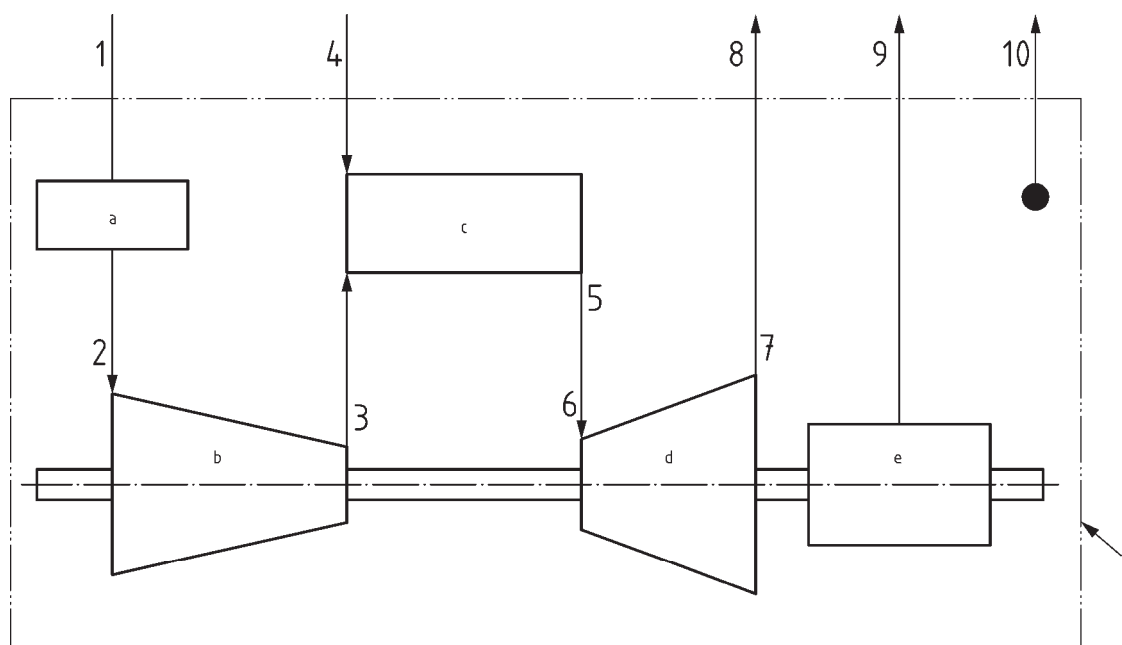


Figure 1 – Test Boundary for Generator Application

- | | |
|-----------------|---|
| a Air filter | d Turbine(s) |
| b Compressor(s) | e Generator |
| c Combustor(s) | f Test boundary for generator application |

The typical test boundary for mechanical drives is shown in Figure 2.

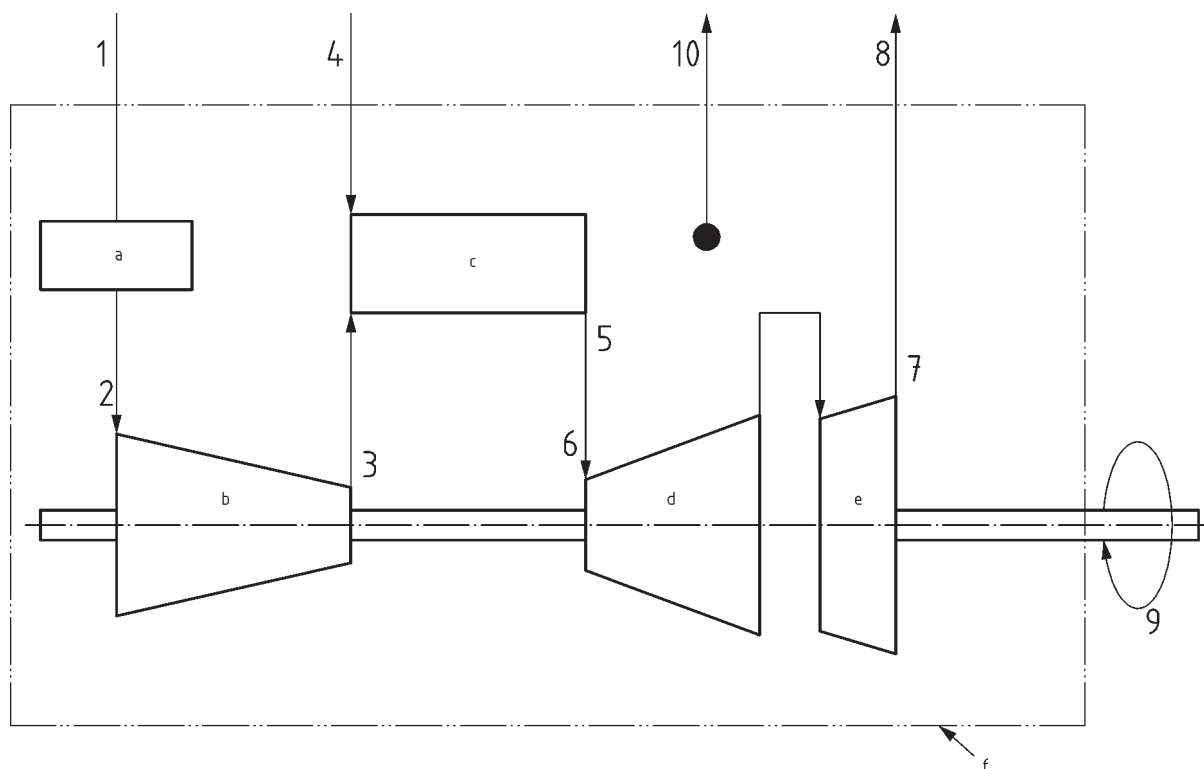


Figure 2 – Test Boundary for Mechanical Drive Application

- | | |
|-----------------|--|
| a Air filter | d Turbine(s) |
| b Compressor(s) | e Power Turbine |
| c Combustor(s) | f Test boundary for mechanical drive application |

Station names are given in Table 1

Table 1 – Station identification nomenclature

Station		Measurands
1	Ambient air	Temperature, pressure, humidity
2	Compressor inlet	Temperature, pressure
3	Compressor outlet	Temperature, pressure
4	Fuel + injection fluid	Flow, temperature, pressure, fuel properties
5	Combustor outlet	N/A
6	Turbine inlet	N/A
7	Turbine exhaust	Temperature, pressure
8	Stack exhaust	Temperature
9	Electrical power	Active power, power factor, frequency, voltage, current
	Shaft power	Torque, rotor speed
10	Losses	Thermal, mechanical, electrical

Note Any additional streams crossing the test boundary should be accounted for.

The losses are needed for the determination of the gas turbine exhaust energy and include all energy fluxes leaving the test boundary. Such losses are typically radiation losses, bearing and gear losses, generator losses and thermal losses. An example for the latter is heat dissipation from compressor air cooling systems in combination with a heat recovery boiler of a combined cycle plant.

Generally the losses have a small influence on the calculated gas turbine exhaust energy and therefore are often taken as constant design value rather than measured. An exception is the heat extracted from cooling systems, which may be determined based on measured flow, temperature and pressure.

5 Symbols

The symbols and nomenclature used in this International Standard are given in Table 2, together with the physical unit.

