



BSI Standards Publication

Gas turbine combined cycle power plants — Thermal performance tests

National foreword

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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

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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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
$AC_{P\ i}$	Additive correction (<i>i</i>) for measured power output	kW
$AC_{Q\ i}$	Additive correction (<i>i</i>) for measured fuel heat input	kW

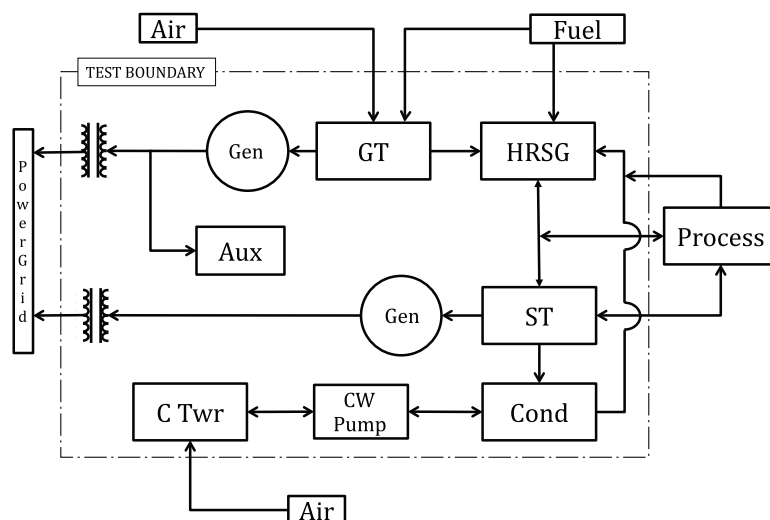
Symbol	Definition	SI unit
BRC	Base reference conditions (guarantee conditions)	–
C_P	Global correction for power output	–
C_Q	Global correction for fuel heat consumption	–
HR_{corr}	Net or gross heat rate of the combined cycle based on fuel lower or higher heating value and corrected to base reference 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
$MC_{P\ i}$	Multiplicative correction (<i>i</i>) for measured power output	–
$MC_{Q\ i}$	Multiplicative correction (<i>i</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.

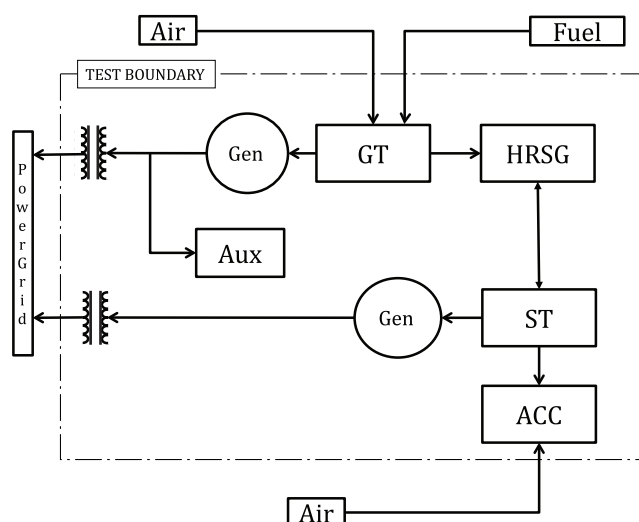
Figures (1) to (7) provide a range of applicable test boundaries. The users of this document should recognize that the test boundaries provided herein are for reference only, and that the actual test boundaries can vary depending on the plant design and the contractually guaranteed scope of supply.



