

Rules for steam turbine thermal acceptance tests

Part 1. Method A: High accuracy for large condensing steam turbines

The European Standard EN 60953-1 : 1995 has the status of a
British Standard

ICS 27.040

Committees responsible for this British Standard

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- Association of Consulting Engineers
- Electricity Supply Industry in England and Wales
- North of Scotland Hydro-electric Board
- Power Generation Association (BEAMA Ltd.)
- South of Scotland Electricity Board

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National foreword

This British Standard has been prepared by Technical Committee MCE/13 and is the English language version of EN 60953-1 : 1995 *Rules for steam turbine thermal acceptance tests Part 1: Method A High accuracy for large condensing steam turbines*, published by the European Committee for Electrotechnical Standardization (CENELEC). It was derived by CENELEC from IEC 953-1 : 1990, published by the International Electrotechnical Commission (IEC). It supersedes BS 752 : 1974, which is withdrawn.

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to:

- IEC Publication 27: *Letter symbols to be used in electrical technology*
- IEC Publication 617: *Graphical symbols for diagrams*

The symbols and signs contained in the present publication have either been taken from IEC Publication 27 or 617, or have been specifically approved for the purpose of this publication.

For general terminology, readers are referred to IEC Publication 50: *International Electrotechnical Vocabulary (IEV)*, which is issued in the form of separate chapters each dealing with a specific field, the General Index being published as a separate booklet. Full details of the IEV will be supplied on request¹⁾.

The terms and definitions contained in the present publication have been either taken from the IEV or specifically approved for the purpose of this publication.

Some Sections and Parts of BS 4727 are identical with or technically equivalent to IEC Publication 50. All Parts of BS 3939, except for Part 1, are identical with IEC Publication 617.

EN 60953-1 was produced as a result of international discussion in which the United Kingdom took an active part.

Cross-references

Publication referred to	Corresponding British Standard
IEC 34-2 : 1972	BS 4999 <i>General requirements for rotating electrical machines</i> Part 102 : 1987 <i>Methods for determining losses and efficiency from tests (excluding machines for traction vehicles)</i>
ISO 5167-1 : 1991 ²⁾	BS 1042 <i>Measurement of fluid flow in closed conduits</i> Part 1 <i>Pressure differential devices</i> Section 1.1 : 1992 <i>Specification for square-edged orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full</i>

Compliance with a British Standard does not of itself confer immunity from legal obligations.

¹⁾ Available from Sales Department, BSI, 389 Chiswick High Road, London W4 4AL.

²⁾ Revision of ISO 5167 : 1980 to which normative reference is made in the text.

ICS 27.040

Descriptors: Turbine, steam apparatus, condensing, thermal test, acceptance test, accuracy, measurement technology, thermal efficiency

English version

Rules for steam turbine thermal acceptance tests
Part 1: Method A
High accuracy for large condensing steam turbines

(IEC 953-1 : 1990)

Règles pour les essais thermiques de réception
des turbines à vapeur
Partie 1: Méthode A
Haute précision pour les turbines à vapeur à
condensation de grande puissance
(CEI 953-1 : 1990)

Regeln für thermische Abnahmeprüfungen für
Dampfturbinen
Teil 1: Methode A
Hohe Präzision für große kondensierende
Dampfturbinen
(IEC 953-1 : 1990)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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Foreword

The text of the International Standard IEC 953-1 : 1990, prepared by IEC TC 5, Steam turbines, was submitted to the Unique Acceptance Procedure and was approved by CENELEC as EN 60953-1 on 1995-11-28 without any modification.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1996-12-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1996-12-01

Annexes designated 'normative' are part of the body of the standard. Annexes designated 'informative' are given for information only. In this standard, appendices B, C and annex ZA are normative, and appendix A is informative. Annex ZA has been added by CENELEC.

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RULES FOR STEAM TURBINE THERMAL ACCEPTANCE TESTS

Part 1: Method A — High accuracy for large condensing steam turbines

INTRODUCTION

The rapid development of measuring techniques, the increasing capacity of steam turbines and the introduction of nuclear power plants necessitated a revision of IEC Publication 46 (1962) regarding acceptance tests.

Since all the needs of the power industry in the different parts of the world could not be satisfied by one single publication, the complete standard is divided into two parts, describing two different approaches for conducting and evaluating thermal acceptance tests of steam turbines and which can be used separately:

- a) Method A, which is Part 1 of the standard (IEC 953-1), deals with thermal acceptance tests with high accuracy for large condensing steam turbines.
- b) Method B, which is Part 2 of the standard (IEC 953-2), deals with thermal acceptance tests with a wide range of accuracy for various types and sizes of steam turbines.

1) *Basic philosophy and figures on uncertainty*

Part 1 provides for very accurate testing of steam turbines to obtain the level of performance with minimum measuring uncertainty. The operating conditions during the test are stringent and compulsory.

Method A is based on the exclusive use of the most accurate calibrated instrumentation and the best measuring procedures currently available. The uncertainty of the test result is always sufficiently small that it normally need not be taken into account in the comparison between test result and guarantee value. This uncertainty will not be larger than about 0.3% for a fossil fired unit and 0.4% for a nuclear unit.

The cost for instrumentation and the efforts for preparing and conducting the tests will generally be justified economically for large and/or prototype units.

Method B provides for acceptance tests of steam turbines of various types and capacities with appropriate measuring uncertainty. Instrumentation and measuring procedures have to be chosen accordingly from a scope specified in the standard which is centred mainly on standardized instrumentation and procedures, but may extend eventually up to very high accuracy provisions requiring calibration. The resulting measuring uncertainty of the test result is then determined by calculating methods presented in the standard and normally, if not stated otherwise in the contract, taken into account in the comparison between test result and guarantee value. The total cost of an acceptance test can therefore be maintained in relationship with the economic value of the guarantee values to be ascertained.

The specifications of the operating conditions during the test are somewhat more flexible in this method; furthermore, procedures are recommended for treating cases where these specifications cannot be met.

When good-standardized instrumentation and procedures are applied in a test, the measuring uncertainty of the result will usually amount to 0.9% to 1.2% for a large fossil fuel fired condensing unit, to 1.1% to 1.4% for a nuclear unit and to 1.5% to 2.5% for back pressure, extraction and small condensing turbines. It is possible to reduce these values by additional improvement in instrumentation, primarily by additional measurements of primary mass flows and/or calibration of measuring devices for primary mass flow.

