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JAPANESE INDUSTRIAL STANDARD

Test Method for Gas Turbines

JIS B 8041—1989

Translated and Published

by

Japanese Standards Association

Printed in Japan

In the event of any doubt arising,
the original Standard in Japanese is to be final authority.

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Test Method for Gas Turbines

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1. Scope

This Japanese Industrial Standard specifies the general rules as a guide concerning the operating conditions and testing methods for obtaining the power output, heat rate or thermal efficiency, and other characteristics of open cycle gas turbines or gas turbine power plants having normal combustion systems.

This Standard is also applicable to gas turbines used for combined-cycle or cogeneration plants or gas turbines using water or water vapor jets, but where required, it may be applied with suitable correction.

Further, it may be applied, with suitable correction, to closed cycle gas turbines, semi-closed cycle gas turbines, free piston gas turbines and gas turbines having special heat sources (for example, chemical processes, supercharged boiler furnaces, and nuclear reactors). However, it is not applicable to aircraft gas turbines.

It is not applicable to tests for development.

Remark: Those units and numerical values shown in { } in this Standard are based on the conventional units and are appended for informative reference.

2. Definitions, Symbols and Units

2.1 Definitions The meanings of the main terms used in this Standard shall be as follows except as specified in JIS B 8042 and JIS B 0128.

(1) mandatory tests The following tests as the main object of this Standard.

(a) Tests for obtaining power (for plants with gas generators only, gas power) and heat rate or thermal efficiency.

(b) Tests for verifying the operation of main protective devices.

(2) optional tests Tests selected by agreement between the customer and the supplier.

For example, tests concerning speed governing system operation, operation of safety devices not included in the mandatory tests, starting characteristics, vibration, exhaust gas properties, noise level, waste heat recovery, thermal discharge, anti-icing system, etc.

(3) standard reference conditions Standard conditions concerning power output, thermal efficiency, and heat rate or specific fuel consumption used as the reference for comparison, concretely consisting of the following conditions.

Applicable Standards, Corresponding International Standard and Reference Standards: See page 41.

- (a) Intake Air Conditions For the intake air at compressor flange (or compressor inlet flare):
a total pressure of 101.3 kPa {1.013 bar, 760 mmHg, or 1.033 kgf/cm²};
a total temperature of 15°C;
a relative humidity 60 %.
 - (b) exhaust gas condition For the exhaust gas at turbine exhaust flange (for regenerative cycles, at recuperator outlet): a static pressure of 101.3 kPa {1.013 bar, 760 mmHg, or 1.033 kgf/cm²}.
 - (c) cooling water condition Where water is used for working fluid cooling, a cooling water inlet temperature of 15°C.
 - (d) heater or cooler for working fluid Where heaters or coolers using atmospheric air are employed, the standard reference conditions shall be: 15°C and 101.3 kPa {1.013 bar, 760 mmHg, or 1.033 kgf/cm²}.
- (4) power output As the expressions of effective power outputs generated by gas turbines, there are the power output at the gas turbine output shaft end, hereinafter referred to as "shaft output", transmission gear shaft output at the transmission gearing (speed reducing or increasing) output shaft end, electrical power output at the generator terminals, gas power possessed by the combustion gas produced by a gas generator, gas power possessed by the air or combustion gas extracted from the gas turbine, etc.
- The above power outputs when measured mechanically or electrically are "measured outputs", which include measured shaft output, measured electrical generator power output, etc., and those power outputs obtained from measured outputs after correction by the debit and credit calculation specified in 7.2.1 and 7.2.2 are the net power outputs, which include net shaft output, net electrical generator power output, etc.
- (5) heat rate or thermal efficiency Heat rate means the quantity of consumed heat per unit power output, and thermal efficiency means the ratio of produced effective work to the supplied heat quantity.

The specific energy of the fuel used is represented by the net specific energy under the following reference conditions. However, the difference between the temperature of supplied fuel and the reference temperature shall be taken into account.