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)		

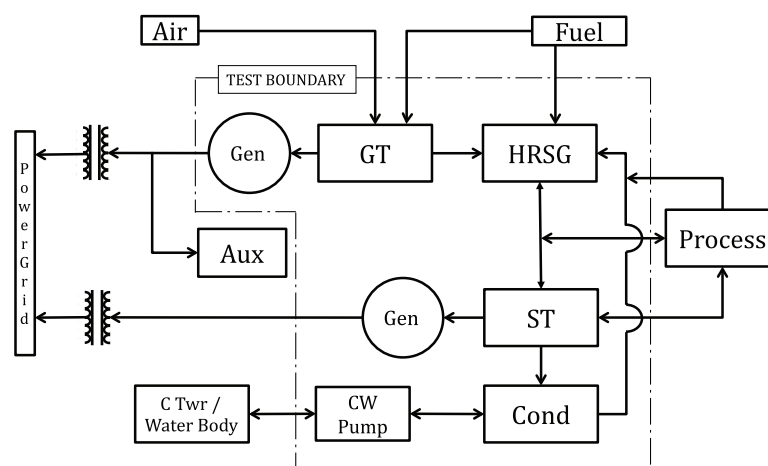
Figure 1 — Combined cycle plant test boundary: sample 1, overall plant test boundary for multi-shaft configuration with process steam and duct firing (e.g. turnkey project)



Key

See [Figure 1](#).

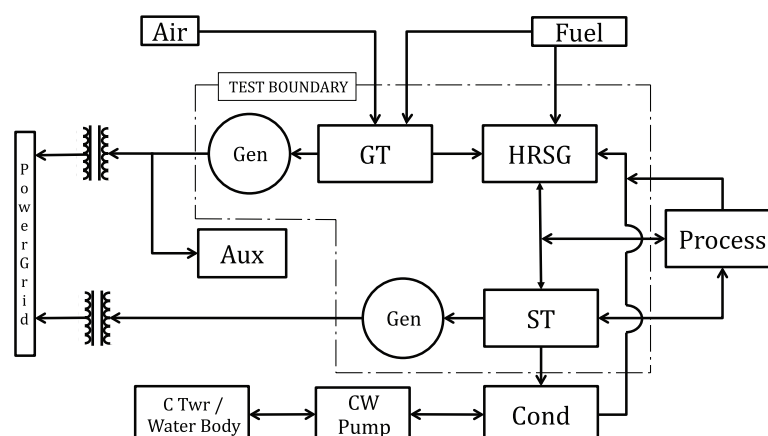
Figure 2 — Combined cycle plant test boundary: sample 2, typical overall plant test boundary with water steam cycle operated in condensing mode (e.g. turnkey project)



Key

See [Figure 1](#).

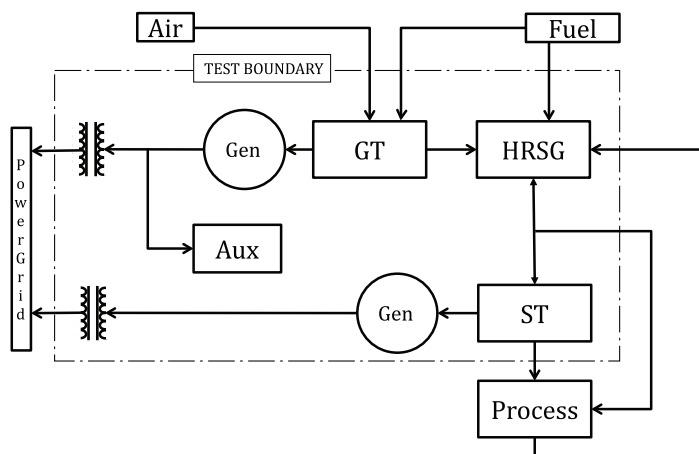
Figure 3 — Combined cycle plant test boundary: sample 3, test boundary including gross power output and gross efficiency (e.g. power island project)



Key

See [Figure 1](#).

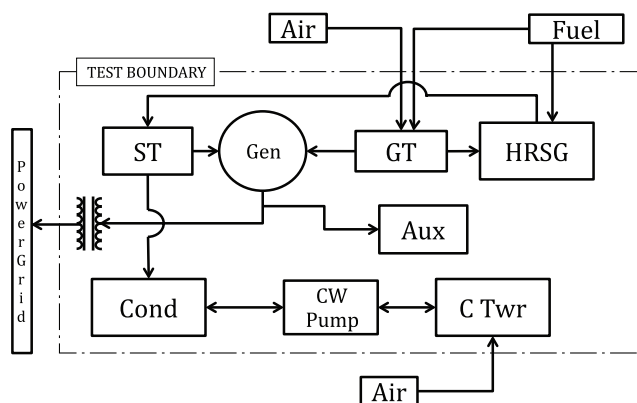
Figure 4 — Combined cycle plant test boundary: sample 4, test boundary including condenser pressure as primary variable for gross power output and gross efficiency



Key

See [Figure 1](#).