2) *Main difference between Methods A and B*

In Method A, much more detailed information concerning the preparation and conduct of the tests and the measuring techniques are contained for guidance of the parties to the test than in Method B. In Method B, the detailed treatment of these objectives is left somewhat more to the discretion and decisions of the participants and necessitates sufficient experience and expertise on their part.

3) *Guiding principles*

The requirements concerning the preparation and conditions of the test and especially such conditions of the test as duration, deviations and constancy of test conditions and acceptable differences between double measurements are more stringent in Method A.

The test should be conducted preferably within eight weeks after the beginning of the operation. It is the intent during this period to minimize performance deterioration and risk of damage to the turbine.

Preliminary tests including enthalpy drop tests should be made during this period to monitor HP and IP turbine section performance. However, these tests do not provide LP section performance and for this reason it is imperative to conduct the acceptance tests as soon as practicable.

Whatever the case, when using Method A, if an enthalpy drop test indicates a possible deterioration of the HP or IP section, or if the plant conditions require that the tests be postponed more than four months after the initial start, then the acceptance tests should be delayed.

An adjustment of the heat rate test results to start-up enthalpy drop efficiencies or for the effects of aging is not permitted when using Method A.

If the test has to be postponed, Method A proposes that the test be carried out after the first major internal inspection; several methods are proposed for establishing the approximate condition of the turbine prior to the tests.

4) *Instruments and methods of measurement*

a) *Measurement of electrical power*

In addition to the conditions required for the measurement of electric power, which are similar in both methods, Method A requires a check of the instruments by a comparison measurement after each test run; the permissible difference between double measurements is limited to 0.15%.

b) *Flow measurement*

For the measurement of main flows the use of calibrated pressure difference devices is required in Method A. The application of a device not covered by international standardization, the throat-tap nozzle, is recommended therein and details of design and application are given.

The calibration of these devices shall be conducted with the upstream and downstream piping and flow-straightener. Methods for the necessary extrapolation of the discharge coefficient from the calibration values are given.

In Method B standardized pressure-difference devices are normally applied for flow measurement. Calibration is recommended where a reduction of overall measuring uncertainty

is desirable. Double or multiple measurement of primary flow is recommended for the reduction of measuring uncertainty and a method for checking the compatibility is described.

c) Pressure measurement

The requirements and recommendations for pressure measurements are essentially similar. Only the methods for the measurement of exhaust-pressure of condensing turbines differ to some extent.

d) Temperature measurement

The requirements are essentially similar in both methods. However detail requirements are more stringent in Method A:

- calibration before and after the test,
- double measurement of the main temperature with 0.5 K maximum difference,
- thermocouples with continuous leads,
- required overall accuracy.

e) Steam quality measurements

Methods A and B are identical.

5) *Evaluation of tests*

The preparatory work for the evaluation and calculation of the test results is covered in a very similar manner in Methods A and B. However, quantitative requirements are more stringent in Method A.

Method B contains some proposals for handling cases where some requirements have not been met to avoid rejection of the test.

In addition, Method B contains detailed methods for calculation of measuring uncertainty values of measured variables and test results.

Method B recommends other methods for conducting and evaluating of the tests after the specified period and without a previous inspection.

6) *Correction of test results and comparison with guarantees*

The correction of test results to guarantee conditions is covered in both Methods A and B.

Method A provides for the comparison of test results to guarantee without consideration of measuring uncertainty.

Method B gives a broader spectrum of correction procedures. Furthermore, the measuring uncertainty of the result is taken into account in the guarantee comparison.

7) *Proposals for application*

Since the acceptance test method to be applied has to be considered in the details of the plant design, it should be stated as early as possible, preferably in the turbine contract, which method will be used.

Method B can be applied to steam turbines of any type and any power. The desired measuring uncertainty should be decided upon sufficiently early, so that the necessary provisions can be included in the plant.

If the guarantee includes the complete power plant or large parts thereof, the relevant parts of either method can be applied for an acceptance test in accordance with the definition of the guarantee value.

1. Scope and object

1.1 Scope

The rules given in this standard are applicable primarily to thermal acceptance tests with high accuracy for condensing steam turbines driving generators for electric power services. Some of the provisions of these rules are relevant to turbines for applications other than driving electric power generators.

These rules provide for the testing of turbines operating with either superheated or saturated steam. They include measurements and procedures required to determine specific enthalpy within the moisture region and describe precautions necessary to permit testing while respecting radiological safety rules in nuclear plants.

These rules contain information also applicable to the testing of back-pressure turbines, extraction turbines and mixed-pressure turbines. Only the relevant portion of the rules need apply to any individual case.

Uniform rules for the preparation, carrying out and evaluation of the acceptance tests are defined in this standard. Details of the conditions under which the acceptance tests shall take place are included.

Should any complex or special case arise not covered by these rules, appropriate agreement shall be reached by manufacturer and purchaser before the contract is signed.

1.2 Object

The purpose of the thermal acceptance tests of steam turbines and turbine plants described in this standard is to verify any guarantees given by the manufacturer of the plant concerning:

- a) turbine plant thermal efficiency or heat rate;
- b) turbine thermodynamic efficiency or steam rate or power output at specified steam flow conditions;
- c) main steam flow capacity and/or maximum power output.

The guarantees with their provisions shall be formulated completely and without contradictions (see 2.4). The acceptance tests may also include such measurements as are necessary for corrections according to the conditions of the guarantee and checking of the results.

1.3 Matters to be considered in the contract

Some matters in these rules have to be considered at an early stage. Such matters are dealt with in the following sub-clauses:

Sub-clause

- 1.1 (paragraph 4)
- 1.2 (paragraph 2)
- 3.1 (paragraphs 3 and 4)
- 3.3.3 (paragraph 1)
- 6.6
- 6.8

2. Units, symbols, terms and definitions

2.1 General

The International System of Units (SI) is used in these rules; all conversion factors can therefore be avoided.

The coherent units for all relevant quantities are given in the Table in 2.2. Some conversion factors are given as well for specific heat rates based on units other than W/W.