Pressure: 101.3 kPa {1.013 bar, 760 mmHg, or 1.033 kgf/cm²}

Temperature: 15°C

2.2 Symbols and Units The main quantity symbols used in this Standard are shown below with their meanings and units.

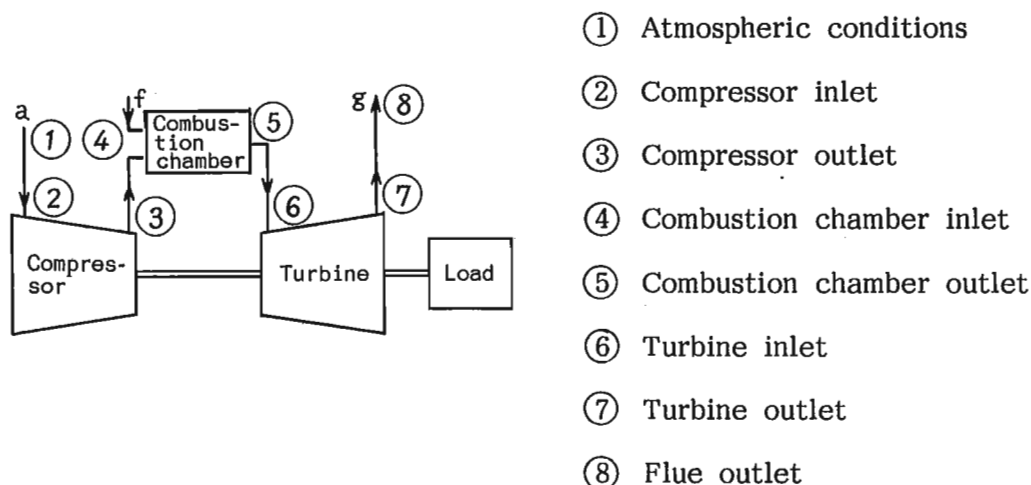
Fig. 1 and Fig. 2 show the symbols used for defining the positions of measuring the condition quantities (pressure and temperature) and flow rate of the working fluid (air, fuel, and combustion gas) passing successively through respective elements of a gas turbine plant (compressor, combustion chamber, and turbine), or defining the various quantities (such as enthalpy) calculated using measured values.

Table 1 shows the quantity symbols and their definitions and units for various quantities relating to the calculation formulae used in the calculation of results of measurement.

Further, the main units used in this Standard are shown in Table 2, and unit conversion factors are shown in (3).

- (1) Symbols for Cycle The station symbols for simple cycles are indicated by numbers as shown in Fig. 1.

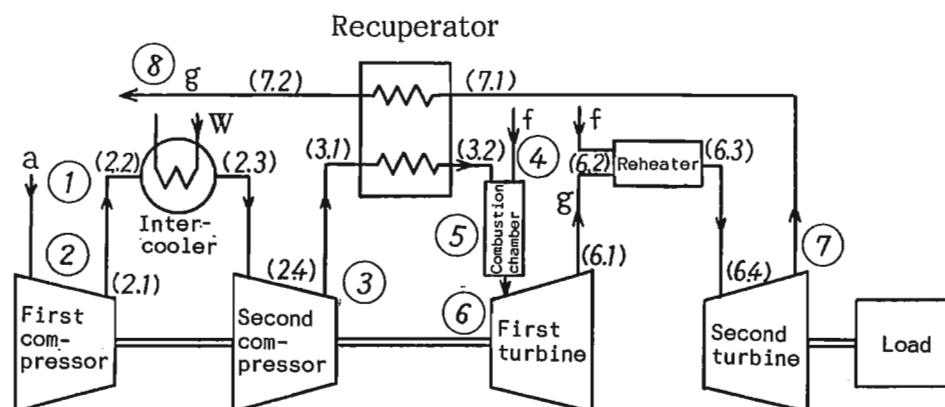
Fig. 1. Station Symbols for a Simple Cycle



For turbine plants having a plurality of compressors or turbines, the first turbine outlet is numbered as (6.1) and the second turbine inlet as (6.2). However, when there is a reheater, as shown in Fig. 2, the reheater inlet is numbered as (6.2), its outlet as (6.3), and the second turbine inlet as (6.4).

Where a recuperator is used, its inlet is numbered as (7.1) and its outlet as (7.2).