Table 2 – Symbols

Symbol	Definition	Unit
$C_{P,i}$	Correction factor for power output	-
$C_{P,i,a}$	Correction factor for power output, from measured to standard reference conditions	-
$C_{P,i,b}$	Correction factor for power output, from specified to standard reference conditions	-
$C\eta,i$	Correction factor for thermal efficiency	-
$C\eta,i,a$	Correction factor for thermal efficiency, from measured to standard reference conditions	-
$C\eta,i,b$	Correction factor for thermal efficiency, from specified to standard reference conditions	-
$\cos \varphi$	Generator power factor	-
$c_{p,al}$	Specific heat (heat capacity) at constant pressure of air	kJ / (kg · K)

Table 2 (continued)

Symbol	Definition	Unit
$c_{p,i}$	Specific heat (heat capacity) of gases at constant pressure	kJ / (kg · K)
$c_{p,g7}$	Specific heat (heat capacity) at constant pressure of exhaust gases	kJ / (kg · K)
h_{a1}	Specific enthalpy of air at temperature T_{a1} entering the compressor	kJ / kg
h_{a3}	Specific enthalpy of air at compressor discharge temperature T_{a3}	kJ / kg
h_{ae}	Specific enthalpy of air at temperature T_{ae} leaking from the control volume	kJ / kg
$h_{ct3.2}$	Specific enthalpy of the air flow from the external cooler at temperature $T_{ct3.2}$ entering the control volume	kJ / kg
$h_{ex,i}$	Specific enthalpy of air at temperature $T_{ex,i}$ extracted from the compressor extraction i	kJ / kg
h_{f4}	Specific enthalpy of fuel at temperature T_{f4} entering the heat source (combustion chamber)	kJ / kg
h_{g6}	Mean specific enthalpy of gases at temperature T_{g6} entering the turbine	kJ / kg
h_{g7}	Specific enthalpy of exhaust gases at temperature T_{g7}	kJ / kg
h_{g8}	Specific enthalpy of exhaust gases at temperature T_{g8}	kJ / kg
HR	Heat rate of the gas turbine, based on low heating value (LHV) of the fuel and electrical power output	kJ / kWh
HR_c	Corrected heat rate of the gas turbine	kJ / kWh
HR_m	Calculated from measured data heat rate of the gas turbine	kJ / kWh
h_{w4}	Specific enthalpy of the injected water or steam mass flow at temperature T_{w4} entering the control volume	kJ / kg
h_0	Specific enthalpy of the fuel at reference temperature $T_{f0}=15\text{ °C}$	kJ / kg
I_S	Secondary current at instrument transformer	A
K_I	Ratio of current transformer	-
K_U	Ratio of voltage transformer	-
$\dot{m}_{a1}$	Compressor inlet air mass flow	kg / s
$\dot{m}_{a3}$	Compressor discharge air mass flow	kg / s
$\dot{m}_{ae}$	Mass flow of sealing and/or leakage air leaving the control volume	kg / s
$\dot{m}_{CA,T}$	Total turbine cooling air mass flow	kg / s

Table 2 (continued)

Symbol	Definition	Unit
$\dot{m}_{CA,CC}$	Combustion chamber cooling air mass flow	kg / s
$\dot{m}_{CA,1stV}$	Cooling air mass flow for 1 st turbine vane row	kg / s
$\dot{m}_{e3}$	Mass flow of extracted compressor discharge air	kg / s
$\dot{m}_{ct3}$	Air mass flow to the external cooler leaving and entering the control volume	kg / s
$\dot{m}_d$	Relative difference in inlet mass flow between the equivalent and the actual compressor (that is, equivalent reduction flow of actual compressor inlet air flow)	%
$\dot{m}_{eq}$	Air inlet mass flow of an equivalent compressor without cooling air extraction lines, but with the same power consumption as the actual compressor	kg / s
$\dot{m}_{ex,i}$	Extraction air mass flow at the compressor extraction line i	kg / s
$\dot{m}_{f4}$	Fuel mass flow entering the control volume	kg / s
$\dot{m}_{g6}$	Gas mass flow entering the turbine	kg / s
$\dot{m}_{g7}$	Mass flow of the turbine exhaust gases	kg / s
$\dot{m}_{g7c}$	Corrected mass flow of the turbine exhaust gases	kg / s
$\dot{m}_{g8}$	Mass flow of the turbine exhaust gases	kg / s
$\dot{m}_{w4}$	Injected water or steam mass flow entering the control volume	kg / s
n_c	Reference speed of the output shaft	1/s
n_m	Specified speed of the output shaft during the test	1/s
N	Number of correction factors	-
P_b	Cooling air booster power consumption	kW
P_c	Net shaft power output at reference conditions	kW
P_{COMP}	Compressor shaft power consumption	kW
P_{e9}	Electrical power output at generator terminals	kW
P_{e9c}	Corrected electrical power output at generator terminals	kW
P_{LL}	Transformer load losses	kW
P_{NLL}	Transformer no-load losses	kW
P_S	Net shaft gas turbine shaft power output during the test	kW
P_{TRL}	Transformer losses	kW
Q_G	Generator losses	kW
$Q_{G,d}$	Generator losses from design	kW
Q_{GB}	Gearbox losses	kW
Q_{a1}	Energy stream of compressor inlet air flow, at spec. enthalpy h_{a1}	kJ / s
Q_{a3}	Energy stream of air flow at combustion chamber inlet, at spec. enthalpy h_{a3}	kJ / s
Q_{ae}	Energy stream of sealing and/or leakage air flow leaving the control volume, at spec. enthalpy h_{ae}	kJ / s
$Q_{ct3,1}$	Energy stream of cooling air flow to cooler inlet, at spec. enthalpy h_{a3}	kJ / s
$Q_{ct3,2}$	Energy stream of cooling air flow from cooler outlet, at spec. enthalpy $h_{ct3,2}$	kJ / s
Q_{e3}	Energy stream of external air extraction flow, at spec. enthalpy h_{a3}	kJ / s
Q_{ex}	Energy stream of cooling air extraction equivalent flow expressed as $\dot{m}_d$, at spec. enthalpy h_{a1}	kJ / s

Table 2 (continued)

Symbol	Definition	Unit
Q_{f4}	Energy stream of fuel entering the combustion chamber, based on fuel low heating value (LHV)	kJ / s
Q_{g6}	Energy stream of turbine inlet flow, at spec. enthalpy h_{g6}	kJ / s
Q_{g7}	Energy stream of exhaust flow at turbine at spec. enthalpy h_{g7}	kJ / s
Q_{g8}	Energy stream of turbine exhaust flow at, spec. enthalpy h_{g8}	kJ / s
Q_{7Ta1}	Energy of turbine exhaust flow, with the reference temperature of its spec. enthalpy indexed to the reference ambient air temperature T_{a1}	kJ / s
Q_{7cTa1}	Corrected energy stream of turbine exhaust flow, with the reference temperature of its spec. enthalpy indexed to the reference ambient air temperature T_{a1}	kJ / s
Q_{7cT0}	Corrected energy stream of turbine exhaust flow, with the reference temperature of its spec. enthalpy indexed to the reference temperature T_0	kJ / s
Q_{lo}	Low heating value (LHV)(lower heating value) of the fuel at 15 °C and constant pressure	kJ / kg
Q_m	Gas turbine mechanical losses	kW
$Q_{m,d}$	Gas turbine mechanical losses from design	kW
Q_r	Radiation and convection heat losses of the whole surface	kW
Q_{th}	Thermal heat losses(for example: heat extracted from compressor air cooling system)	kW
$Q_{th,m(d)}$	Thermal heat losses, measured or from design	kW
Q_{w4}	Energy of injected steam/water flow, at spec. enthalpy h_{w4}	kJ / s
$Q_{w4,mc}$	Measured energy of injected steam/water flow, corrected to design if applicable	kJ / s
Q_{10}	Sum of engine losses ($Q_m+Q_G+Q_r+Q_{th} +Q_{GB}$)	kW
$SH = h_{f4} - h_0$	Sensible heat of the fuel	kJ / kg
S_m	Measured apparent power which is the product of measured (rms) voltage and (rms) current	kVA
S_r	Rated apparent power which is the product of rated (rms) voltage and (rms) current	kVA
T_0	Standard reference temperature for specific enthalpy of air and gases	K
T_{f0}	Reference temperature(=15°C) for specific enthalpy of fuel	°C
T_{a1}	Ambient air temperature	°C
T_{a3}	Air temperature at compressor discharge	°C
T_{ae}	Temperature of sealing and/or leakage air flow leaving the control volume	°C
T_c	Control temperature at reference conditions	°C
$T_{ct3.2}$	Temperature of the air flow from the external cooler entering the control volume	°C
$T_{ex,i}$	Extraction air temperature at the compressor extraction line i	°C
T_{f4}	Temperature of fuel entering the heat source (combustion chamber)	°C
T_{g6}	Temperature of gases entering the turbine	°C
T_{g7}	Average temperature of exhaust gases	°C
T_{g7c}	Corrected average temperature of exhaust gases	°C
T_{g7m}	Measured average temperature of exhaust gases	°C
T_{g8}	Mass flow average temperature of exhaust gases at the stack (simple cycle applications)	°C

