

INTERNATIONAL STANDARD

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**Rules for steam turbine thermal acceptance tests –
Part 0: Wide range of accuracy for various types and sizes of turbines**

**Règles pour les essais thermiques de réception des turbines à vapeur –
Partie 0: Plage de précision étendue pour différents types et dimensions de
turbines**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RULES FOR STEAM TURBINE THERMAL ACCEPTANCE TESTS –**Part 0: Wide range of accuracy for various types and sizes of turbines****FOREWORD**

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This first edition cancels and replaces IEC 60953-2, published in 1990. This edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- a) IEC 60953-2:1990 has been used as the basis to develop IEC 60953-0;
- b) Outdated measuring techniques have been updated and the corresponding reduction of the expected test result measuring uncertainty indicated;
- c) Guarantee of power output at specified steam flow has been included;
- d) A proposal for assignment of unaccounted for leakages has been included;
- e) Correction methods and guarantee comparisons are updated;
- f) Various appendices deleted:
 - Appendix B (flow nozzle)
 - Appendix E (generalized correction curves)
 - Appendix G (power measurement uncertainty)

g) Annex added:

- Annex E (Temperature variation method) taken over from IEC 60953-3:2002, Annex L

The text of this International Standard is based on the following documents:

Draft	Report on voting
5/248/FDIS	5/250/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

A list of all parts in the IEC 60953 series, published under the general title *Rules for steam turbine thermal acceptance tests*, can be found on the IEC website.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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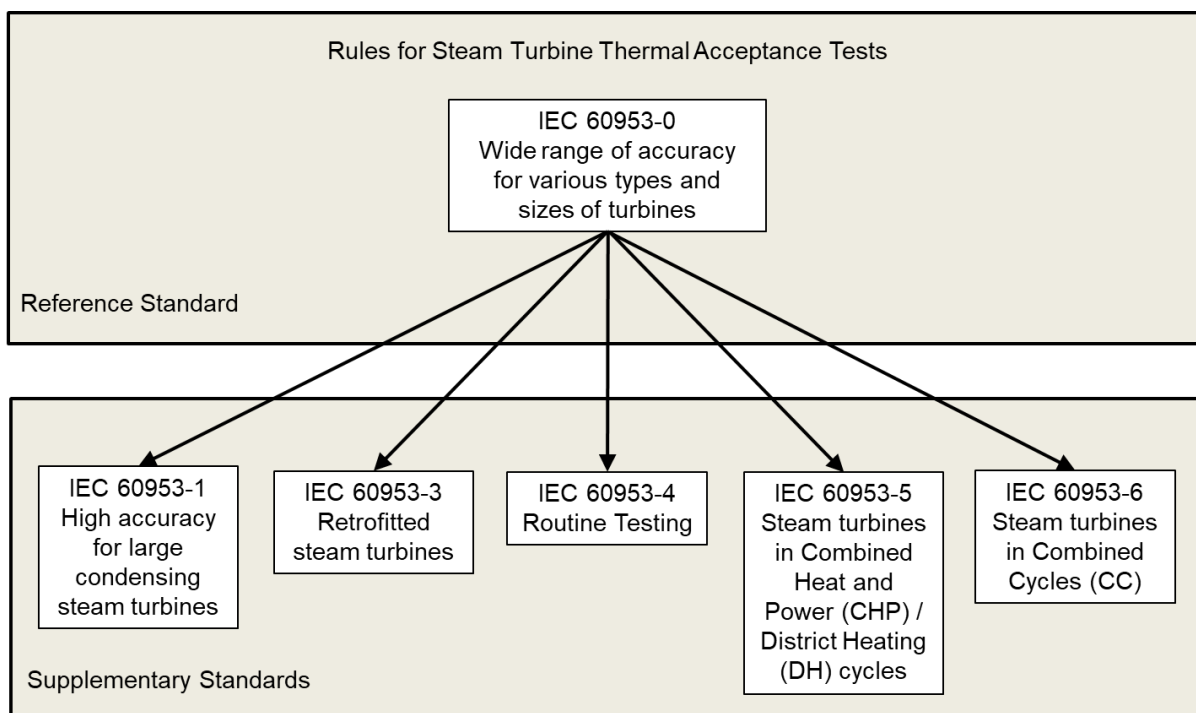
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INTRODUCTION

The continuing development of measuring techniques, the increasing capacity of steam turbines and increasing variety of steam turbine configurations has necessitated a revision of IEC 60953:1990.