Fig. 2. An Example of Station Symbols for a Cycle with a Plurality of Elements



Respective kinds of fluids are distinguished by using the following suffixes.

a: air b: lubricating oil c: lubricant coolant f: fuel
g: gas after combustion chamber s: steam w: water

The condition quantity and flow rate of liquids are indicated as follows according to the kind and position of the fluid.

Example: Fuel temperature at combustion chamber inlet T_{t1}

Gas flow rate at turbine outlet m_{gt}

Where symbols other than the station symbols shown above are used, their explanations shall be appended.

- (2) Quantity Symbols and Their Definitions and Units The main quantity symbols used in this Standard and their definitions and units are as shown in Table 1.

Basic units frequently used are shown in Table 2, and numerical values used for conversion of units are shown in (3).

Pressures and temperatures of air or gas indicate absolute total pressures and absolute total temperatures, unless otherwise specified.

Table 1. Quantity Symbols and Their Definitions and Units

Quantity symbol	Definition	Unit	Specification clause
C_{pc}	Specific heat of lubricant coolant	kJ/kg·K	7.6
h_{a0}	Enthalpy of air at standard reference temperature (15°C)	kJ/kg	7.6, 7.7
h_{a1}	Enthalpy of air at temperature T_{a1}	kJ/kg	7.6
h_{a2}	Enthalpy of air at temperature T_{a2} (compressor inlet)	kJ/kg	7.7
h_{a3}	Enthalpy of air at temperature T_{a3} (compressor outlet)	kJ/kg	7.7
h_{a4}	Enthalpy of air at temperature T_{a4} (Combustion chamber inlet)	kJ/kg	7.7
h_e	Enthalpy of air or gas at temperature T_e leaving control volume	kJ/kg	7.6
h_t	Enthalpy of fuel at temperature T_t at inlet of control volume	kJ/kg	7.6
h_{t0}	Enthalpy of fuel at standard reference temperature (15°C)	kJ/kg	7.3, 7.6, 7.7
h_{t4}	Enthalpy of fuel at temperature T_{t4} (combustion chamber inlet)	kJ/kg	7.3, 7.7
h_{g0}	Enthalpy of combustion gas at standard reference temperature (15°C)	kJ/kg	7.6, 7.7

Table 1. (Continued)

Quantity symbol	Definition	Unit	Specification clause
h_{g5}	Enthalpy of combustion gas at combustion chamber outlet	kJ/kg	7.7
h_{g6}	Enthalpy of gas at temperature T_{g6} (turbine inlet)	kJ/kg	7.7
$h_{g6.1}$	Enthalpy of gas at temperature $T_{g6.1}$ (compressor turbine outlet)	kJ/kg	7.7
$h_{g6.2}$	Enthalpy of gas at temperature $T_{g6.2}$ (power turbine inlet)	kJ/kg	7.6
h_{g7}	Enthalpy of gas at temperature T_{g7} (turbine outlet)	kJ/kg	7.6
h_{g8}	Enthalpy of gas at temperature T_{g8} leaving control volume	kJ/kg	7.6
$h'_{g \text{ in}}$	Enthalpy of working fluid at temperature $T'_{g \text{ in}}$ and pressure $p'_{g \text{ in}}$ at driven machine inlet	kJ/kg	7.6
$h'_{g \text{ out}}$	Enthalpy of working fluid at temperature $T'_{g \text{ out}}$ and pressure $p'_{g \text{ out}}$ at driven machine outlet	kJ/kg	7.6
M	Torque	kN·m	7.2
m_{a1}	Mass rate of air at compressor inlet entering control volume	kg/s	7.6, 7.7
m_{a2}	Mass rate of air at compressor inlet (generally $m_{a1} = m_{a2}$)	kg/s	7.7
m_{a3}	Mass rate of air at compressor outlet	kg/s	7.7
m_{a4}	Mass rate of air at combustion chamber inlet	kg/s	7.7
m_c	Mass rate of lubricant coolant	kg/s	7.6
m_e	Mass rate of air or gas leaving control volume, such as leakage from shaft sealing device, extracted air, etc.	kg/s	7.6, 7.7
m_{f4}	Mass rate of fuel at combustion chamber inlet	kg/s	7.3, 7.6, 7.7
$m_{f(d)}$	Fuel quantity consumed during test duration $[t_{(d)}]$	kg	7.3
m_{g5}	Mass rate of gas at combustion chamber outlet	kg/s	7.7
m_{g6}	Mass rate of gas at turbine inlet	kg/s	7.7
m_{g7}	Mass rate of gas at turbine outlet	kg/s	7.6, 7.7
m_{g8}	Mass rate of gas leaving control volume	kg/s	7.6
m'_{g}	Mass rate of working fluid at driven machine inlet	kg/s	7.6
n	Speed of rotation	min ⁻¹	
n_0	Speed of rotation corresponding to standard reference conditions	min ⁻¹	7.4