Table 2 (continued)

Symbol	Definition	Unit
T_m	Control temperature during the test	°C
T_{w4}	Temperature of injected water or steam entering the control volume	°C
U_s	Secondary voltage at instrument transformer	V
η	Thermal efficiency of the gas turbine based on electrical power output and fuel lower heating value	-
η_C	Corrected thermal efficiency of the gas turbine	-
η_m	Measured/calculated thermal efficiency of the gas turbine	-
η_{ic}	Combustion chamber efficiency from design, taken into account the total radiation and convention heat losses	-
$\Delta_{TOT,i}$	Additive correction factor i for turbine outlet temperature	K
$\Delta_{TOT,i,a}$	Additive correction factor i for turbine outlet temperature, from measured to standard reference conditions	K
$\Delta_{TOT,i,b}$	Additive correction factor i for turbine outlet temperature, from specified to standard reference conditions	K
θ	Ratio of the absolute gas turbine compressor inlet air temperatures at test (measured), and at reference conditions	-
δ	Ratio of the ambient absolute pressure to the reference ambient absolute pressure	-

Note:

1. Air or gas temperatures are assumed to be total temperature unless otherwise agreed
2. The general equation of specific enthalpy of ideal gases is $h = h_T - h_{T0} \approx c_p(T - T_0)$

where

h_{T0} is the gas specific enthalpy at the standard reference temperature T_0 of the enthalpy and

T is the actual gas temperature.

Usually $T_0 = 0^\circ\text{C}$: in this case $h_{T0} = 0$ and $h = h_T \approx c_p T$; but it can be assumed equal to the ambient air temperature, or to any other temperature.

6 Preparation for tests

6.1 General

Performance Testing requires complex and detailed preparations. Since the purpose of such tests may vary, it is important to establish upfront the test objectives, identify the participating parties and their role in the process. A clear determination of the equipment boundaries and associated instrumentation shall avoid any potential disagreements after the test. A detailed test procedure specific to the test site/supplier's test facility and conditions shall be agreed by all parties involved.

6.1.1 Agreements before the test

Many factors influence significantly the results of acceptance tests. Therefore tests shall always be carefully programmed, organized and conducted so that the results are of the highest practical accuracy.

6.1.2 Test objectives

The objective of any tests is to determine performance characteristics of the gas turbine in accordance to any previously drawn up agreements such as the Purchase Agreements, Test Criteria Documents, EPC requirements, Power Purchase Agreements, Contractual Services Agreement etc. A detailed procedure for conducting the tests and evaluating the results shall be issued and agreed upon prior to conducting the tests. This test procedure shall provide full details of the method of measurement and about method used for correcting the results from test conditions to the reference conditions or the criteria set out in the pertinent documents. This test standard does not deal with tests needed to determine the environmental emissions, noise and vibration, that generally form part of other test procedures. However, these tests can be carried out concurrently with acceptance tests as per the purchase contracts or other related documents.

6.1.3 Performance degradation

The performance degradation of gas turbine during operation is an existing phenomenon. The degradation on the gas turbine is caused primarily by fouling and erosion of the gas flow path, and also by wear and tear. The agreement to apply degradation corrections to the performance test results is strictly a commercial issue between the parties and beyond the scope of this standard.

In most cases, the gas turbine performance guarantees are made based on equipment “new and clean” condition. The contractual agreements between the parties should define the period when the equipment is considered as new and clean and state if performance corrections are permitted, when equipment is tested beyond this period.

The detailed methodology on how to apply degradation correction may be derived from Comparative Tests, fleet performance of similar units, predictive degradation curves, or other methods. It should be also noted that actual measurement of degradation through Comparative Testing over short time periods is difficult because the rate of deterioration and measurement uncertainty have similar magnitudes and by the fact that during commissioning the control parameters could be changed. The degradation correction may be additive or multiplicative and could be applied to the test results or the guarantees made to the gas turbine as indicated in 8.2.2.5.

6.1.4 Design, Construction and start up considerations

The following recommendations should be considered when establishing the requirements for instrumentation accuracy, calibration, documentation and location of permanent and temporary instrumentation to be used during the test.

1. If permanent installed instrumentation will be used during the test, the requirements of 6.4 should be implemented if possible at early stages of the design. The ability to conduct post test calibrations or to substitute with temporary instrumentation also should be considered.
2. For temporary instrumentation, the design should cater to allow connections and spools sections, pressure connections, thermo wells and electrical tie-ins. To meet the required flow meters measurement uncertainty limits, use of flow straighteners is recommended.
3. The instrumentation layout shall be as given in this scope for measurement uncertainty and if possible allow the ability to validate critical test measurements. (e.g. pressure, temperature, fuel flow, power output)

6.2 Test procedure

The performance test shall be conducted based on a test procedure, which was developed to provide detailed guidance on the test execution. This document supplements the contract obligations and clarifies particulars of contract issues. It shall provide the course of action for performing the test. Prior to the execution, the test procedure shall be agreed upon, by authorized signatures of all parties to the test. The following topics should be included within the test procedure:

- a) Base reference conditions and guarantees
- b) The criteria for acceptance at the test completion.
- c) Test control borders and the locations of the measuring sensors
- d) Details about instrumentation including : type, location and calibration requirements
- e) The requirements for the stabilization period prior to the test commencement.
- f) The details concerning fuel handling, including a procedure for fuel samples collection, handling, method of analysis, frequency of sampling, as well as the distribution of duplicate fuel samples for each party, including a set of samples to be kept in case of additional analysis
- g) Allowable range of fuel conditions, including constituents and heating value
- h) Required operating conditions, e.g. test load, rotating speed, isolation list (see also Table 9)
- i) Required levels of equipment cleanliness and inspections prior to test
- j) Procedure to account for performance degradation
- k) Recording of test readings and observations
- l) Number of test runs and duration of each run
- m) Frequency of data acquisition, data acceptance and rejection criteria
- n) Method of combining test runs to calculate the final test result
- o) Numerical values, curves or algorithms for correction under conditions differing from the specified conditions
- p) Requirements for data storage, document retention, data and test report distribution
- q) Method for agreeing and documenting any modification to test procedure
- r) Method for documenting the specific gas turbine control parameters pre-test and post-test.

