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Gas turbine combined cycle power plants — Thermal performance tests

Turbines à gaz — Centrales à cycle combiné — Essais de performance thermique

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Foreword

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

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

Introduction

This document specifies standard rules for preparing, conducting, evaluating and reporting thermal performance tests in order to determine and/or verify the power output, the thermal efficiency (heat rate) and/or other performance test parameters for gas turbine driven combined cycle power plants. It provides information on methods of measurement considering uncertainties and on methods for corrected results obtained under test conditions in order to compare to guaranteed or specified conditions.

The objective of testing conducted per this document is to determine combined cycle thermal performance characteristics in accordance with any previously drawn up agreements such as the purchase agreements, test criteria documents, engineering, procurement and construction (EPC) requirements, power purchase agreements, power and water purchase agreements, contractual services agreements.

The document also provides guidelines for comparative tests designed to check performance differentials of the combined cycle and cogeneration power plants, for testing before and after modifications, upgrades or overhauls. Improvements to achieve additional performance of the combined cycle may include modification/substitutions of main components and additions of components inside test boundary. This comparative testing philosophy may also be used for “periodic testing” of the plant in order to monitor overall plant performance degradation, while giving due consideration to the relative testing uncertainty.

Gas turbine combined cycle power plants — Thermal performance tests

1 Scope

This document specifies standard rules for preparing, conducting, evaluating and reporting thermal performance tests on combined cycle and cogeneration power plants driven by gas turbines for base and part load operation with or without supplementary firing.

This document is applicable to

— thermal performance tests for general information,

— thermal acceptance tests for determining the performance of the combined cycle plant in relation to a contractual guarantee, and

— comparative tests designed to check the performance differentials of the combined cycle and cogeneration power plants, for testing before and after modifications, upgrades or overhauls.

It can be used to determine the following thermal performance test goals and expected values, under specific operating and reference conditions within defined test boundaries:

— electrical power output;

— heat rate or thermal efficiency;

— process steam and/or district heat w/o generation of electrical power output by means of a steam turbine.

This document does not apply to individual equipment component testing, which is covered by corresponding standards.

It is not intended to be applied to the following test goals:

— environmental testing for example emissions, noise;

— vibration testing;

— operational testing;

— absolute or comparative performance of specific components of the combined cycle covered by dedicated standards (e.g. gas turbines).

2 Normative references

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

ISO 2314:2009, *Gas turbines — Acceptance tests*

ISO 3675, *Crude petroleum and liquid petroleum products — Laboratory determination of density — Hydrometer method*

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

ISO 6974-1, *Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 1: General guidelines and calculation of composition*

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

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

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

ISO 10715:1997, *Natural gas — Sampling guidelines*

ISO 10790, *Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, density and volume flow measurements)*

ISO 12185, *Crude petroleum and petroleum products — Determination of density — Oscillating U-tube method*

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

ISO 17089-1, *Measurement of fluid flow in closed conduits — Ultrasonic meters for gas — Part 1: Meters for custody transfer and allocation measurement*

ISO 20765-1, *Natural gas — Calculation of thermodynamic properties — Part 1: Gas phase properties for transmission and distribution applications*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ASTM D1945, *Standard Test Method for Analysis of Natural Gas by Gas Chromatography*

ASTM D4052, *Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter*

ASTM D4809, *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter*

ASTM D4868, *Standard Test Method for Estimation of Net and Gross Heat of Combustion of Burner and Diesel Fuels*

DIN 51900-1, *Testing of solid and liquid fuels — Determination of gross calorific value by the bomb calorimeter and calculation of net calorific value — Part 1: Principles, apparatus, methods*

3 Terms and definitions

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

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

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

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

3.1
absolute test
test carried out in order to prove an absolute guarantee or an absolute expected performance

3.2
comparative test
test carried out in order to prove a relative change or improvement of performance

EXAMPLE For retrofits.

3.3
performance test
means test of performance of power output, efficiency or heat rate, heat duty, process steam mass flows, etc., as specified

EXAMPLE Performance tests could be specified in contractual agreements.

3.4
preliminary test
test or tests in advance of the actual *performance test* (3.3) to check the complete measuring system and main components to verify that the power plant is in a suitable condition before conducting the actual performance test

3.5
simple cycle
thermodynamic cycle consisting only of successive compression, combustion and expansion

Note 1 to entry: Generation of electrical *power* (3.16) output driven only from a *gas turbine* (3.29) or from the gas turbine in *combined cycle* (3.28) using a bypass stack. The working fluid enters the gas turbine from the atmosphere and is discharged into the atmosphere.