2.2 Symbols, units

For the purpose of these rules the following symbols, definitions and units shall be used:

Grandeurs	Symboles	Unités	Exemples de multiples et sous-multiples	Autres unités ISO
Puissance	P	W	kW	
Débit masse	$\dot{m}$	kg/s		
Pression absolue	p_{abs}	Pa	kPa	bar ¹⁾
Pression manométrique	p_e	Pa	kPa	bar ¹⁾
Pression ambiante (barométrique)	p_{amb}	Pa	kPa	bar ¹⁾ mbar
Différence de pression	Δp	Pa	kPa	
Température thermodynamique	T, Θ	K		
Température Celsius	t, ϑ			°C
Ecart de température	Δt	K		
Distance verticale	H	m	mm	
Enthalpie massique	h	J/kg	kJ/kg	
Chute d'enthalpie massique	Δh	J/kg	kJ/kg	
Chaleur massique	c	J/kg · K	kJ/kg · K	
Titre (masse de vapeur saturée sèche par unité de masse de vapeur humide)	x	kg/kg	g/g	
Vitesse de rotation	n	s ⁻¹		min ⁻¹
Vitesse linéaire	v	m/s		
Masse volumique	ρ	kg/m ³		
Volume massique	v	m ³ /kg		
Diamètre	D	m	mm	
Accélération de la pesanteur	g	m/s ²		
Rendement thermique	η_h	W/W	kW/kW	
Rendement thermodynamique	η_d	W/W	kW/kW	
Consommation spécifique de chaleur	HR	W/W	kW/kW	
Consommation spécifique de vapeur	SR	kg/W · s ou kg/J	kg/kW · s kg/kJ	kJ/kW · s, kJ/kW · h kg/kW · h
Débit de chaleur	$\dot{Q}$	J/s	kJ/s	
Facteur de cavitation	K	1		
Concentration	C	Selon nature du traceur		
Facteur de correction selon 6.6a)	F	1		
Facteur de correction selon 6.6b)	F^*	1		
Exposant isentropique	κ	—		
Coefficient de décharge	C_d	—		
Coefficient de débit	α	—		

¹⁾ Admitted by CIPM and ISO for temporary use with fluids only.

Relation between Heat Rate and Thermal Efficiency:

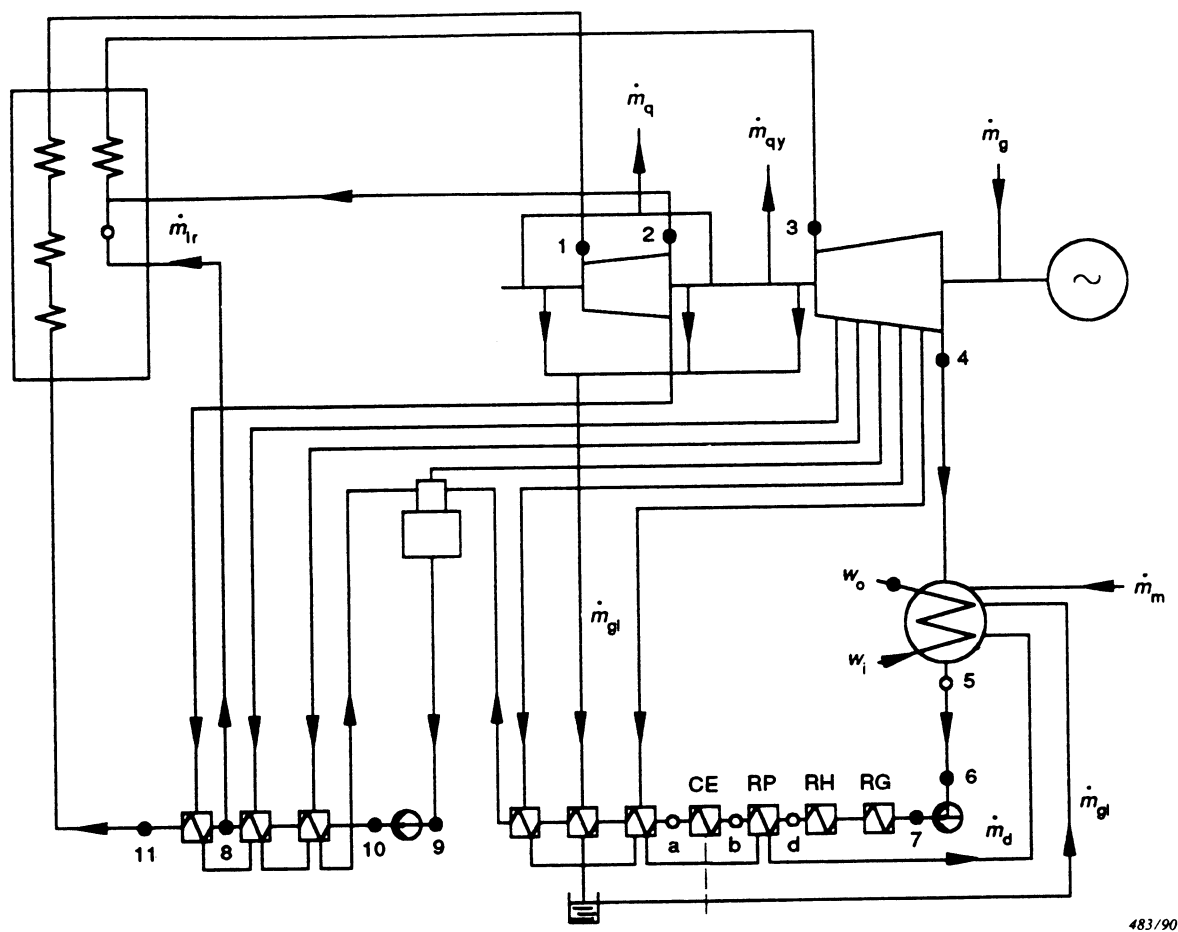
Units used for HR	Relationship
W/W, kW/kW, kJ/kW · s	$HR = \frac{1}{\eta_t}$
kJ/kW · h	$HR = \frac{3600}{\eta_t}$
kJ/MW · s	$HR = \frac{1000}{\eta_t}$
kcal/kW · h	$HR = \frac{859.845}{\eta_t}$
BTU/kW · h	$HR = \frac{3412.14}{\eta_t}$