Figure 5 — Combined cycle plant test boundary: sample 5, Overall plant test boundary including back pressure steam turbine(s) for generation of process steam



Key

See [Figure 1](#).

Figure 6 — Combined cycle plant test boundary: sample 6, overall plant test boundary for single shaft configuration (e.g. turnkey project)

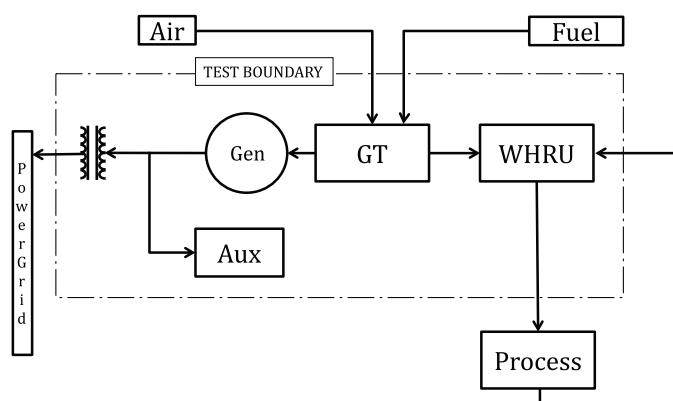
**Key**See [Figure 1](#).

Figure 7 — Cogeneration plant test boundary: sample 7, gas turbine combined cycle plant with waste heat recovery unit for generation of hot water or process steam

6 Preparation for test

6.1 General

Thermal performance testing requires specific and detailed preparations. Since the purpose of such tests varies depending on the equipment, site conditions and contractual scope, it is crucial that a dedicated test procedure document is established and agreed well in advance of the planned test date. The procedure document should be developed in accordance with this document and approved by all responsible parties. Sufficient time to development the final procedure should be considered to allow the parties involved for addressing comments. A clear determination of the equipment boundaries, associated instrumentation and correction methodology shall avoid any potential disagreements after the test.

6.2 Performance degradation

The thermal performance degradation of combined cycle equipment during operation is an existing phenomenon. This is associated with effects of fouling, erosion, wear and tear of gas turbine components, as well as those of the water/steam cycle equipment.

Thermal performance tests should be carried out immediately after the completion of the commissioning. However, agreement to apply degradation corrections to the performance test results is strictly a commercial issue between the parties and beyond the scope of this document.

In most cases, the combined cycle thermal performance guarantees are made based on “new and clean” equipment conditions. 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 or predictive degradation curves.

6.3 Measurement classification

Measurements of variables used in calculation of test results are considered primary variables. These measurements directly relate to the boundary conditions and require instrumentation accuracy in accordance with this document.

Measurements of variables that are not included in the calculation and correction of the results but provide indication that the required test conditions are met will be designated as secondary variables. Examples of these variables are gas turbine exhaust temperature or steam turbine inlet pressure and temperature. Instruments used for secondary measurements may require field verification against suitable calibrated instruments (i.e. loop checks using portable calibration equipment). In this case, the recommended calibration tolerance is 0,25 % of the measurement span or 0,5 K, and the reference device should be such that it provides an accuracy ratio greater than 4 versus a field instrument.

6.4 Design and construction phase recommendations

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 for any thermal performance test.