6.3 Test preparation

The equipment shall be capable of reliable operation at full load before any test at the suppliers test facility or on site test commences. Where on site testing is to be undertaken, the tests should be carried out very shortly after the commissioning process has been completed. For the plants that are already in commercial operation the tests shall be carried out in clean and undamaged condition. Appropriate degradation allowance may be applied as agreed in commercial contracts

A test director shall be appointed by the test conducting party. The appointed test director shall be responsible for seeing that all tests are conducted in professional manners and this test standard used as a guideline for the execution of the tests. The previously agreed test procedure shall be the basis for conducting the tests.

Prior to the tests, all parties involved in the testing shall be in agreement with the procedures for at least the following items:

- a) Conduct a survey of all plant identifying any deficiencies in equipment and for procedures, which might affect the performance test.
- b) inspection of the fuel flow measuring system

- c) The gas turbine compressor blades should be visually inspected and cleaned (off line washing with previous hand washing if necessary) unless only limited running, from a known clean condition, has been undertaken before the test and all the components are clean and ready for test.
- d) Gas turbine compressor inlet guide vane angle has been verified by measurement and adjusted to control specifications if necessary.
- e) Gas turbine TIT (turbine inlet temperature) control parameters based on the exhaust temperature and other relevant factors.
- f) Calibration of all temporary instruments before shipment to site and valid certificates to be less than 12 months, traceable to national or international laboratories.
- g) Location and proper installation of all temporary and unit (if applicable) instruments and crosschecked with the calibration certificates and serial numbers.
- h) Electrical power output measurement including power factor (gross and/or net if applicable).
- i) Data acquisition system for monitoring all relevant parameters and the frequency of data collection.
- j) Data that is required manually and the frequency of data collection.
- k) Use of operating screen prints for additional information which may include plant emission readings and any alarms that may affect the running of the acceptance tests.
- l) Detailed schedule of all the tests including the duration of all tests.
- m) Operation modes and settings of the gas turbine (e.g. bypass or boiler, anti-icing, compressor bleed, etc.).
- n) A preliminary and recent fuel analysis (with fuel density and calorific value) is available to ensure that the fuel is substantially as intended.
- o) Sampling methodology and the frequency of sampling of the primary fuel. The number of samples to be retained by the operator, the conducting test team and spare sample shall be agreed prior to the test. Identification of the names of the laboratories for fuel analyses. Portable gas analysis equipment may be selected for this use, if it meets the accuracy requirements of this standard.
- p) A proper number of personnel, of suitable skill, is available for the correct use of the instruments and for collecting the test data.
- q) An effective indication and intercom system is available to indicate the starting and the end of the tests and the various pauses wherein the readings of the different instruments shall to be taken.

6.3.1 Equipment preparation

Proper preparation of the gas turbine test is essential. Where a site test is to be undertaken this preparation is not considered part of normal commissioning activity of the plant that is being acceptance tested from new. For on site tests it is normal practice that the supplier of the equipment inspects the plant to be tested and provide instructions as to the restorative action that is required prior to conducting the tests. In any case, before the tests, the machine shall be placed at the disposal of the supplier for examination and cleaning. A pre-test readiness report that demonstrates the equipment has been properly prepared shall be issued to all the parties concerned by the tester of the plant prior to conducting the tests.

6.3.2 Test deviation agreements

Any test deviation outside the performance test procedure or this test standard shall be agreed prior to the test completion and shall be handed over in writing to all parties involved.

A meeting shall be held with all parties involved to agree if the preceding tests were conducted in accordance with performance test procedure and the guidelines given in the test standard. It shall also be agreed whether the collected data are acceptable to all parties involved in the tests. Once this has been agreed, the test shall be designated as an official test.

6.3.3 Schedule and location of test activities

A test schedule should be prepared to include at least the sequence of events, anticipated time of test and requirements to notify of the parties. Other activities such as preparations to the test, conduct of the test and completion of the report results should also be provided. The location shall be designated at the actual plant site or other test facilities, where working conditions could be acceptable to all parties.

6.3.4 Preliminary to tests

All parties to the test shall be given timely notification, as defined by prior agreement, to allow them the necessary time to respond and to prepare personnel, equipment, or documentation. Updated information should be provided, as it becomes known.

6.3.5 Pre test records

Dimensions and physical conditions of parts (pipe length, orifice diameters) of the gas turbine required for calculations or other test purposes shall be determined and recorded before the test. Serial numbers and data from nameplates should be recorded to identify the gas turbine and auxiliary equipment tested. All instrumentation should be identified and model and serial numbers recorded. Documentation shall be developed or be made available for calculated or adjusted data to provide independent verification of algorithms, constants, scaling, calibration corrections, offsets, base points, and conversions.

6.4 Instruments and measuring methods

6.4.1 General requirements

This section describes the instruments, methods and precautions to be employed in testing gas turbines and components in accordance with this International Standard. Where there is no specification in this clause concerning the instruments and the measurement method used, these shall be subject to agreement by the parties to the test.

The use of advanced electronic instruments and devices together with a computer controlled data recording and processing system is preferred in respect of achieving test data and results with the highest level of accuracy. However manual recording of analogue instruments is allowed in cases where non-electronic instrumentations are used.

The instruments and measuring methods mentioned and described hereafter are state of the art and commonly employed at the time this International Standard is published, however, new technology and methods of measurement may be adopted for performance testing as they are available provided they comply with the requirements for the maximum uncertainties specified herein.

Instruments, devices and measurements shall be employed in accordance with relevant International Standards, unless otherwise agreed.

Users of this standard shall develop a site and equipment specific uncertainty calculation based on the implicit understanding that all parties to a performance test are interested in test results with lowest practical uncertainty.

The final uncertainty of a test result will be unique for each test because of the differences in the scope of supply, fuel used, turbine sensitivity coefficients, instrumentation and driven equipment characteristics. Therefore, it is not the intention of this standard to define limits for the overall uncertainty of a test.

To ensure reliable and accurate test results, limits for the uncertainty of required measurements and also for the permissible variations of the operating parameters during a test are established in this standard.

For comparative testing, unlike absolute level of testing, the determination of uncertainty is different, since the desired result is the difference in power or efficiency rather than the absolute level. The viability of the test is based on selecting the appropriate instrumentation and defining the sensitivities in such a way that the uncertainty will be only a relative small percentage of the expected differential.

6.4.1.1 Measurement uncertainty

In general, no measurement or test is perfect and imperfections give rise to error of measurements in the result. Consequently, the result of a measurement is only an approximation to the value of measurand, i.e. the specific quantity subject to measurement. When applied to gas turbine testing, the general term measurand may cover many different quantities, e.g. gas turbine heat rate, plant efficiency, electrical or mechanical power, the mass flow of water or steam, temperature and pressure of fluids. A detailed way to conduct a measurement uncertainty is given in Annex A. The application of uncertainty analysis to a test has the following objectives:

- a) enables to quantify the quality of a test result ;
- b) identifies the contribution of each measurement to the overall test uncertainty;
- c) provides a mechanism for improving the quality of the test.

If the instruments for a performance test are qualified with an uncertainty equal to or better than the maximum uncertainties as specified in Table 3 then the test results will follow with an inherently high level of accuracy. In such cases the determination of the overall test uncertainty is not mandatory.

However, where one or more test instruments are not in conformance with the uncertainty levels of Table 3 the following procedure may be applied:

A pre-test uncertainty analysis shall be performed by using the limit for each measurement specified in Table 3 along with the appropriate sensitivity factors for the turbine being tested. This shall provide a benchmark for the overall test uncertainty.

Then the number and type of instrument(s) for each parameter shall be selected so that the result of the overall uncertainty is equal to or less than the previously calculated benchmark.