[SOURCE: ISO 11086:1996, 1.8, modified.]

3.6
open cycle
combined cycle (3.28) with the steam turbine bypassed in which the working fluid enters the gas turbine from the atmosphere and is discharged through a heat recovery steam generator stack into the atmosphere

Note 1 to entry: The generation of electrical power output in a *combined cycle* (3.28) plant operating in open cycle is provided only from the gas turbine, as the steam turbine is bypassed.

3.7
test boundary
imaginary boundary drawn encompassing the major equipment included in the test scope

3.8
heat duty
thermal net/gross output produced from the *combined cycle* (3.28) plant

3.9
heat rate
HR
ratio of the fuel energy supplied per unit time to the electrical power produced

Note 1 to entry: Inverse of thermal efficiency.

Note 2 to entry: The heat rate is expressed in units of kilojoules per kilowatt hour.

[SOURCE: ISO 11086:1996, 5.31, modified.]

3.10
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 1 to entry: 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.

Note 2 to entry: HHV at constant volume and a reference temperature of 15 °C shall be determined by means of a bomb calorimeter method. Then LHV 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.

3.11
high pressure
HP
highest pressure level of the working fluid

3.12
intermediate pressure
IP
medium pressure level of the working fluid

3.13
low pressure
LP
lowest pressure level of the working fluid

3.14
mechanical loss
reduction of power output due to bearing and windage losses of gas and steam turbine rotors

[SOURCE: ISO 11086:1996 5.34, modified.]

3.15
hot water
host that can accept or supply energy (non-fuel) to a cycle

3.16
power
quantity expressed in terms of mechanical shaft power at the turbine coupling or electrical power of the turbine-generator

3.17
primary variable
value that is measured and used for calculation and correction of test results

3.18
process steam
host that can accept or supply energy (non-fuel) to the cycle

EXAMPLE District heating, steam consumers (refinery, pulp and paper industries, petrochemical industries), steam producers (auxiliary boilers, steam from other power plant blocks), etc.

3.19
secondary variable
value that is measured but that will not be used for calculation of the results

Note 1 to entry: These variables are measured to ensure that the required test conditions are not violated and to provide information for future use.

3.20
standard reference condition
condition for the ambient air or intake air at the compressor flange (alternatively, the compressor intake flare) equal to

— absolute pressure of 101,325 kPa (1,01325 bar; 760 mmHg),

— temperature of 15 °C, and

— relative humidity of 60 %

Note 1 to entry: The conditions are defined in ISO 2533.

Note 2 to entry: 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 3 to entry: An inlet water temperature of 15 °C applies if cooling of the working fluid is used.

Note 4 to entry: These reference conditions may be different if otherwise agreed in contractual documents or agreements.

3.21
thermal efficiency
ratio of electrical *power* (3.16) output to the heat consumption

Note 1 to entry: Inverse of heat rate.

Note 2 to entry: It can be based on lower or higher heating value.

[SOURCE: ISO 3977-1:1997, 2.3.4, modified.]

3.22
total efficiency
ratio of the sum of electrical *power* (3.16) output and *thermal output* (3.23) to the heat consumption

3.23
thermal output
energy as *process steam* (3.18), *hot water* (3.15) or other export of thermal energy from the cycle

3.24
thermal performance guarantee
guaranteed value for net/gross *power* (3.16) output, net/gross *heat rate* (3.9), or net/gross *thermal efficiency* (3.21), *process steam* (3.18) mass flows and/or *heat duty* (3.8)

3.25
tolerance
allowed deviation from a specific requirement

Note 1 to entry: To define in contractual agreements.

3.26
uncertainty
parameter associated with the result of a measurement, which characterises the dispersion of the values that can reasonably be attributed to the measurand

Note 1 to entry: 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 document.

Note 2 to entry: 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.

3.27
cogeneration power plant
gas turbine based power plant which delivers both electricity and heat

Note 1 to entry: Heat can be delivered in form of process steam or hot water/district heat water to one or more external consumers. The plant can include a steam turbine, but can also deliver the steam or hot water produced in the heat recovery steam generator or waste heat recovery unit direct to the external consumer.

3.28
combined cycle
CC
thermodynamic cycle employing the combination of a gas turbine cycle with a steam or other fluid Rankine cycle

[SOURCE: ISO 11086:1996, 1.12]

3.29
gas turbine
GT
rotary engine that converts fuel thermal energy into mechanical work

Note 1 to entry: It consists of one or several rotating compressors, a thermal device(s) that heats the working fluid, one or several turbines, a control system and essential auxiliary equipment. Any heat exchangers (excluding waste exhaust heat recovery exchangers) in the main working fluid circuit are considered to be part of the gas turbine.