Since all the needs of the power industry could not be satisfied by one single performance test standard covering the requirements for all of the steam turbine configurations and accuracy, the revision to this standard is based upon one reference standard and various supplementary parts as indicated below:



1) Basic philosophy and figures on uncertainty

IEC 60953-0 provides for acceptance tests of steam turbines of various types and capacities with corresponding measuring uncertainty, it is based upon the Method B of IEC 60953-2:1990. Additional and alternative guidance will be given for specific steam turbine applications in the supplementary standards where it is required.

Instrumentation and measuring procedures are chosen accordingly from a scope specified in the standard series which is centred mainly on standardized instrumentation and procedures, but may extend up to high accuracy provisions requiring calibration of flow measuring devices. The resulting measuring uncertainty of the test result is then determined by calculating methods presented in the standard series 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.

When good-standardized instrumentation and procedures are applied in a test, the measuring uncertainty given in Table 6 can be achieved. The parties to the test should reach agreement on the measuring uncertainty desired for the acceptance tests.

2) 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 are defined.

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

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.

Adjustment of the heat rate and power output test results for the effects of aging preferably by use of start-up enthalpy drop efficiency tests or by application of a standard allowance according to 7.9 is to be applied unless otherwise agreed in the contract.

3) Instruments and methods of measurement

a) Measurement instruments (for electrical power, pressure, temperature)

The measuring instruments used should be individually calibrated shortly before the test.

b) Flow measurement devices

For the measurement of main flows, uncalibrated or calibrated standardized flow measuring devices may be used.

Typically uncalibrated standardized flow measuring devices are used, however 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.

4) Evaluation of tests

The preparatory work for the evaluation and calculation of the test results is covered.

Detailed methods for calculation of measuring uncertainty values of measured variables and tests results are given.

5) Correction of test results and comparison with guarantees

The correction of test results to guarantee conditions is covered. The measuring uncertainty of the result is taken into account in the guarantee comparison.

6) 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.

This standard series 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 this standard series can be applied for an acceptance test in accordance with the definition of the guarantee value.

RULES FOR STEAM TURBINE THERMAL ACCEPTANCE TESTS –

Part 0: Wide range of accuracy for various types and sizes of turbines

1 Scope

1.1 General

The rules given in this document are applicable to thermal acceptance tests covering a wide range of accuracy on steam turbines of every type, rating and application. Only the relevant portion of these rules will apply to any individual case.

The rules provide for the testing of turbines, whether 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.

Uniform rules for the preparation, carrying out, evaluation, comparison with guarantee and calculation of measuring uncertainty of acceptance tests are defined in this standard. Details of the conditions under which the acceptance test can take place are included.

Should any complex or special case arise which is not covered by these rules, appropriate agreement is to 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 cycles described in this document is to verify guarantees given by the manufacturer of the equipment concerning:

Efficiency guarantees

- a) Thermal efficiency;
- b) Heat rate;
- c) Thermodynamic efficiency;
- d) Steam rate;
- e) Power output.

Capacity guarantees

- a) Main steam flow capacity;
- b) Maximum power output at specified steam conditions according to IEC 60045-1 (other than steam flow);
- c) Nuclear: thermal load capacity of the steam turbine under defined conditions.