The application and the use of overall uncertainty figures to the final performance test results are outside the scope of this standard, as these are primarily contractual and its rationalisation should be agreed prior to the acceptance tests. However, when uncertainty of measured of relative performance levels is to be calculated it is essential that for all instrument readings the random and systematic error associated with the readings are known.

6.4.1.2 Maximum allowable uncertainties

To achieve test results with highest possible accuracy it is mandatory to establish the maximum permissible uncertainties of measuring instruments, devices or parameters.

During preparation of a performance test the measurement methods shall be carefully evaluated and the instruments and apparatus calibrated to prove that they are in compliance with the uncertainties summarized in Table 3 for units generating electrical power.

Table 3 – Maximum permissible uncertainties

Individual instrument or parameter	Max. uncertainty	Remarks
Barometric pressure	$\pm 0.05 \%$	Instrument uncertainty
Air inlet temperature	$\pm 0.2 \text{ K}$	Instrument uncertainty
Relative humidity	$\pm 2 \%$	Instrument uncertainty
Electrical power metering	$\pm 0.2 \%$	Instrument uncertainty
Current transformer	$\pm 0.2 \%$	Equivalent to accuracy class 0.2S
Voltage transformer	$\pm 0.2 \%$	Equivalent to accuracy class 0.2S
Mechanical power (torque)	$\pm 1.0 \%$	Instrument uncertainty
Frequency / Shaft speed	$\pm 0.25 \%$	Instrument uncertainty
Gas fuel pressure	$\pm 0.25 \%$	Instrument uncertainty
Gas fuel temperature	$\pm 0.2 \text{ K}$	Instrument uncertainty
Gas fuel heating value	$\pm 0.5 \%$	Combined uncertainty of gas composition
Gas fuel mass flow	$\pm 0.5 \%$	Combined uncertainty of temperature, pressure, volumetric flow and gas composition
Oil fuel temperature	$\pm 0.2 \text{ K}$	Instrument uncertainty
Oil fuel heating value	$\pm 1.0 \%$	Combined uncertainty of laboratory analysis
Oil fuel mass flow	$\pm 0.5 \%$	Combined uncertainty of volumetric flow and temperature
Turbine exhaust temperature	$\pm 3 \text{ K}$	Instrument uncertainty
Inlet pressure loss	$\pm 50 \text{ Pa}$	Instrument uncertainty
Exhaust pressure loss	$\pm 50 \text{ Pa}$	Instrument uncertainty

6.4.1.3 Calibration

The calibration, defined as set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument of measuring system, or values represented by a material measure of a reference material, and the corresponding values realized by standards (ISO/IEC Guide 99), is providing the input quantity for the correction or compensation of the recognized error arising from a systematic effect as well as the quantity of the remaining uncertainty (Type B standard uncertainty, ISO/IEC Guide 98-3) which is required for the determination of the combined standard uncertainty of the final test result.

The instruments and devices required for the determination of the performance as defined in the test procedure shall be properly calibrated versus reference standards to allow elimination of the systematic effect of the candidates, where applicable, and to verify that their uncertainties are in compliance with the maximum uncertainties given in Table 3.

The calibration shall include sufficient points covering the operation range expected for the performance test as well as considering hysteresis effects. If on-site plant instruments and devices are used for performance testing, the required calibration may be accomplished with working standards. Likewise, on-site calibration checks of temporary test equipment can be done using working standards.

Each instrument shall be provided with a calibration certificate proving the traceability of the calibration procedure to national or international standards and shall be reported as recommended by EA (European co-operation for Accreditation) in the publication Expression of Uncertainty of Measurement in Calibration (EA-04/02) or other recognized organizations. Certificates of calibration shall meet the requirement stated in Section 6.3 item f.

The adjustment of the measuring instrument or system for systematic error from calibration can either be done by compensating the systematic effect with an algebraically added correction or a numerical correction factor applied to the measurement result. Where electronic data collection systems are used for performance testing, the adjustment of the systematic type of deviation by means of correction can be replaced by using polynomial regression curves generated with the method of least square fitting based on the calibration data of the reference standard and the relating electronic signal of the measuring instrument.

The need for re-calibration of various sensors will be determined based on the sensor manufacturer recommendations for specific applications.

6.4.2 Pressure measurement

Preferably calibrated electronic pressure transducers based on sensing technology such as piezo, capacitive etc. with temperature compensation shall be used to assure highest level of measurement accuracy. However instruments like manometers (U-tube or single leg type), dead-weight gauges Bourdon or other elastic type gauges may also be used where applicable.

The methodology, number and type of instruments used for the measurement of a pressure shall be carefully evaluated considering magnitude and range of parameter, accuracy requirement as well as specific flow dynamics and design of equipment.

Attention shall be paid to location and installation of pressure instruments in a manner that no additional errors induced by environmental conditions such as radiation, vibration, etc. or leakage of pipe and fitting increase the uncertainty of the reading.

6.4.2.1 Barometric pressure

The absolute atmospheric pressure shall be measured with a barometric pressure transmitter calibrated with a maximum uncertainty of 0.05%. The instrument shall be located outside of any closed containment in a stable and protected environment at an elevation equal to the centreline of the gas turbine shaft.

Barometric pressures from local weather stations shall not be used.

6.4.2.2 Compressor inlet pressure

Compressor inlet pressure is defined as the total pressure prevailing at the compressor inlet. It is an absolute pressure based on the algebraic sum of the barometric pressure, the gauge static pressure and the dynamic pressure, when the quantities are measured and evaluated separately.

The dynamic pressure is usually calculated using the mean velocity and air density in the section where static pressures are measured. This mean velocity is computed from the area of this section and the rated flow.

If no inlet duct, silencer or filter is used; inlet pressure shall be taken as barometric pressure.

Where the mean velocity at the compressor flange or in the vicinity of the compressor inlet flare is below 20 m/s, static pressure may be measured at one station only. In the event of the velocity being higher than 20 m/s, static pressure shall be taken as the average of three stations, placed as near symmetrically as possible in a place normal to the mean flow.

For closed cycle installations, the procedure for measuring compressor inlet pressure shall be the same as that specified for compressor outlet pressure

6.4.2.3 Turbine outlet pressure

Turbine outlet pressure is defined as the static pressure prevailing at the turbine exhaust flange (or regenerator outlet flange, if a regenerative cycle is used), and is obtained in the same manner as for the compressor inlet pressure. The static pressure shall be taken as the arithmetic average of the measurements at three stations placed as nearly symmetrically as possible in the section.

If no outlet duct is used, outlet static pressure shall be taken as barometric pressure.

Where conditions of high velocity and pressure gradients exist at the chosen location, measurement methods shall be agreed to ensure that the value obtained is representative of the mean weighted pressure. Alternatively, a calculated exhaust pressure relative to ambient may be considered.

6.4.2.4 Compressor outlet pressure and turbine inlet pressure

If turbine inlet temperature is determined by indirect means, it may be necessary to measure the compressor outlet pressure or, if practicable, the turbine inlet pressure.

Static pressure shall be measured by one or more probes as applicable. In case of multiple probes, the pressure value will be the arithmetic average of the measurements. Dynamic pressure shall be computed from the estimated mean velocity in the relevant section.

6.4.2.5 Fuel gas pressure

For the determination of the fuel gas density at line conditions the fuel gas pressure shall be measured in conjunction with the fuel gas temperature installed as close as possible to the fuel meter.