[SOURCE: ISO 3977-1:1997, 2.1, modified.]

3.30
heat recovery steam generator
HRSG
energy recovery heat exchanger that produces *process steam* (3.18) and/or drives a steam turbine

Note 1 to entry: It may contain provisions for supplementary firing.

3.31
multi-shaft combined cycle
combined cycle (3.28) in which the useful power output from the cycle is taken from more than one shaft

[SOURCE: ISO 11086:1996, 26.7, modified.]

3.32
single shaft combined cycle
combined cycle (3.28) in which the useful *power* (3.16) output from the cycle is taken from one shaft

[SOURCE: ISO 11086:1996, 26.6]

3.33
steam turbine
ST
rotary engine in which the kinetic energy of a moving fluid (steam) is converted into mechanical energy by causing a bladed rotor to rotate

3.34
waste heat recovery unit
WHRU
heat exchanger to deliver hot fluid (not gas) where there is no change of phase to the working fluid, which is commonly a water/glycol blend

4 Symbols and units

For the purposes of this document, the symbols and units shown in Table 1 apply.

Table 1 — Global symbols

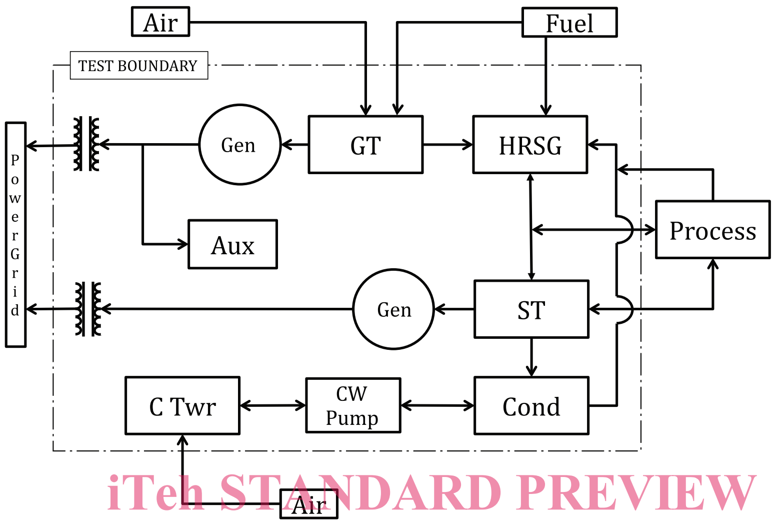
Symbol	Definition	SI unit
AC_{Pi}	Additive correction (i) for measured power output	kW
AC_{Qi}	Additive correction (i) for measured fuel heat input	kW
BRC	Base reference conditions (guarantee conditions)	–
C_P	Global correction for power output	–
C_Q	Global correction for fuel heat consumption	–
HR_{corr}	Net or gross heat rate of the combined cycle based on fuel lower or higher heating value and corrected to base reference conditions	kJ/kWh
$HR_{elec,\ meas}$	Heat rate of the combined cycle based on measured electrical power output and measured fuel lower or higher heating value	kJ/kWh
$HR_{total,\ meas}$	Heat rate of the combined cycle based on measured electrical power output, measured thermal output and measured fuel lower or higher heating	kJ/kWh
h_f	Specific enthalpy of fuel at temperature entering in the heat source	kJ/kg
h_0	Specific enthalpy of fuel at standard reference conditions 15 °C / 1,01325 bar	kJ/kg
$\dot{m}_{CW}$	Cooling water mass flow	kg/s
$\dot{m}_{fuel}$	Fuel mass flow	kg/s
$\dot{m}_{process}$	Process steam or hot water mass flow	kg/s
MC_{Pi}	Multiplicative correction (i) for measured power output	–
MC_{Qi}	Multiplicative correction (i) for measured fuel heat input	–
P_{CC}	Gross or net power output of the combined cycle	kW
P_{corr}	Gross or net power output corrected to base reference conditions	kW
$P_{gross,meas}$	Measured gross power output	kW
$P_{net,meas}$	Measured net power output	kW
PF	Power factor	–
P_{GT}	Gas turbine power output	kW
P_{PL}	Part load power output of combined cycle	kW
$P_{PL,GT}$	Part load power output of gas turbine	kW
P_{ST}	Steam turbine power output	kW
Q_{CC}	Corrected heat input of the combined cycle	kW
Q_{meas}	Measured heat input	kJ/s
η_{corr}	Net or gross thermal efficiency of the combined cycle based on fuel lower or higher heating value and corrected to base reference conditions	%
$\eta_{elec,meas}$	Thermal electrical efficiency of the combined cycle based on measured electrical power output and measured fuel lower or higher heating value	%
$\eta_{total,meas}$	Thermal total efficiency of the combined cycle based on measured electrical power output, measured thermal output and measured fuel lower or higher heating value	%