2.3 Subscripts, superscripts and definitions

Quantity	Subscript	Position or definition
Power	b	At generator terminals
	a	Taken by auxiliaries not driven by the turbine (see 4.2.3); (see also IEC 34)
	g	Net power output: $P_g = P_b - P_a$
	c	At turbine coupling, less power required by turbine auxiliaries, if driven separately (see 4.2.3)
	i	Internal to the turbine
Initial steam flow rate and output	mech	Mechanical losses of pump and pump drive
	max	Values for fully opened control valves
Steam condition and flow rate	1	Directly upstream of high pressure (HP) turbine stop valve(s) and the steam strainer(s) (if any) that are included in the turbine contract
	2	At exhaust of the turbine HP from which steam passes to the reheater
	3	Directly upstream of intermediate pressure (IP) turbine stop valves
	4	At exhaust of the turbine(s) discharging to the condenser
Condensate and feed water conditions and flow rates	5	At condenser discharge
	6	At inlet to condensate pump
	7	At discharge from condensate pump
	8	See figure 1a
	9	At inlet of boiler feed pump
	10	At outlet of boiler feed pump
	11	At outlet of final feed heater
	b	After passage through the condensate pump and any coolers (oil, generator, gas/air) included in the contract
	d	At outlet from the drain cooler
	a	At outlet of air ejector condenser
	is	Refers to water taken from the feed-water system to the superheater for regulation of the initial steam temperature
	ir	Refers to water taken from the feed-water system to the reheater for control of the reheated steam temperature

Quantity	Subscript	Position or definition
Make up water conditions and flow rate	m	Measurements adjacent to the inlet flange of the condensate system or of the evaporator
Gland steam conditions and flow rates	g	Steam supplied to glands from a separate source
	gl	Leak-off steam from glands and valve stems returned to the system and included in the initial steam flow
	q	Flow of leak-off steam from glands and valve stems at inlet end or before a reheater which is led away for any extraneous purpose and neither it nor its heat is delivered to any part of the turbine cycle
	qy	Leak-off flows similar to q, but coming from a point or points downstream of a reheater
Main steam flow rate and concentration	M	Main steam flow at outlet of reactor
Mass flow rate and concentration	F	Refers to feed-water for reactor
	core	Refers to medium fluid passing through reactor core
	cond	Refers to condensed steam
Mass flow rate and concentration	inj	Refers to injected tracer solution
	E	At entry into core of PWR
	R	Recirculated water flow from water separator
Condenser cooling water	w	
	wi	Condenser inlet
	wo	Condenser outlet
	wio	Average value between condenser inlet and outlet
Efficiency	t	Thermal
	td	Thermodynamic
Enthalpy drop	s	Refers to isentropic enthalpy drop
Velocity	throat	At throat of flow-metering nozzle
Static pressure	sat	Saturation pressure of water at pertinent temperature
Concentration	wat	In water phase
	L	In pump loop of BWR
	B	In blow-down water of PWR
	inj	Of injected tracer
	O	At injection point before tracer injection
Test results and guaranteed values	g	Guaranteed
	c	Corrected
	m	Measured
Correction factor F or F*	tot	Product of all individual correction factors
	1, 2, 3	Numbering of individual correction factors
	η	For correction of efficiency
	P	For correction of output
General use	i, j	Numbering subscripts

Quantity	Superscript	Definition
Efficiency	/	Reference value of computer-calculated efficiency
General	—	Average value



GC: Generator gas cooler
OC: Oil cooler
DC: Drain cooler
EC: Air ejector condenser

The point number remains the same for the same item of any other turbine type: for example, Point 9 will be at the inlet of the feed pump, Point 8 may be anywhere between Points 6 and 11.

FIG. 1a. — Reheating regenerative condensing turbine with feed-water heating.

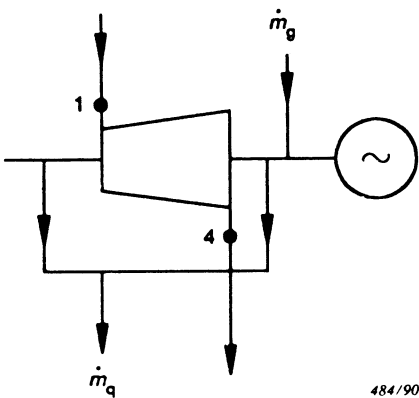


FIG. 1b. — Straight condensing or back-pressure turbines without feed-heating.

FIG. 1. — Diagram for interpretation of symbols and subscripts.

2.4 Definition of guarantee values and test results

For the quantitative description of the thermodynamic performance of a steam turbine or steam turbine plant, several quantities are technically appropriate and generally applied. Guaranteed values are expressed as such quantities and, consequently, test results are to be evaluated in the same manner.

The general definition of these quantities is always quite obvious. The details, however, may be different in each case and shall be fully considered (see also 1.2).

2.4.1 Thermal efficiency

For a power station turbine with regenerative feed heating, the thermal efficiency is the significant criterion. It is defined as the ratio of power output to heat added to the cycle from external sources.

$$\eta_t = \frac{P}{\sum (\dot{m}_j \Delta h_j)} \quad (1)$$

where:

$\dot{m}_j$ are the mass flows, to which heat is added

Δh_j the resulting enthalpy rises

For each specific case a guarantee heat cycle together with the guarantee terminal parameters has to be defined as a basis for guarantee definition and test evaluation. It should be as simple as possible and as near as practicable to the cycle configuration to be realized for the test (see also 3.4.4).

A practical definition for a turbine plant with single reheat and feed heating according to figure 1a is then:

$$\eta_t = \frac{P_b \text{ (or } P_g \text{ or } P_c)^*}{\dot{m}_1 (h_1 - h_{11}) + \dot{m}_3 (h_3 - h_2)} \quad (2)$$

Any additional heat and/or mass flow added to or subtracted from the cycle for example by make-up flow $\dot{m}_m$, spray attemperator flow $\dot{m}_{ir}$ or $\dot{m}_{is}$ or additional extraction for steam air preheater has to be accounted for in the evaluation by an appropriate correction of the test result (see Clause 6). Losses are not included in this definition, but treated according to 5.2.3.4.