Table 1. (Continued)

Quantity symbol	Definition	Unit	Specification clause
n_c	Stabilized speed of rotation	min^{-1}	6.2
n_m	Maximum speed of rotation	min^{-1}	6.2
n_r	Rated speed of rotation	min^{-1}	6.2
n_t	Test speed of rotation	min^{-1}	7.4
P	Net shaft output	kW	7.3, 7.6
P_c	Corrected net shaft output	kW	7.4
P_g	Measured shaft output	kW	7.2
P_m	Measured shaft output	kW	7.7
P_{sh}	Shaft output	kW	7.6
P_t	Test net shaft output	kW	7.4
p_{a0}	Pressure of air at standard reference conditions (101.3 kPa)	kPa	7.4
p_{a1}	Pressure of air entering control volume	kPa	
$p_{a1(t)}$	Pressure of atmospheric air at test	kPa	7.4
p_{a2}	Pressure of air at compressor inlet	kPa	5.5.3
p_{a3}	Pressure of air at compressor outlet	kPa	5.5.5
p_e	Pressure of extracted air or extracted gas leaving control volume	kPa	
p_{g6}	Pressure of gas at turbine inlet	kPa	5.5.5
p_{g7}	Pressure of gas at turbine outlet	kPa	5.5.4
$p_{g7.2}$	Pressure of gas at recuperator outlet	kPa	5.5.4
p_{g8}	Pressure of exhaust gas leaving control volume	kPa	
$p'_{g \text{ in}}$	Pressure of working fluid at driven machine inlet	kPa	7.6
$p'_{g \text{ out}}$	Pressure of working fluid at driven machine outlet	kPa	7.6
Q_{10}	Constant-pressure net specific energy of fuel at standard reference temperature (15°C)	kJ/kg	7.3, 7.6 7.7
Q_m	Mechanical loss	kW	7.6
Q'_{mc}	Mechanical loss of driven compressor (excluding mechanical loss of transmission gearing)	kW	7.6
Q_{mgs}	Mechanical loss in gas generator and power loss in auxiliary devices	kW	7.7
Q_{mt}	Mechanical loss of power turbine (including mechanical loss of transmission gearing)	kW	7.6
Q_r	Heat loss by radiation and convection	kW	7.6

Table 1. (Continued)