6.4.3 Temperature measurement

Recommended instruments for measuring temperatures are:

- a) resistance thermometers (IEC 60751, Industrial platinum resistance thermometer sensors)
- b) thermocouples [IEC 60584 (all parts)]

Other temperature measuring devices such as thermistors and liquid in-glass thermometers may also be used provided they are properly calibrated with uncertainty in compliance with the limits given in this standard.

Each instrument used for testing shall be calibrated or compared with an instrument certified by a recognized authority to verify that they are within the maximum uncertainty limits.

Where the temperature of a fluid stream is measured with the dynamic component of temperature exceeding 0.5K, a stagnation (total temperature) type thermometer shall be used, or alternatively the appropriate correction shall be applied to the measurement made with a standard probe.

6.4.3.1 Air inlet temperature

Depending on the test boundary definition the air inlet temperature is equal either to the ambient air temperature or the compressor inlet temperature.

6.4.3.2 Ambient air temperature

Instruments required for the measurement of the ambient air temperature shall be installed at the location where the air stream is crossing the specified test boundary, typically at the filter house of the air inlet duct. Special care is required for the protection and shielding of the temperature probes from solar and other radiation sources as well as from high (> 10 m/s) air flow across the sensing element.

In case of multiple gas turbine units, installed in one or more rows or staggered, with or without evaporative cooling systems (within the inlet air system) every effort shall be taken to find the most representative and accurate location(s) for the determination of the weighted average of the ambient air temperature and humidity, where the test boundary is entered.

The number of instruments shall depend on the shape and the size of the air filter system inlet area. The temperature shall be measured with four instruments uniformly distributed over the cross sectional area of the inlet. It is recommended to locate one sensor for each 10 m² of inlet area. In case where inhomogeneous

temperature profile exists over the inlet section, the number of probes shall be increased accordingly. If the difference of the maximum and minimum temperature is larger than 5 K, such as in case of nearby plant equipment producing hot streams directed towards the air inlet duct, the root cause shall be investigated and where possible eliminated.

6.4.3.3 Compressor inlet temperature

The air temperature at the compressor inlet may be used for energy balance calculation. It shall be measured with instruments having a maximum uncertainty of 0.2°K. At least two sensors shall be used and readings taken simultaneously to calculate the mean value. If the temperature is measured at a location where the air velocity is higher than 20 m/s, the measured temperature shall be corrected with the computed dynamic portion of the total temperature using the calculated air velocity.

In case of evaporative cooling or other fogging systems in operation care should be taken for the selection of the measurement location(s) in order to prevent sub-cooling of the temperature element(s) by water droplet impingement.

6.4.3.4 Turbine inlet temperature TIT

Operation of the gas turbine at the specified temperature setting during testing is fundamental to the determination of thermal performances. Generally, gas turbines are designed on the basis of turbine inlet temperature, which is, except for special cases such as closed cycle gas turbines, virtually impossible to measure. Therefore the turbine inlet temperature can only be determined by indirect means based on heat balance calculations. The procedure for the calculation of the ISO turbine inlet temperature is defined in 8.3.5.2.

For the measurement of the turbine inlet temperature of closed cycle turbines, two sensors may be sufficient.

6.4.3.5 Turbine outlet (exhaust) temperature

Typically the scope of a gas turbine includes the measurement devices for the turbine outlet temperature because it is used in the gas turbine operation, control and protection system as primary input parameter. Gas turbine manufacturers, through development and experience, are determining the number and location of the temperature measurement probes in the exhaust plenum or in the inter-stage area (on multiple shaft or reheat gas turbines), accounting for non-uniform temperature and flow velocity profiles as well as thermal radiation and conduction effects.

If temporary test instrumentation is used for the measurement of the turbine outlet temperature, a minimum of four sensors or appropriate traverse probes shall be located at centres of equal cross sectional areas considering spatial temperature and flow velocity gradients. If, for practical reasons, it is necessary to place the sensors close to, or at, the turbine exhaust flange, more than four sensors may be required to assure adequate accuracy. For closed cycle turbines, two temperature probes may be sufficient. The casing and the duct between the turbine exhaust flange and the measuring station shall be properly insulated.

The exhaust gas temperature shall be measured near the test boundary, which is often the interface plane between the gas turbine and Heat Recovery Steam Generator or the gas turbine exhaust stack. The exhaust gas from a gas turbine usually has a non-uniform temperature and velocity profile. Therefore, the individual measured exhaust gas temperatures may be averaged. The method shall be defined by the manufacturer. The preferred method is for the manufacturer to provide a calculation method based on either field test data from other similar units, or from analytical means such as CFD modelling.

6.4.3.6 Combustion chamber air inlet temperature

It may be necessary (see 8.3.4) to determine the mean total temperature at the inlet to the combustion chamber and estimate the temperature rise therein. Methods for measurement of the mean total temperature at the entry to the combustion chamber will vary according to the detailed design of the machine. Necessary precautions shall be taken into account against radiation

6.4.3.7 Fuel temperature

Fuel temperature may need to be measured at two different locations, close to the flow meter for the calculation of the fuel supply and, if applicable, for liquid fuel return and at the test boundary for the determination of the sensible heat.

6.4.4 Fuel measurements

6.4.4.1 Gaseous fuel

Since each energy stream shall be determined with reference to the point at which they cross the test boundary, the choice of the test boundary can have a significant impact on the test results. It may be at a different location depending on what parameter is being determined (i.e. gas turbine efficiency vs. exhaust gas energy via heat balance). An example might be the use of a fuel pre-heater, which requires the use of different temperature values for efficiency and exhaust energy.

6.4.4.1.1 Gas fuel characteristics

Gaseous fuel characteristics shall include the determination of

- a) density
- b) heating value
- c) composition
- d) temperature
- e) pressure
- f) flow

Upon agreement between the parties to the test, heating value and density may be calculated or taken from records of the gas supplier, provided the dates and times of the records are concurrent with test dates and times, and the bases of the values selected are completely described in the test reports. In addition the calibration data of the reference measurement instrumentation shall be traceable to International Standards with the uncertainty in compliance with the limits given in these Standards.

For blast furnace or refinery gas and other gases, the composition of which varies continuously, sampling shall be carried out with such frequency during the period of the test that a fair and representative heating value of the gas is obtained by averaging the results. When possible, it is recommended that a gas chromatograph be used during the test.

6.4.4.1.2 Gas fuel density

The gas density and compressibility at test conditions shall be calculated with the methods specified in ISO 6976 and ISO 12213-2 respectively, based on fuel gas pressure and temperature measured at the flow meter. Both, density and compressibility shall be determined with the actual molar fuel gas composition.

For gas mixtures not covered by the referenced standards parties shall agree on the method to be used to calculate the density.

6.4.4.1.3 Heating value

The lower heating value (LHV), called also net heating value of gaseous fuel shall be determined by computation according to ISO 6976, using the specific heating values at constant pressure of the component gases and their normalized proportions in the fuel and based on a combustion reference temperature of 15°C.

Alternatively any other type of calorimeter may be used, if the uncertainty values required by the standard are met. The method to be applied shall be previously agreed upon by all parties to the test.

In any case, adjustment shall be made for sensible heat of the fuel where the actual temperature at test conditions is above or below 15 °C.

6.4.4.1.4 Fuel gas composition

The molar fuel gas fractions shall be determined by a certified laboratory in accordance with the chromatographic method for hydrocarbons up to C8 as described in ISO 6974-1, also called "Tailored Analysis". If gas analysis is required for higher hydrocarbons up to hexadecane (C16), ISO 6975 shall be applicable (Extended Analysis).