- a) Suitable access and isolation capability for permanently installed instrumentation and temporary test provisions, such as fuel sampling tapping point and fuel flow measurement should be taken into account in the design, as this will reduce manpower and downtime required during the preparations for testing.
- b) If permanently installed instrumentation is to be used during the test, the requirements of [Table 4](#) should be implemented if possible during early stages of the design. The ability to conduct post-test calibrations or to substitute with temporary instrumentation should also be considered. The signal processing and data logging should also meet the requirements of this document. If the permanently installed instrumentation has a local readout, then the display shall be in such a position that reading the display is convenient for the reader or inspector (especially flow devices). This is also applicable for the attached name plate identifications.
- c) In the case of precision power measurement for testing, it is recommended that current and voltage transformers in accordance with [6.7.2.3](#) are installed for the performance tests. The burden of the measuring transformers should be measured and recorded to check if the load is inside the calibration range.
- d) For temporary installed instrumentation, the design should allow for connections and spools sections, pressure connections, thermowells and electrical tie-ins. All tapping points for pressure transmitter and differential pressure transmitter connection including required isolating valves shall be made available for installing temporary precision test instrumentation. This also applies to the provision of free thermowells and power meter connections for testing purposes. All test instrument tapping points for connection of temporary precision test instrumentation need to be serviceable and accessible. Where possible these should be located such that scaffolding is not required for access. Suitable and correct isolation valves should be provided to allow safe connection and removal of static and differential pressure transducers for the performance test.
- e) Flow meters used for performance testing shall be designed, manufactured and located in a suitable straight section with sufficient upstream and downstream lengths to ensure conformity with the test codes. To meet the required flow meters measurement uncertainty limits, use of flow straighteners is recommended. Flow meters should ideally be of flanged construction (if pressure line allows it) so that they can be removed for calibration and if necessary replaced. A removal spool piece is recommended and should be inserted during all commissioning activities to prevent damage to the flow devices. In any case the flow element installation shall occur after any acid cleaning, as well as gas or steam blows, since those activities could have negative impact on the uncertainty and/or could easily invalidate calibration data on meters.
- f) The instrumentation layout should allow for contingency in duplicating and validating measurements used for determination of performance test results. This should be the case for power measurement and fuel flow in particular.
- g) Instrument loops should minimize signal interference and measurement error. If instrument transformers are used, adequate wire size should be used to reduce voltage drops.

- h) The design of the plant should consider accessible installation and provisions for air inlet temperatures (e.g. downstream chillers or evaporative coolers) and steam turbine exhaust pressures, as well as gas turbine (GT) exhaust, heat recovery steam generator (HRSG) module and HRSG stack temperatures and pressure measurements.

6.5 Test procedure

The performance test shall be conducted based on a test procedure developed to provide detailed guidance for the test preparation and execution as well as evaluation. This test procedure document supplements the contract obligations and clarifies particular contract issues. It shall provide the course of action for conducting the test, as well as methods of measurement and the method used for correcting the results from test conditions to reference conditions, or any other criteria set out in the contract. Prior to the execution, the test procedure shall be agreed upon by all the relevant parties to the test.

The following topics are strongly recommended to be included within the test procedure (unless known to be not applicable) in order to ensure highest possible quality of test preparation and execution.

- a) Brief description of the plant.
- b) Base reference conditions, guarantees or expected values.
- c) Required operating conditions and control conditions, e.g. load settings, power augmentation system conditions, supplementary firing conditions, gas turbine inlet cooling or heating conditions, district heating and process steam conditions, air cooled condenser or cooling tower (wet mode or dry mode), allowable range of fuel conditions (constituents and heating value).
- d) Responsibilities of test participants.
- e) The criteria for conformity with guarantees.
- f) Schematic diagram of the cycle, showing test boundary/envelope and test measurement points.
- g) A schedule for instrumentation including type, location, calibration requirements and systematic uncertainty.
- h) Requirements for the stabilization period prior to the test commencement and stability criteria during the test based on [Table 8](#).
- i) Details concerning fuel handling, including a procedure for fuel samples collection, handling, method of analysis, laboratories for fuel analyses, 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. On site gas chromatograph equipment for gas analysis may be used, if it meets the accuracy requirements of [Table 4](#).
- j) A cycle isolation list showing the position of valves required for the performance tests. This should include details of the normal operating position of plant valves (open/closed) and the position required during the performance test. Ideally the list should be prepared in table format so that it can be used as a check sheet during the performance test.
- k) Number of auxiliary consumers in service (pumps, compressors, etc.) and auxiliary load line-up.
- l) A list of the inspections required ahead of the performance test. It is envisaged that this will include inlet guide vane (IGV) angle checks, IGVs hand cleaning, visual inspections to check the cleanliness of the gas turbine compressor and IGV blades. For new plants, the major components should be in a clean and undamaged condition.
- m) Number of test runs and duration of each run.
- n) Frequency of data acquisition, data acceptance and rejection criteria.
- o) Optional template for manual readings where found necessary.