To keep the sum of corrections small, it may be reasonable to include in the guarantee definition, by means of additional terms, important heat and mass flows, present in the cycle configuration for the test for technical reasons (e.g. spray attemperator, reactor blow down, etc.).

This, however, also modifies the thermodynamic character of the definition and the resulting values of the thermal efficiency are not directly comparable with those according to formula (2). Furthermore, the correction procedure will not be avoided altogether in this way, because it is improbable that the values of these additional flows during the test coincide exactly with those in the amended guarantee definition.

It is impracticable to describe in these rules all the possible variations in turbine cycles. In cases of complicated deviations of test cycle configuration from guarantee definition it is advisable to use the correction procedure according to 6.6.1.

* According to contract specification.

2.4.2 Heat rate

The heat rate traditionally has been used (and is still used) for the same objective as thermal efficiency, which is applied in these rules.

In a coherent unit system (SI):

$$HR = \frac{1}{\eta_t} \quad (3)$$

The unit of the so calculated heat rate is kW/kW = kJ/kW · s

Heat rate values expressed in other units can be converted easily to thermal efficiency values, taking into account the appropriate conversion factors (see 2.2).

2.4.3 Thermodynamic efficiency

For a turbine receiving all the steam at one initial steam condition and discharging all the steam at a lower pressure (condensing or back-pressure turbine without regenerating feed-heating or reheat) the thermodynamic efficiency is the most appropriate measure of performance. It is defined as the ratio of power output to isentropic power capacity (product of steam mass flow and isentropic enthalpy drop between initial steam condition and exhaust pressure).

$$\eta_{td} = \frac{P}{\dot{m} \Delta h_s} \quad (4)$$

The numerical value of thermodynamic efficiency does not depend on the initial steam and exhaust conditions, but is the indication for the efficiency of the expansion only.

The formula defining the thermodynamic efficiency for a straight condensing turbine without feed-heating according to Figure 1b is then:

$$\eta_{td} = \frac{P_b \text{ (or } P_g \text{ or } P_c) *}{\dot{m}_1 \cdot \Delta h_{s\ 1,4}} \quad (5)$$

where:

$\Delta h_{s\ 1,4}$ is the isentropic enthalpy drop between initial steam condition at point 1 and pressure at point 4.

2.4.4 Steam rate

The steam rate traditionally has been used (and is still used) as a performance criterion for turbines as described in 2.4.3. It is defined as the ratio of initial steam flow rate to power output and is connected with thermodynamic efficiency as follows in coherent units (SI):

$$SR = \frac{\dot{m}}{P} = \frac{1}{\eta_{td} \cdot \Delta h_s} \quad (6)$$

Steam rate values expressed in other units can be converted to thermodynamic efficiency values after determination of the relevant Δh_s value, taking into account the appropriate conversion factors (see 2.2).

* According to contract specification.

Since numerical steam rate values depend also on initial steam and exhaust conditions, they are not comparable for turbines with different specified conditions. Therefore, thermodynamic efficiency is used in these rules.

2.4.5 *Main steam flow capacity*

The maximum flow rate of main steam with all regulating valves wide open under specified steam conditions (usually the steam conditions according to the definition of the other guarantee values) is a measure of the maximum flow capacity of the turbine.

2.4.6 *Maximum power output*

The power output of the turbine at the maximum flow rate of main steam can be guaranteed for a specified guarantee heat-cycle, which may differ to some extent from the guarantee heat cycle valid for the thermal efficiency.

3. Guiding principles

3.1 *Advance planning for test*

The parties to any test under these rules shall reach agreement as to the testing procedure, the interpretation of guarantees, the number, location, and arrangement of measuring points and measuring devices, valves and piping arrangements at the time of design of the turbine plant and of the piping. This especially applies to steam turbines in nuclear power stations where subsequent modifications are often impracticable and the measuring points are not always accessible once the plant has started to operate. It is recommended that, for the most important measurements, special connection facilities such as flanges and thermometer wells be provided for the measuring equipment so that the acceptance tests can be carried out without impairing the instruments for normal operation.

The instrumentation has to be selected in such a way that power and heat flows which enter and leave the "system", as defined in the contract, and the conditions at its boundaries can be determined.

All necessary preparations and precautions have to be taken to meet the specifications of these rules regarding measuring accuracy.

The following is a list of typical items upon which agreement should be reached during the plant design:

- a) Location of, and piping arrangement around flow measuring devices on which test calculations are to be based.
- b) Number and location of valves required to ensure that no unaccounted for flow enters or leaves the test cycle, or bypasses any cycle component. In a nuclear plant there may be some make-up line or emergency valving that cannot be blocked and for which accounting must be made.
- c) Number and location of temperature wells and pressure connections required to ensure correct measurements at critical points.
- d) Number and location of duplicate instrument connections required to ensure correct measurements at critical points.
- e) Handling of leak-off flows to avoid complications in testing or the introduction of errors.
- f) Means of measuring pump shaft leakages.
- g) Method of determining steam quality including sampling technique as required. The recommended methods are given in 4.7.

Specification, installation, precision class and calibration of the normal station instrument transformers shall be chosen suitably if it is intended to use them for the acceptance test (see also 4.2.7).

3.2 Preparatory agreements and arrangements for tests

- a) Before the test, the parties to the tests shall reach an agreement as to the test programme, the specific objectives of the tests, the measuring methods and the method of operation with due regard to a limitation of the necessary corrections, the method for correcting the test results and for guarantee comparison with due regard to the contract conditions.
- b) Agreement shall be reached as to the variables to be measured, the measuring instruments and who is to supply them, the location of the indicating instruments and the operating and recording personnel required.
- c) Agreement shall be reached on the methods of obtaining the comparison measurement (see 3.5).
- d) Agreement shall be reached on such matters as the means of securing constancy of steam conditions and output.

- e) Instruments liable to failure or breakage in service should be duplicated by reserve instruments, properly calibrated, which can be put into service without delay. A record of such change of instrument during a test shall be clearly made on the observer's record sheet.