Gas analysis data of online gas chromatographs may be acceptable by mutual agreement of the parties to the test and provided that the chromatographs are properly calibrated, traceable to international standards. Alternatively, for the verification of the online chromatograph, gas fuel samples may be analyzed by a certified laboratory and compared with the online results taken simultaneously with the samples.

The moisture fraction in industrial natural gas is usually of a small magnitude having a negligible effect on the heating value of the gas. Therefore the determination of the moisture content is not required. However, where indications reveal that the gas contains moisture above common standard, the fraction thereof shall be analyzed by either laboratory analysis or dew point measurement method.

In certain gaseous fuels such as blast furnace gas, the fraction of dust in the fuel is of importance and shall be measured. Dust may have an impact on the accuracy of the measurements of gas mass flow, due to possible erosion or other mechanical effects on the flowmeter. However, owing to the wide range of dust characteristics, loadings, etc., the parties shall agree previously on the procedure to be used by qualified personnel with experience in this class of fuels.

6.4.4.1.5 Fuel gas sampling

Fuel gas samples shall be taken in accordance with in ISO 10715 using special sample containers. It is recommended to take at least two sets of samples, one at the beginning and one at the end of a test run. Additional sets of samples may be taken within the test period where the gas composition is fluctuating.

A minimum of three samples per set shall be taken, one for the laboratory analysis plus an additional spare sample. The spare samples shall be retained until laboratory results are released and considered to be acceptable. The fuel characteristics used for test run analysis shall be determined from the average of the characteristics from the individual fuel samples taken at the beginning and completion of each test run.

6.4.4.1.6 Gaseous fuel flow measurement

The actual volume of flow per unit of time (flow rate) of gaseous fuels shall preferably be determined by means of either a turbine type flow meter in accordance with ISO 9951, a positive displacement volumetric flow meter, an orifice metering run or a coriolis meter meeting the applicable requirements of a recognised international or national standard.

In the event of such a method not being practicable, gas consumption may be determined from flow measurement by means of nozzles, orifices or venturi meters, which shall be designed, arranged and instrumented in accordance with ISO 5167 (all parts).

The computation of the actual fuel mass flows at test conditions is based on the equations outlined in ISO 9951 and ISO 5167 (all parts) respectively and in conjunction with ISO 6976 for the determination of the gas density.

Ultrasonic flow meters or others shall also be permitted provided the devices are individually calibrated and comply with the uncertainty requirements given in this International Standard.

Fuel meters used for performance testing shall be individually calibrated to reduce the maximum uncertainty of fuel mass flow to 0,5%.

6.4.4.2 Liquid fuel measurement

6.4.4.2.1 Liquid fuel characteristics

Parties to the test shall agree upon the fuel sampling method. Fuel characteristics shall include the determination of:

- a) density
- b) heating value
- c) viscosity where applicable
- d) temperature
- e) composition
- f) flow

6.4.4.2.2 Density

Density of crude or liquid petroleum fuel may be obtained by hydrometer method as described in ISO 3675 or other equivalent standard. The actual density at test conditions shall be determined by interpolating between the analysis results using the measured fuel temperature.

6.4.4.2.3 Heating value

The higher heating value (HHV) (gross heating value) at constant volume and a reference temperature of 15°C shall be determined by means of a bomb calorimeter method. Then the lower heating value (LHV) (net heating value) at constant volume is found by calculation deducting the latent heat of the calculated amount of water vapour produced from the measured hydrogen content of the fuel.

The foregoing determination should be carried out in accordance with DIN 51900-1 or equivalent standard by a physical or chemical laboratory agreed upon by the parties. Continuous flow calorimeter or other ISO approved instrumentation may also be used.

In each case, adjustment shall be made for sensible heat of the fuel with a test temperature different than 15°C. The specific heat may be taken from the Table 4.

Table 4 – Liquid fuel properties

Fuel	Viscosity	Specific heat
Gas oil	$< 9,5 \times 10^{-6} \text{ m}^2/\text{s}$ at 20 °C	1,88 kJ/kg/K
Light fuel oil	$< 49 \times 10^{-6} \text{ m}^2/\text{s}$ at 20 °C	1,76 kJ/kg/K
Medium fuel oil	$< 110 \times 10^{-6} \text{ m}^2/\text{s}$ at 50 °C	1,63 kJ/kg/K
Heavy or extra heavy fuel oil	$< 380 \times 10^{-6} \text{ m}^2/\text{s}$ at 50 °C	1,59 kJ/kg/K

6.4.4.2.4 Liquid fuel composition

The liquid fuel mass fractions (C, H, N, O, S) shall be determined by the following codes: for Carbon, Hydrogen and Nitrogen ASTM D5291, Trace Nitrogen by ASTM D4629, Sulphur by ISO 14596 or ISO 20846 and Oxygen by DIN 51451. In addition the determination of water shall be done by ISO 3733 and for ash by ISO 6245 respectively. With the results of the fuel analysis the specific heat and enthalpy for the fuel and the exhaust gas can be established. Also the exhaust gas composition can then be determined.

6.4.4.2.5 Liquid fuel sampling

A fuel sampling location shall be identified and agreed upon prior to the test. The sampling shall be selected as close as possible to the test boundary, upstream of the metering station, such that the liquid fuel sample represents the characteristics of the fuel flowing through the metering device. Special care should be taken to ensure that the sampling location is not influenced by all the processes outside of the test boundary that may change the composition of the fuel (strainers, filters etc).

Sets of at least three liquid fuel samples should be taken at the beginning and completion of a test. If unsteady fuel supplies are suspected, samples may be taken more often. One sample from each set shall be sent to a qualified laboratory. One sample should be provided to the owner and the third should be retained until all fuel analysis is completed and the results are accepted by all parties. The fuel characteristics used for test analysis shall be determined from the average of the characteristics from individual fuel samples taken before and after each test.

6.4.4.2.6 Liquid fuel flow measurement

Where the liquid fuel flow is measured with a nozzle, orifice or venturi flow section, such meter shall be designed, arranged and instrumented in accordance with a recognized standard, for example ISO 5167 (all parts). Other flow devices such as positive displacement volumetric, vortex, coriolis or ultrasonic flow meters shall also be permitted. In any case, the fuel flow measuring device shall be suitably calibrated to ensure that the maximum uncertainty is less than 0,5 %

Calibrated volumetric measuring tanks may also be used provided that the required uncertainty of measurement can be demonstrated.

A weigh tank system shall be free upon its pivot and unconstrained by any external force such as might be applied by unsuitably designed or unsuitably placed pipe connections. It shall be calibrated before the test with an overall maximum uncertainty of measurement not exceeding 0,5% of the measured quantity.

Any spill or leakage from control valves or burners shall either be reintroduced into the fuel system downstream of the fuel flow meter or its quantity shall be separately measured and deducted from the total measured flow.

6.4.5 Power measurement

6.4.5.1 Electrical power measurement

These tests shall be performed using electrical measurement equipment in accordance with the standards of IEC (International Electro-technical Commission) or other recognized standards.

The definition of electrical power output to be verified may be given at different stations as indicated in Figure 3 depending on the test boundary stipulated by contractual scope or guarantee definition etc. The power may be measured at any station if properly equipped with adequate transformers and in conformance with the requirements of this International Standard.

It is to be noted that design and nomenclature may be different to the terms used by gas turbine manufacturers.