- p) Numerical values from tables (considering interpolation), curves or algorithms for correction under conditions differing from the specified conditions. The curves or algorithms, however, can be replaced by a computing model to be used for the correction from the reference conditions in line with [8.2](#) with agreement of the relevant parties involved. In case of correction curves it is advised that a sufficient order for each polynomial formula is provided to achieve accurate results and that 6 decimal places in scientific format may be considered, i.e. $y = a_n \cdot x^n + \dots + a_2 \cdot x^2 + a_1 \cdot x + a_0$, where constants a_i are in the format 0,000 000E $\pm$ 00.
- q) Method of combining test runs to calculate the final test result.
- r) Requirements for data storage, document retention, data and test report distribution.
- s) Method for agreeing and documenting any modification to test procedure.
- t) Method for documenting the control parameters during the test.
- u) Method for recording observations and deviations before, during or after test.
- v) Pre-test uncertainty analysis based on systematic uncertainties of the instrumentation (see [6.10](#)) and typical random uncertainties to check the requirements of [Table 4](#).

6.6 Field preparations for the performance test

Prior to the tests, the plant shall be placed at the disposal of the equipment supplier, the original equipment manufacturer (OEM) or engineering, procurement and construction (EPC) responsible for examination and cleaning (approval from load dispatch centres or other relevant parties involved might be considered). All parties to the test shall be given timely notification, to allow them the necessary time to respond and to prepare personnel, equipment or documentation. Updated information should be provided, as it becomes available.

In addition to following the test procedure, the testing parties should do as follows.

- a) Conduct a survey of all the components within the combined cycle plant in order to identify any deficiencies in equipment or process that might affect the performance test and to confirm that all components are ready for the performance test.
- b) Audit electrical power output measurement, inspect condition of the devices and check for possible consistency with other existing station power measurements.
- c) Audit the fuel flow measuring system, inspect condition of the devices and check for possible consistency with other existing station fuel flow measurements.
- d) Conduct gas turbine checks and preparation in accordance with ISO 2314. This applies in particular to the gas turbine compressor blades, inlet guide vanes (IGVs) and compressor inlet which 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.
- e) Prior to the commencement of tests, obtain valid calibration certificates for all temporary and station instruments used for primary variables.
- f) If certified instrumentation is not installed for secondary variables, conduct field calibration checks of secondary variables against reference calibrated instruments. These should be done considering the full loop against the calculated engineering value in the control system. Certificates of reference instruments used shall be made available. Typical secondary variables are listed in [Annex A](#).
- g) Verify instrument setup: location and proper installation of all relevant temporary and station instruments.
- h) Verify data acquisition setup: monitoring relevant parameters, frequency of data collection, remove any data filters (dead bands).