Instruments shall be located and arranged so that they may be read accurately with comfort by the observer. The calibration environment should be as close as practicable to the environment in which the instrument will operate during the test. This may be accomplished by locating the instruments in a controlled environment.

- f) The determination of the enthalpy of steam superheated less than 15 K, or of the quality of steam containing moisture, may be made only when the parties agree upon the method to be employed for this determination. The agreement, the method for making the determination and the method of applying the enthalpy or quality values to the test results shall be fully described in the test report.

The rate of flow of steam of any quality may be determined, where practicable, by condensing it completely and then measuring the condensate flow.

- g) Agreement shall be reached as to the method of calibration of instruments, by whom and when.
- h) For any of the measurements necessary for a test under these rules, any methods may be employed other than those prescribed in these rules, provided they are mutually agreed upon in writing before the test by the parties to the test. Any such departure from the prescribed methods shall be clearly described in the test report. In the absence of written agreements, the rules herein shall be mandatory.
- i) An independent expert may be a party to all agreements.
- j) Agreement shall be reached on the minimum number of operating and recording personnel that is required.

3.3 *Planning of the tests*

3.3.1 *Time for acceptance tests*

Unless otherwise provided in the contract, acceptance tests on site should be planned to take place if practicable within eight weeks* after the first synchronization, or immediately following an inspection outage, provided any deficiencies affecting performance have been corrected. In any event, except with written agreement to the contrary, the acceptance test shall take place within the guarantee period specified in the contract.

3.3.2 *Direction of acceptance tests*

The responsibility for the direction of the acceptance tests shall be clearly assigned by the parties prior to the test, preferably to one person. This person is responsible for the correct execution and evaluation of the acceptance tests, and serves as arbitrator in the event of disputes as to the accuracy of observations, conditions, or methods of operation. He is entitled and obliged to obtain information on all necessary details.

Accredited representatives of the purchaser and the manufacturer may at all times be present to verify that the tests are conducted in accordance with these rules and the agreements made prior to the tests.

A party to the contract who is not responsible for the direction of the acceptance tests shall also be given the opportunity of obtaining information a sufficient time before the tests.

3.3.3 *Cost of acceptance tests*

The contract shall stipulate who is to bear the costs of acceptance tests and any repeated acceptance tests (see also 3.5, 3.7 and 3.9).

3.4 *Preparation of the tests*

3.4.1 *Condition of the plant*

Prior to commencement of the acceptance tests, it is essential to be satisfied that the steam turbine and driven machine are in suitable condition, together with the condenser and/or feedheaters if included in the guarantee. It is also essential to verify that leaks in the condenser, feedheaters, pipes and valves have been eliminated.

Prior to the acceptance tests, the supplier shall be given the opportunity to check the condition of the plant, if necessary by making his own measurements. Any deficiency determined at this time shall be rectified.

Although these rules deal specifically with the performance testing of steam turbine generators, it is required that all other equipment supplied as part of the same turbine generator contract shall be in full and correct working order and in normal commercial disposition during the turbine generator tests. This requirement does not apply if other equipment has been ordered as an extra to the contract after the performance guarantees have been contractually agreed, or if special measures to render the equipment non-operative

* It is the intention, during this period, to minimize performance deterioration and risk of damage to the turbine. Enthalpy drop tests or preliminary tests should be made during this period to monitor HP and IP turbine section performance. However, these tests do not provide LP section performance and for this reason it is imperative to conduct the acceptance test as soon as practicable.

In any event, if either the enthalpy drop test shows undue deterioration to the HP or LP section, or if plant conditions delay the tests for more than four months after initial operation, the acceptance test should be postponed.

Adjusting of heat rate test results to startup enthalpy drop efficiencies or for the effects of ageing is not permitted.

during the tests have been agreed beforehand between the parties to the test and are described in prominent detail in the test report. An example of equipment in this category would be piping and valves, supplied as part of the same turbine generator contract, designed to permit steam to by-pass part or all of the turbine expansion stages for temperature-matching purposes during start-up.

3.4.2 *Condition of the steam turbine*

The condition of the steam turbine can be determined by an internal inspection of the steam path generally by opening the steam turbine or by comparison measurements according to 3.5.

Opening the turbine or an individual casing in order to locate a defect may be taken into consideration if large and inexplicable deviations are apparent from the comparison measurements.

3.4.3 *Condition of the condenser*

When the guarantees include the condenser performance and are based upon cooling water flow and temperature, the condenser shall be clean and the system shall be tested for sufficient air tightness. Agreement of the two parties to these matters shall be reached.

The condition of the condenser shall be checked by opening the water boxes or measuring the terminal temperature difference. In the case of deposits* the condenser shall be cleaned by the purchaser prior to the acceptance tests at the request of the supplier, or the parties concerned by the test may agree on a suitable correction.

3.4.4 *Isolation of the cycle*

The accuracy of the test results depends on the isolation of the system. Extraneous flows should be isolated from the system and internal flows which bypass in an unaccounted-for way either cycle components or mass-flow measuring equipment should be eliminated, if practicable, to obviate the need for measurement. If there is any doubt about the ability to isolate these flows during the test, preparations shall be made prior to the test to measure them.

All unused connections shall be blanked-off. If this is not practicable the connections shall be broken at a suitable point so that the outlets are under constant observation.

The equipment and flows to be isolated and the methods to accomplish this should be agreed well ahead of the initial operation date of the turbine. The isolation of the cycle has to be described in the test report.

When the system is properly isolated for a performance test, the unaccounted-for leakage resulting in unaccounted-for losses in storage volumes should be less than approximately 0.1% of the initial steam flow at full load. Excessive unaccounted-for leakages shall be eliminated before continuing the test. Water storage in the condenser hot well, deaerating and other extraction feedwater heaters, boiler drum(s), moisture separators, reheaters, and any other storage points within the cycle are to be taken into account (see also 5.2.3.4).

3.4.4.1 *Isolation of equipment and flow*

The following list includes items of the equipment and extraneous flows that shall be isolated from the primary turbine feedwater cycle:

a) Large-capacity storage tanks.

* Deposits: salts or metal on the steam side and slime, ashes, bacteria, algae, etc., on the cooling water side.