Quantity symbol	Definition	Unit	Specification clause
Q_{rc}	Radiation heat loss from driven compressor casing	kW	7.6
Q_{rb}	Heat loss by radiation and convection from combustion chamber	kW	7.7
Q_{rt}	Heat loss by radiation and convection from power turbine casing (at the part between measuring positions for temperatures $T_{6.2}$ and T_7)	kW	7.6
q	Heat consumption per unit time	kW	7.3
T_{a0}	Temperature of air at standard reference conditions (15 + 273.15 K)	K	7.4
T_{a1}	Flow-weighted average temperature of air entering control volume	K	7.6
$T_{a1 (t)}$	Temperature of atmospheric air entering compressor at test	K	7.4
T_{a2}	Temperature of air at compressor inlet	K	5.4.2
T_{a4}	Temperature of air at combustion chamber inlet	K	5.4.5, 7.7
$T_{c in}$	Temperature of coolant at lubricant cooler inlet	K	7.6
$T_{c out}$	Temperature of coolant at lubricant cooler outlet	K	7.6
T_e	Temperature of air or gas leaving control volume, such as leakage from shaft sealing device, extracted air, etc.	K	7.6
T_f	Temperature of fuel at control volume inlet	K	7.6
T_{f0}	Temperature of fuel at standard reference temperature (15°C)	K	
T_{f4}	Temperature of fuel at combustion chamber inlet (generally $T_{f4} = T_f$)	K	7.7
T_{g6}	Reference turbine inlet temperature ⁽¹⁾	K	5.4.4, 7.7
$T_{g6.2}$	Power turbine inlet gas temperature	K	7.6
T_{g7}	Turbine outlet gas temperature	K	5.4.3, 7.6
$T_{g6 (t)}$	Turbine inlet gas temperature corresponding to standard reference conditions	K	7.4
$T_{g7 (t)}$	Turbine outlet gas temperature corresponding to standard reference conditions	K	7.4
$T_{g6 (t)}$	Turbine inlet gas temperature at test	K	7.4
$T_{g7 (t)}$	Turbine outlet gas temperature at test	K	7.4

Table 1. (Continued)

Quantity symbol	Definition	Unit	Specification clause
T_{gs}	Flow-weighted average temperature of gas leaving control volume	K	7.6
$T'_{g\text{ in}}$	Working fluid temperature at driven machine inlet	K	7.6
$T'_{g\text{ out}}$	Working fluid temperature at driven machine outlet	K	7.6
$t_{(a)}$	Test duration	s	7.3
δ	Ratio of atmospheric pressure at test to standard reference pressure		7.4
ϵ	Heat rate		7.3, 7.4
η	Thermal efficiency		7.3, 7.4
η_b	Combustion chamber efficiency		7.6, 7.7
θ	Ratio of atmospheric temperature at test to standard reference temperature		7.4
ω	Angular velocity	rad/s	7.2

Note (1) This temperature means that defined in 7.7 and accords with the "Reference turbine inlet temperature" defined in ISO 2314 Gas turbines - Acceptance tests 8.6 Turbine inlet temperature.

Table 2. Units Used

Quantity	Designation of unit	Unit symbol
Length	Meter	m
Time	Second, minute, hour	s, min, h
Mass	Kilogram	kg
Speed of rotation	Revolutions per second Revolutions per minute	s^{-1} min^{-1}
Force Weight	Newton {Weight kilogram}	N {kgf}
Energy Work	Joule {Weight kilogram-meter, watt-hour, calory}	J, N·m { $kgf \cdot m$ $W \cdot h$ cal}
Power Motive power	Watt {weight kilogram-meter per second, meter-horsepower}	W, N·m/s, J/s { $kgf \cdot m/s$ PS}
Pressure	Pascal Bar {weight kilogram per square meter}	Pa, N/m ² bar {kgf/m ² }
Kinematic viscosity	Square meter per second {stoke}	m ² /s {St}
Temperature Celsius temperature	Kelvin Celsius degree	K °C
Temperature interval	Kelvin Celsius degree	K °C

- (3) Unit Conversion The conversion between units shall be performed in accordance with JIS Z 8202, and examples of conversion frequently used are shown below.

1 kgf	=9.806 65 N
1 kgf·m	=9.806 65 J
1 kcal	=4.186 05 kJ
1 kW·h	=3.6 MJ
	=860 kcal
1 kgf·m/s	=9.806 65 W
1 PS	=75 kgf·m/s
	=735.5 W
1 kgf/m ²	=9.806 65 Pa
1 atm	=101.325 kPa
	=1.013 25 bar
	=760 mmHg
	=1.033 23 kgf/cm ²
1 bar	=100 kPa
	=750.062 mmHg
1 cSt	=1 μm ² /s
K	=t (°C) + 273.15

3. Preparation for Testing

The preparation for the tests shall be performed as follows:

- (1) Tests shall be performed as earlier as possible after installation of the plant and in the normal condition of the machines.
- (2) Where pipes or ducts are installed to by-pass certain elements or for air extraction for a certain purpose, the valves provided on such piping shall be set to satisfy the specified conditions.
- (3) Where required for the evaluation of test results and for other purposes, the dimensions and conditions (clearance and the like) of the gas turbine parts shall preliminarily be measured and recorded.
- (4) Before starting the tests, the machine number and data shall be recorded from the nameplate to identify the gas turbine to be tested and its auxiliary devices.
- (5) Where the noise and vibration are measured, the background noise and vibration at the site shall be measured and recorded before starting operation.
- (6) The tolerances on the test results shall be decided by agreement between the customer and the supplier. The tolerances shall be specified by considering the degree of influence of the respective measuring accuracies specified in 5. on the test results.
- (7) It is desirable to preliminarily appoint a commander of the tests by agreement between the customer and the supplier. The commander of the tests shall direct, proceed and control the tests.

- (8) Preparatory tests may be performed for the following purposes.

Further, the preparatory tests may be regarded as regular tests according to agreement between the customer and the supplier.

- (a) Verification of the fact that the gas turbine and its auxiliary devices are in an adequate condition for performing the regular performance tests.
- (b) Inspection of measuring instruments.
- (c) Familiarization with the test procedure.

4. Test Operating Conditions

4.1 General Requirements The general requirements for the test operation shall be as follows.

- (1) In the execution of tests, efforts shall be made so as to operate the turbine plant under conditions as close as possible to the standard reference conditions or other specified conditions.
- (2) The conditions of suction air shall be specified directly before the compressor inlet flange, and the conditions of exhaust gas shall be specified directly after the turbine outlet flange for a non-regenerative gas turbine, and directly after the turbine outlet flange on the recuperator gas side in the case of a regenerative cycle gas turbine.
- (3) Where performance values under certain operating conditions are to be corrected to performance values under the standard reference conditions or other specified conditions, the methods of correction specified in 7.4 shall be employed.
- (4) The performance of gas turbines is sharply influenced by the pressure and temperature of suction air and the exhaust gas pressure, and may sometimes be influenced by humidity. Therefore, it is mandatory to clearly report these values under the standard reference conditions or other specified conditions and under the operating conditions at the tests.
- (5) The fuel for tests shall be the specified fuel or a fuel of a kind and properties substantially the same as those specified. If it is impossible, agreement shall preliminarily be made as to the selection of the test fuel and the method of evaluating the test results.
- (6) The heat rate test of a gas turbine plant using not less than two kinds of fuels may be performed by using one kind of fuel if agreed upon between the customer and the supplier.
- (7) Where a special adjustment different from that for normal operation is performed for testing, a written agreement shall be made between the customer and the supplier.
- (8) In recording the readings during the tests, the actual readings before instrumental correction shall be recorded on preliminarily prepared recording sheets, and in addition, the testing date, the time of day of reading, and the reader's name shall be clearly recorded.

Where these recording sheets and automatic recording sheets are reproduced, hand copying shall not be made. Therefore, the paper used shall desirably be such that permits reproduction by a copying machine.

Each one copy of these records shall be apportioned to both parties and, safely kept by them.

- (9) Where an obvious inconsistency is found as a result of examining the measured values obtained during a test or from a series of tests, the whole series of tests or a part of it shall be discarded. However, this does not apply where the validity of the test results can be proved by using related supplementary data or where such inconsistency is permitted by agreement between the customer and the supplier.

4.2 Operating Conditions The operating conditions shall be as follows:

- (1) In performing the following tests, the gas turbine shall be operated under steady-state conditions, as a rule.

- (a) Power output test
- (b) Heat rate or thermal efficiency test
- (c) Exhaust gas test
- (d) Noise test

- (2) Steady-State Conditions The steady-state conditions shall mean such that the indication values of measuring instruments important for the purposes of the test, are observed continuously through a given period of time⁽²⁾ agreed upon between the customer and the supplier, and are stably maintained within the range of the maximum permissible variations shown in Table 3 and succeeding clauses.

Where the operating conditions have been altered, measurements shall be made after the steady-state conditions are reached under the renewed operating conditions.

Note ⁽²⁾ Time duration required for stabilization before starting measurement for tests, or the test duration including the former.