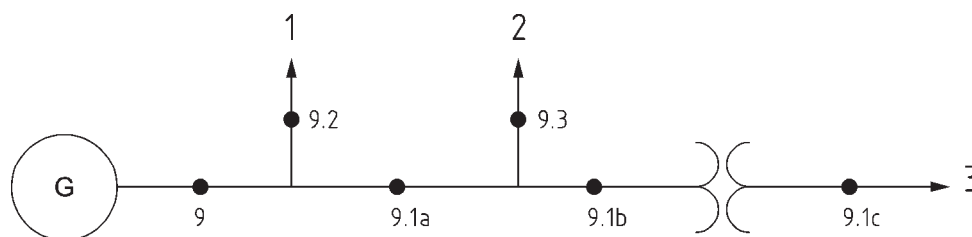


Figure 3 – Stations definition of electrical power

- 1 Excitation
- 2 Auxiliary
- 3 to grid

Table 5 – Station definitions for electric power measurement

Station	Description of measurement
9	Gross electrical power at generator terminals. In case of dynamic excitation of the generator this power corresponds with the power at station 9.1a.
9.1a	Net electrical power of generator = gross electrical power at generator terminals minus excitation power
9.1b	Net electrical power low voltage = net electrical power of generator minus equipment or plant auxiliary
9.1c	Net electrical power high voltage = net electrical power low voltage minus step-up transformer losses
9.2	Excitation power (static excitation)
9.3	Equipment or plant auxiliary

The metering method of the electrical power, the two-watt meter or preferably three-wattmeter method, is depending on the various types of the power generating and distributing arrangements, which typically are three-phase systems with Star or Delta generator connection in three- or four-wire configuration.

In order to select the appropriate metering equipment and define the corresponding instrument transformer connection the particular site configuration shall be reviewed during planning and preparation of the test.

6.4.5.1.1 Electrical power metering

For the measurement of the active power single-phase or poly-phase precision Watt- or Watthour-meters of an accuracy class of not more than 0,2% shall be used. If the power meter is not equipped with an integrated feature to measure the power factor, the instantaneous reactive power shall be recorded with a Var-or Var-hour meter of an accuracy class of 0,5% or less.

In cases where excitation and/or auxiliary power, branched off the main generator bus line, is metered to determine the net electrical output based on gross power measurement, the accuracy of the corresponding Watt- or Watthour-meter shall be of a magnitude that the contribution to the uncertainty of the net output is less than 0.03%.

The recording time for Watthour-meters shall be measured with such a precision that the contribution to the uncertainty of the power to be determined is less than 0,03%.

Power metering equipment used for testing shall be calibrated against reference standards traceable to recognized international standards. The calibrations shall be made in such a manner that the expected test load, voltage and frequency conditions are covered.

Preferably portable test instruments, properly calibrated in a laboratory, shall be used. However switchboard instruments may be used by mutual consent of the parties and provided that the requirements given in this International Standard are fulfilled.

Metering systems, such as poly-phase meters, which cannot be verified and calibrated by separate single-phases, shall not be used.

6.4.5.1.2 Instrument transformers

Correctly rated and calibrated voltage and current transformers of at least 0.2% accuracy class or better shall be used. The instrument transformers shall be designed solely for metering purpose with no unknown burden other than that of test instrument and leads i.e. protective relay or voltage regulator devices shall not be connected to the transformers.

The calibrations shall cover the expected field test conditions such as turn ratio, phase angle and rated burden.

The connecting leads between meter and instrument transformer shall be arranged so that effects such as inductance, voltage drop or any other cause are minimized. Twisted and shielded pairs for current leads are reducing the impact of inductance and voltage drop may be minimized by choosing appropriate wire gauge and resistance considering wire length and load of voltage transformer.

6.4.5.2 Mechanical power determination

6.4.5.2.1 Torque measurement

Either of the types of apparatus described in the following sections may be applied to measure torques used in the derivation of the mechanical outputs of gas turbines.

6.4.5.2.2 Absorption dynamometers (mechanical, or any fluid types, or a combination of any of these)

The dynamometer selected shall be chosen so that the minimum measured torque at any speed is at least 20 % of its normal maximum rated torque. Absorption dynamometers shall be constructed so that the cooling fluid enters and leaves in a plane through the axis so as to avoid tangential velocity components. Similar precautions shall also be taken regarding external windage. Hose connections, if used, shall impose no sensible tangential restraint. Dashpots, if used for damping oscillations, shall be demonstrated to impose equal resistance to motion in either direction. Effective radius arms of dynamometers shall be measured with an uncertainty not exceeding 0,1%. A manufacturer's certificate may be accepted as evidence for the accuracy.

The force-measuring device shall be checked against certified weights in the directions of both increasing and decreasing load. The positive or negative error of the force-measuring device shall not exceed 0,1% of the maximum load to be read in the test. The average of increasing and decreasing loadings shall be accepted as the calibration only if the difference remains within 0,3% of the maximum test load.

Tests shall be considered unsatisfactory should there be irregularities in the operation of the dynamometer, for example a period surging of load, such as might be due to the action of water in the dynamometer, or some resonant condition that produces pulsations of indicated torque in excess of $\pm 2\%$.

6.4.5.2.3 Shaft torque meter

The calibration certificate for the shaft torque meter shall be verified before the test series current in accordance with the manufacturers recommendations for the specific application. If the system is affected by temperature, it shall be recalibrated after the test at the temperature experienced during the test. Calibration

shall be performed with the torsion-indicating means undisturbed from pre-test to the end of the post-test determination. In any case, observations shall be taken with a series of increasing loadings to a value above maximum test readings, followed by a series of decreasing loads. Loading shall always progress in one direction except at maximum value. The average of increasing and decreasing loads shall be accepted as the calibration only if the difference is within 1% of the maximum test load.

Readings shall be taken with sufficient frequency and averaged with sufficient data in order not to be influenced by the oscillation of the shaft torque.

6.4.5.3 Power determination, gas generator

The power of a gas generator can be determined by replacing the power turbine by a nozzle or equivalent opening restrictor at full load. The power is defined as that produced by an isentropic expansion from measured conditions at generator outlet (total pressure and temperature) to the ambient atmospheric pressure.

6.4.5.4 Power determination, other cases

Where output is in a form which is not electrical and when it is not practicable to measure the output on the shaft itself (for example pumps, compressors, etc.), reference shall be made to the appropriate standard for testing the driven machine. Such standards may be used only after mutual agreement by the parties involved.

6.4.6 Speed measurement

An instrument of the speed-indicating type may be used for initial setting of the test speed and for checking constancy of speed during test periods. Each shaft of a multi-shaft engine shall be equipped with a speed-indicating device.

For checking constancy of speed during test periods, electronic pulse counter type speed indicators are recommended for visual readout as well as recording.

Either positively driven or no-contact type tachometers shall be used for all speeds. Hand-held tachometers are not recommended, because of the possibility of slip.

When mean rotational speed influences test results, an integrating type revolution counter, positively driven from the shaft, shall be used. Counting and time accuracy shall be such that uncertainty of mean speed does not exceed 0,25 %. Whenever electronic type pulse counters are used for power and efficiency determinations, readings shall be taken with sufficient frequency that the average of all readings will not differ from the average of alternate readings by more than 0,25 %.

6.4.7 Other measurements

6.4.7.1 Humidity

When the moisture content of the air entering the test boundary shall be measured, an instrument with the capability of determining relative humidity within an uncertainty of 2% points shall be used.

The number of instruments shall depend on the shape and the size of the air filter system inlet area .

In case of multiple gas turbine units, installed in one or more rows or staggered, with or without evaporative cooling systems (within the inlet air system) every effort shall be taken to find the most representative and accurate location(s) for the determination of the weighted average of the ambient air temperature and humidity, where the test boundary is entered.

The humidity may be determined with direct measurement using a hygrometer or with measurement of wet and dry bulb temperature, barometric pressure and calculating the relative humidity by means of psychrometric charts, tables or algorithms.