- b) Evaporators and allied equipment such as evaporator condenser and evaporator pre-heaters.
- c) Bypass systems and auxiliary steam lines for starting, compatible with safe operation.
- d) Bypass lines for condensate primary-flow-measuring devices.
- e) Turbine sprays.
- f) Drain lines on stop, intercept and control valves.
- g) Interconnecting lines to other units.
- h) Demineralizing equipment.

Isolation of demineralizing equipment does not necessarily mean removing the equipment from the cycle. It does, however, mean that all ties with other units shall be isolated and such equipment as recirculating lines that affect the primary flow measurement shall be isolated or the flows measured.

- i) Chemical-feed equipment using condensate.
- j) Boiler vents.
- k) Steam-operated soot blowers.
- l) Condensate and feedwater flow bypassing heaters.
- m) Heater drain bypasses.
- n) Heater shell drains.
- o) Heater water-box vents.
- p) Hogging jets.
- q) Condenser water-box priming jets.
- r) Steam or water for station heating.
- s) Blow down from steam generator.

3.4.4.2 *Flows which shall be determined if not isolated*

The following extraneous flows which enter or leave the cycle in such a manner as to cause an error in the flows through the turbine shall be isolated from the system or measured:

- a) Boiler fire door cooling flow and boiler-slag-tap-cooling coil flow.
- b) Sealing and gland cooling flow on the following (both supply and return):
 - 1) condensate pumps;
 - 2) boiler feed pumps;
 - 3) boiler-water or reactor circulating pump;
 - 4) heater drain pumps when not self-sealed;
 - 5) turbines for turbine-drive pumps;
 - 6) control rod seals on nuclear reactors.
- c) Desuperheating water.
- d) Boiler feed pump minimum-flow lines and balance drum flow.
- e) Steam for fuel oil atomization and heating.
- f) Boiler blowdowns.

- g) Boiler fill lines.
- h) Turbine water-seal flow.
- i) Desuperheating water for turbine cooling steam.
- j) Emergency blowdown valve of turbine gland leakage and sealing system.
- k) Turbine water-seal overflows.
- l) Steam and water lines installed for washing the turbine.
- m) Steam, other than gland leak-off steam, to the steam-seal regulating valve.

- n) Make-up water, if necessary.
- o) Pegging steam (such as higher stage extraction at light loads) for low-pressure operation of deaerator.
- p) Heater vents shall be closed if practicable. If not, they shall be throttled to a minimum.

- q) Deaerator overflow line.
- r) Water leakage into any water-sealed flanges, such as water-sealed vacuum breakers.
- s) Pump seal leakage leaving the cycle.
- t) Automatic extraction steam for industrial uses.
- u) Steam to air preheaters (if isolation is not practicable).
- v) Water and steam sampling equipment. If it is impracticable to isolate water and steam sampling equipment, and if the sampling flow is significant, it shall be measured.

- w) Deaerator vents.
- x) Reactor-core spray.
- y) Sub-cooled water used for moisture separator or reheater coil drain cooling.

- z) Continuous drains from wet steam turbine casings and connection lines (if not included in the guarantee).

3.4.4.3 *Suggested methods and/or devices for isolating equipment from turbine feedwater cycle*

The following methods are suggested for isolating miscellaneous equipment and extraneous flows from the primary turbine feedwater cycle and for checking such isolation:

- a) Double valves and tell-tales.
- b) Blank flanges.
- c) Blank between two flanges.
- d) Removal of spool piece for visual inspection.
- e) Visual inspection for steam blowing to atmosphere such as safety valves.

- f) Closed valve which is known to be leak-proof (test witnessed by both parties) and not operated prior to or during the test.
- g) Temperature indication (only acceptable under certain conditions — mutual agreement necessary).
- h) Accurate measurements of levels in any tanks which should be isolated from the system.

- i) Very important isolating valves (for example, HP and LP bypass valves) should be inspected and, if necessary, sealed prior to the test.

3.4.5 *Checks for leakage of condenser and feedwater heaters*

Condensers and feedwater heaters shall be checked for leakage and steps shall be taken to eliminate any significant leakage (see Appendix A).

In case of doubt the check can be repeated after the test.

3.4.6 *Cleanliness of the steam strainers*

If necessary, the steam strainers shall be cleaned before the acceptance tests.

3.4.7 *Checking of the test measuring equipment*

All measuring equipment shall be examined before the test as to its condition and suitability. It shall be further established whether the measuring instrument, the point of installation, and the installation are in accordance with relevant requirements. The results of all those checks shall be recorded in the test report.

3.5 *Comparison measurements*

For various reasons extraneous to the turbine generator it may not be practicable to conduct full-scale performance tests within the time limit specified in 3.3.1. In such circumstances, the following data, in well defined conditions of pressure, temperature, initial steam quality for wet steam units etc., should be recorded from the earliest practicable date:

- a) turbine stage pressures;
- b) turbine stage temperatures;
- c) power output;
- d) opening of governing valves;
- e) enthalpy drop efficiency if steam is superheated;
- f) Willans line, i.e. graph of steam flow/power output;
- g) flow of leak-off steam from glands, etc.

The same readings taken in the same conditions just before the test and compared with the original readings will enable any significant changes in the conditions of the turbine to be determined.

The parties interested in the tests shall agree on the action to be taken in consequence of deterioration. In some circumstances, it may be appropriate that the test should be conducted immediately after the first major inspection provided that any deficiencies in the turbine generator unit affecting performance have been corrected during the inspection period.

3.6 *Settings for tests*

3.6.1 *Load settings*

The guarantee may be given and the tests carried out either on the basis of specific valve opening or a specific power output*. In planning the programme, it should be remembered that:

- a) Tests at "valve point" positions tend to result in the best performance.

* For nuclear power stations, the tests are carried out based on the guaranteed thermal output of the reactor.

- b) "Valve point" loads and flows will probably not occur at the exact values expected by the manufacturer.
- c) Test points should be chosen such that the manufacturer may have the opportunity to demonstrate and the purchaser may have the opportunity to know what the performance is in relation to that guaranteed.

When the tests are carried out at specific valve opening it shall be permissible, in order to obtain the most economical load, to adjust the load to within $\pm 5\%$ of the load specified for the guarantee.