- i) Verify certificates and validity of calibrations for all primary variables, as per the requirement of this document. Also, crosscheck them against the nameplates and serial numbers of test equipment and instrumentation.
- j) Confirm adequate controls and operation modes of the plant (e.g. anti-icing, gas turbine inlet conditioning, process steam extractions, district heating, cooling tower or air cooled condenser). Also, agree on how to document their state during the test.
- k) Verify calibration and settings of station instrumentation and valves, in order to produce conditions as close as possible to the reference conditions. Also agree on how to document their state during the test.
- l) Obtain data sheets and calibration certificates of station flow elements (if available) including distributed control system (DCS) calculation methods.
- m) Record and determine dimensions and physical conditions of any part (vessels, piping, orifices, etc.) of the plant required for calculations or other test purposes.
- n) Finalize the detailed test programme document, including tests sequence, durations and load requirements.
- o) Obtain a recent fuel analysis (with fuel density and lower or higher heating value) or fuel composition to ensure that the fuel characteristics are as expected.
- p) Identify the names of the laboratories for fuel analyses.
- q) Appoint a test director from the conducting party, who will oversee and lead the test programme.
- r) Ensure that a suitable number of personnel are available to support equipment installation and preparation activities. Also, if needed, for collecting the test data.
- s) Implement an effective communication system to indicate the starting and the end of the tests and to inform all personal involved in recording of manual readings when to take each value.
- t) Finalize a cycle isolation list, getting agreement with plant operations and operator support for conducting cycle isolation. It is recommended to separate the isolation in all electrically operated valves (these can be checked from the control room ahead of tests), all valves that are closed for normal operation and closed for the performance tests and all valves that are open for normal plant operation and closed for the performance test. These valves are normally closed before the start of the test.
- u) Finalize auxiliary load line-up list, confirming support from plant operations.
- v) Conduct a condenser vacuum drop test (if applicable) by means of shutdown of vacuum system of the condenser, e.g. for 10 min. The vacuum slope in mbar/min should be in the expected range of condenser supplier, e.g. 1 mbar/min. A visual inspection of tube condition bypass gap baffle can be conducted under field preparations. These checks can be conducted under commissioning tests to avoid unnecessary delays during a test programme.
- w) Perform inspection of evaporative coolers or chillers, i.e. under field preparations.
- x) Conduct preliminary test runs.
- y) Record and agree in writing any deviations to the preparations specified in the test procedure.
- z) Prepare a list of representatives and contact details of those involved in testing.

6.7 Instruments and measuring methods

6.7.1 General

This subclause describes the instruments, methods and precautions to be employed when testing combined cycle power plants in accordance with this document. Where there is no specification 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 instrumentation is used.

The instruments and measuring methods mentioned and described hereafter are state of the art and commonly employed at the time this document 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.

6.7.2 Electrical power measurement

6.7.2.1 General

The metering method of the electrical power, preferably the three-watt meter method, depends on the various types of the power generating and distributing arrangements, which typically are three-phase systems with Delta generator connection in three-wire configuration or Star generator connection in 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, in accordance with IEC or other recognized standards.

6.7.2.2 Power metering equipment

For the measurement of the active power output, single-phase or poly-phase precision Watt or Watt-hour meters of accuracy class of 0,2 % or better shall be used, in accordance with [Table 4](#). If the power meter is not equipped with an integrated feature to measure the power factor, the reactive power shall be recorded with a Var or Var-hour meter of an accuracy class of 0,5 % or better.

In cases where excitation and/or auxiliary power, branched off the main generator bus duct, is metered to determine the net electrical output based on gross power measurement, the accuracy of the corresponding Watt or Watt-hour-meter shall have an accuracy class of 3 % or better in accordance with [Table 4](#).

If a Watt meter is being used to measure the active power output, the instantaneous active power shall be measured frequently during a test run and averaged over the test run period to determine average power (kilowatts) during the test. In this case the measurement frequency shall not be less than once every 30 s. Conversely, auxiliary power or power factor measurements done via Watt meter and Var meter, respectively, can be done every 60 s.

Power output 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 tests load, voltage, power factor 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 document are fulfilled.

6.7.2.3 Instrument transformers

For power output metering, correctly rated and calibrated voltage and current transformers of 0,2 % accuracy class or better shall be used, in accordance with [Table 4](#). The respective 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. In certain cases, an exception to the minimum accuracy class requirement can be made depending on country regulations and the standard used to devise the instrument transformer.

The calibrations shall cover the expected field test conditions such as voltage, current, turn ratio, phase angle and expected 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 which 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.