5 Test boundary

The concept of a test boundary identifies the scope of hardware within the combined cycle power plant subject to thermal performance testing while considering the reference conditions used to establish the performance parameters (i.e. heat/power output, efficiency or heat rate). It provides the basis for the definition and layout of instrumentation required to determine the energy streams crossing the test boundary. It also determines the actual conditions during testing for correcting the test results to reference conditions.

A combined cycle power plant can have a range of equipment within the plant boundary. Depending on the scope of supply, and the understanding between parties, either the entire plant or only a portion of the plant including gas turbine(s) within the test boundary can be tested. This document provides flexibility in terms of the test boundary, and hence, the test boundary is typically defined along with the base reference conditions that are used to specify the performance parameters.

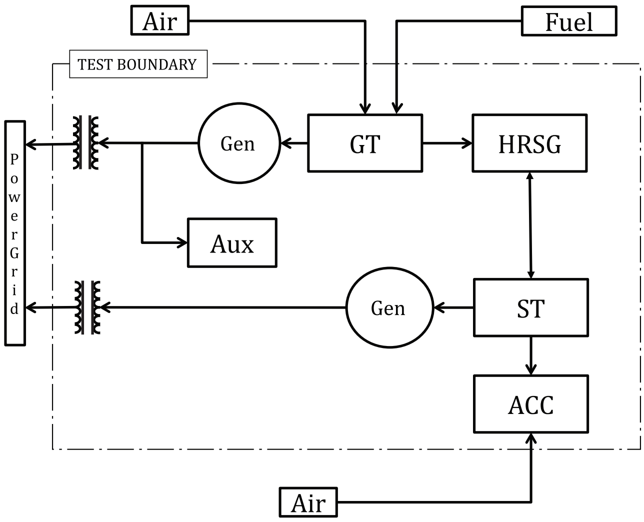
Figures (1) to (7) provide a range of applicable test boundaries. The users of this document should recognize that the test boundaries provided herein are for reference only, and that the actual test boundaries can vary depending on the plant design and the contractually guaranteed scope of supply.



Key

ACC	air cooled condenser(s)	GT	gas turbine(s)
Aux	auxiliary consumption	HRSG	heat recovery steam generator(s)
C Twr	cooling tower(s)	Process	heat in form of process steam or hot water / district heat
Cond	condenser(s)	ST	steam turbine(s)
CW Pump	circulation water pump(s)	WHRU	waste heat recovery unit(s)
Gen	generator(s)		

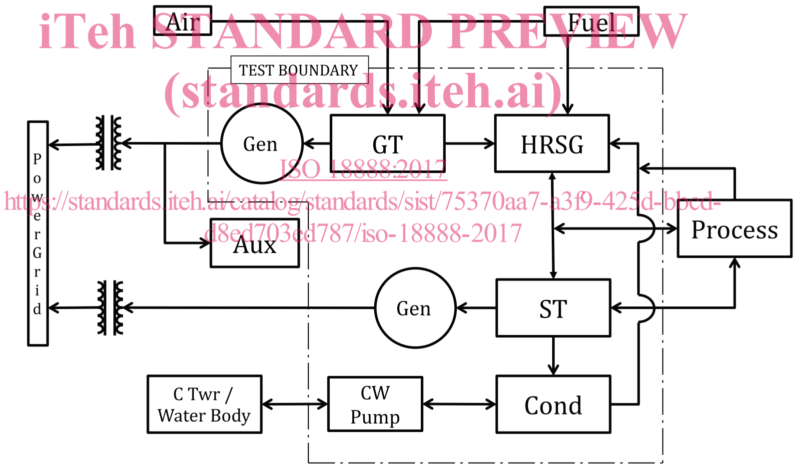
Figure 1 — Combined cycle plant test boundary: sample 1, overall plant test boundary for multi-shaft configuration with process steam and duct firing (e.g. turnkey project)



Key

See Figure 1.

Figure 2 — Combined cycle plant test boundary: sample 2, typical overall plant test boundary with water steam cycle operated in condensing mode (e.g. turnkey project)



Key

See Figure 1.

Figure 3 — Combined cycle plant test boundary: sample 3, test boundary including gross power output and gross efficiency (e.g. power island project)