As it might be difficult to set the load for a partial valve opening test exactly at the appropriate value, it shall be permissible to run two or more tests to straddle the load and obtain by interpolation the actual test result at the load adjusted in accordance with this clause.

In the event of variable pressure operation of a full arc admission turbine, tests shall be conducted with control valves wide open. The same applies to throttle control if the guarantee is based upon wide open control valves.

Manually operated nozzle or bypass valves, if provided, shall be in the position contemplated by the guarantee. If the contract or specification is not clear in this respect, the parties shall come to an agreement.

3.6.2 *Special settings*

No special adjustments shall be made to the turbine, for test purposes that are inappropriate for commercial and continuous operation under any and all of the specified outputs and operating conditions. Exceptions are air bleed adjustments to control the vacuum, the use of load-limiting devices or other similar test control means, such as isolation of the cycle to prevent extraneous flows and/or internal by-pass flows of steam or water by closing certain drains or other valves. These shall be consistent with the terms of the guarantee and practicable with regard to operating safety and technique.

The turbine shaft seals shall be adjusted to normal operating conditions before a test and arrangements made to measure outward or inward flow that will influence test results.

3.7 *Preliminary tests*

Preliminary tests may be run for the purpose of:

- a) determining whether the turbine is in a suitable condition for the conduct of an acceptance test,
- b) checking all instruments,
- c) training personnel in test procedures.

After a preliminary test has been made, it may be considered, if mutually agreed, as an acceptance test.

If the preliminary tests are unsatisfactory, the causes shall be investigated and, if necessary, the turbine shall be placed at the disposal of the manufacturer so that the latter may examine it and ascertain whether it is in a suitable condition for an acceptance test.

3.8 *Acceptance tests*

3.8.1 *Constancy of test conditions*

All tests shall be preceded by a period temperature and flow stabilization, the duration of which shall be agreed upon by the parties interested in the test, since it will vary with the size of the turbine, the internal conditions, and the amount of load-change.

Any condition, the variation of which may influence the results of the test, shall be caused to become as nearly constant as practicable before the test begins, and shall be so maintained throughout the test, within the permissible variations according to 3.8.2.

In order to maintain constancy of throttling, the travel of the governing valve, in the opening direction only, should be limited to the chosen position and the governor should be sufficiently overwound to ensure that it does not respond to normal changes in system frequency.

3.8.2 *Maximum deviation and fluctuation in test conditions*

Except upon agreement to the contrary by the parties, the maximum permissible deviation of the average test conditions for each variable from that specified and the maximum permissible fluctuation of the variable during any one test run, shall not exceed the limit prescribed in Table I.

In general, it is more desirable to conduct the test as soon after first synchronization as practicable (see 3.3.1), even if the conditions in Table I cannot be met. In this instance, the correction curves shall be applicable for the test conditions.

3.8.3 *Duration of test runs and frequency of readings*

The requisite test duration is dependent on the steadiness of operating conditions and the speed of acquisition of test data. Accurately measurable changes in the level of water stored in the system may be a limiting factor.

The recommended duration of an acceptance test run is 2h. This may be reduced by agreement, but should be not less than 1 h.

During this period, readings of differential pressure flow-meters measuring primary flow should normally be taken every half minute. Readings of electrical power output, if based on indicating wattmeters in the absence of integrating meters (see 4.2.6) should be taken at intervals of not more than one min. Readings of primary pressures and temperatures should be taken at intervals of not more than 5 min. Fluctuating conditions necessitate shorter intervals between readings, especially of flowmeters, or a longer test duration in order to achieve a representative average (see 4.3.5). The duration of the capacity test should be chosen accordingly.

The time of the reading should be indicated to the observers through signals from a main clock. It may alternatively be taken from the observers' watches, which shall be synchronized with each other prior to each test run.

TABLE I
Maximum deviation and fluctuation in operating conditions

Variable	Max. permissible deviation of the average of the test from that specified	Max. permissible rapid fluctuation from the average during any one test run (see Note 1)
Initial steam pressure	$\pm 3\%$ of absolute pressure (see Note 2)	$\pm 0.5\%$ of absolute pressure
Initial and reheat steam temperature	Superheat ≤ 25 K ± 8 K Superheat > 25 K ± 15 K	± 2 K ± 1 K
Primary flow	Not specified	See 4.3.5
Dryness fraction at inlet for turbines supplied with wet steam	± 0.005	± 0.001
Exhaust pressure (condensing turbine)	$\pm 2.5\%$ of absolute pressure (see Note 5)	$\pm 5\%$
Feed water temperature	± 8 K (see note 3)	—
Extraction pressure	See note 4	—
Power	$\pm 5\%$	$\pm 0.25\%$
Voltage	$\pm 5\%$	—
Power factor	May vary between unity and specified value minus 0.05	—
When the condenser is included in the guarantee		
Cooling water inlet temperature	± 5 K	± 1 K
Cooling water flow	$\pm 10\%$	—
Air inlet temperature (for air-cooled condensers)	± 10 K	± 2 K

- Notes
1. — A rapid fluctuation is one whose frequency is greater than twice the frequency of the reading.
 2. — In any event the manufacturer's allowable variations in pressure and temperature should not be exceeded.
 3. — Possible limitations may be specified by the boiler manufacturer or the contract.
 4. — Deviations of a few percent in the extraction pressures as compared with the design values normally have a negligible effect on the overall performance. Should there be disproportionately large deviations in the extraction steam flow suggesting malfunctioning of the heaters, the effect on the overall performance may be serious, and agreement should then be reached on the course to be followed.
 5. — If the test exhaust pressure deviates from that specified by more than 2.5% or 3 kPa, whichever is larger, the exhaust pressure correction should be verified by test on demand by one of the parties.

3.8.4 Reading of integrating measuring instruments

The mean values of the electrical output and the mass flow can also be determined by integrating measuring instruments by dividing the difference in the readings at the beginning and at the end of a test run by the corresponding time interval.

All integrating measurement instruments should be read simultaneously. Related indicating measurement instruments should be read at or nearly at the same time.

It is advisable to take simultaneous readings of all integrating instruments at regular intervals during the test run. This will enable checks for consistency to be made and permits the period for evaluation to be adjusted, if required, after the conclusion of the test run.