6.7.2.4 Speed measurement

Since the influence of shaft speed to the combined cycle performance mainly depends on the gas turbine behaviour refer to ISO 2314:2009, 6.4.6 for the requirements regarding speed measurements.

6.7.3 Flow measurements

6.7.3.1 General

Since each energy stream shall be determined with reference to the point at which it crosses the test boundary, the choice of the test boundary can have a significant impact on the test results. An example might be the inclusion or exclusion of a fuel pre-heater.

Each measurement variable of a flow device, such as static/differential pressure, temperature, pulses and fluid properties, shall be recorded individually to allow intrinsic calculation of the mass flow rate. Therefore, flow computer or other control system calculated flow values are not to be used as they are usually not in conformance with the requirements of this document.

6.7.3.2 Gaseous fuel flow measurement

The fuel flow per unit of time (flow rate) of gaseous fuels shall be determined by one of the following.

- a) Turbine type flow meter, in accordance with ISO 9951.
- b) Differential pressure device, in accordance with ISO 5167 (all parts).
- c) Coriolis meter, in accordance with ISO 10790.
- d) Ultrasonic flow meter, in accordance with ISO 17089-1.

The fuel flow meter specified shall meet the applicable requirements of a recognized international or national standard.

Accurate gas analysis during the calibration is mandatory for fuel flow meters which measurements depend directly from the gas properties (e.g. coriolis meter).

Other flow meters covered by a recognized international or national standard, and meeting the uncertainty requirements of this document, can also be used.

Meters shall be selected to meet uncertainty requirements of this document, in accordance with [Table 4](#).

The computation of the actual fuel mass flows at test conditions is based on the formulae outlined in respective standards, in conjunction with ISO 6976 for the determination of the gas density and ISO 12213-2 for gas compressibility.

6.7.3.3 Liquid fuel flow measurement

It is recommended to measure the liquid fuel flow by means of following meters.

- a) Nozzle, orifice or venturi flow section, in accordance with ISO 5167 (all parts).
- b) Ultrasonic flow meter, in accordance with ISO 12242.
- c) Coriolis flow meter, in accordance with ISO 10790.

Other flow devices such as positive displacement flow meters are also permitted, as long as they meet the requirements of [Table 4](#) and are calibrated and installed per recognized standards.

6.7.3.4 Water/steam flow measurement

Depending on the plant configuration and equipment scope, several steam or water flows can cross the boundary at different points, such as condenser cooling water flow, process steam/water, GT steam/water injection and GT inlet heating and cooling flows.

For better accuracy, feed water measurements are preferred for determining downstream steam flows, instead of direct measurement of steam flow.

In the case of spray water injection used to control the final steam temperature, a heat balance around the attemperator can be done, using measurements of steam and water temperatures, pressures and feed water flow.

Water and steam flows can be measured with nozzle, orifice or venturi flow section in accordance with ISO 5167 (all parts), an ultrasonic flow meter in accordance with ISO 12242, or a Coriolis flow meter in accordance with ISO 10790. Other flow devices are also permitted, as long as they meet the requirements of [Table 4](#) and are calibrated and installed per recognized standards.

6.7.4 Temperature measurements

6.7.4.1 General

This subclause presents requirements and guidance regarding the measurement of temperature. It also discusses applicable temperature measurement devices, calibration of temperature measurement devices, and application of temperature devices.

6.7.4.2 Acceptable temperature measurement devices

- Thermocouples in accordance with IEC 60584 (all parts) may be used to measure temperature of any fluid above 150 °C. The maximum temperature is dependent on the type of thermocouple and sheath material used. The thermocouple is a differential-type device. The thermocouple measures the difference between the measurement location in question and a reference temperature (cold junction). The greater this difference, the higher the signal from the thermocouple. Therefore, below 150 °C the signal becomes low and subject to induced noise causing inaccuracy. It is recommended to measure the temperature of any fluid above 150 °C.
- Resistance temperature devices (RTD) in accordance with IEC 60751 may be used to measure temperature from any low temperature to the highest temperature recommended by the RTD manufacturer. It is recommended to measure the temperature of any fluid below 250 °C.