The guarantees with their provisions are formulated completely and without contradictions (see 3.4). 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 are to be considered at an early stage. Such matters are dealt with in the following subclauses:

Subclause

- 1.1 (paragraph 4)
- 1.2 (paragraph 2)
- 4.1 (paragraph 3 and 4)
- 4.3.2 (paragraph 1)
- 7.6
- 7.8
- 7.9 (paragraph 1)

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/IEC Guide 98, *Uncertainty of measurement*

IEC 60045-1, *Steam turbines – Part 1: Specifications*

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

ISO 12242, *Measurement of fluid flow in conduits – ultrasonic transit-time meters for liquids*

ISO 18888, *Gas turbine combined cycle power plants – Thermal performance tests*

ANSI/IEEE C57.13, *IEEE Standard requirements for instrument transformers*

3 Units, symbols, 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 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 3.2. Some conversion factors are given as well for specific heat rates based on units other than W/W.

3.2 Symbols, units

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

Quantity	Symbol	Unit	Examples of multiples and sub-multiples	Other ISO units
Power	P	W	kW	
Flow rate	$\dot{m}$	kg/s		
Pressure, absolute	p	Pa	kPa	bar ^a
Ambient pressure (barometric)	p_{amb}	Pa	kPa	bar ^a , mbar
Pressure difference	Δp	Pa	kPa	bar, mbar
Thermodynamic temperature	T, Θ	K		
Celsius temperature	t, θ			°C
Temperature difference	Δt	K		
Vertical distance	H	m	mm	
Specific enthalpy	h	J/kg	kJ/kg	
Specific enthalpy of saturated water	h'	J/kg	kJ/kg	
Specific enthalpy of saturated steam	h''	J/kg	kJ/kg	
Specific enthalpy drop	Δh	J/kg	kJ/kg	
Specific heat	c	J/kg/K	kJ/kg/K	
Quality, i.e., dryness fraction of saturated steam by weight	x	kg/kg	g/g	
Rotational speed	n	s ⁻¹		min ⁻¹
Velocity	v	m/s		
Density	ρ	kg/m ³		
Specific volume	v	m ³ /kg		
Diameter	D	m	mm	
Acceleration due to gravity	g	m/s ²		
Thermal efficiency	η_t	W/W	kW/kW	
Thermodynamic efficiency	η_{td}	W/W	kW/kW	
Heat rate	HR	W/W	kW/kW	kJ/kW·s, kJ/kW·h
Steam rate	SR	kg/W·s or kg/J	kg/kW·s, kg/kJ	kg/kW·h
Heat flow rate	$\dot{Q}$	J/s	kJ/s	
Cavitation factor	K	1		
Concentration	C	According to nature of tracer		
Correction factor according to 7.6a)	F	1		
Correction factor according to 7.6b)	F^*	1		
Isentropic exponent	κ			
Discharge coefficient	C_d			
Flow coefficient	α			
General quantity	x			
Weight factor for averaging	γ			
Confidence limit	V			
Relative measuring uncertainty of x	$\tau_x = \frac{V_x}{x}$			
Tolerance of steam table	R			

^a Admitted by CIPM and ISO for temporary use with fluids only.

Relation between Heat Rate and thermal efficiency:

Units used for HR	Relation
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	$HR = \frac{3412.14}{\eta_t}$

3.3 Subscripts, superscripts and definitions

Quantity	Subscript	Position or definition
Power	b	At generator terminals
	a	Taken by auxiliaries not driven by the turbine; (see also IEC 60034)
	g	Net power output: $P_g = P_b - P_a$
	c	At turbine coupling, less power required by turbine auxiliaries, if driven separately
	i	Internal to the turbine
	mech	Mechanical losses of pump and pump drive
Initial steam flow rate and output	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
	e	At extraction point of extraction turbine
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 Gland steam conditions and flow rates	m	Measurements adjacent to the inlet flange of the condensate system or of the evaporator
	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 measurement of 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 Mass flow rate and concentration	M	Main steam flow at outlet of reactor
	F	Refers to feed-water for reactor
	core	Refers to medium fluid passing through reactor core
	cond	Refers to condensed steam
	inj	Refers to injected tracer solution
	E	At entry into core of PWR
Condenser cooling water	R	Recirculated water flow from water separator
	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
	tot	Product of all individual correction factors
Correction Factor F or F*	1, 2, 3	Numbering of individual correction factors
	H	For correction of efficiency
General use	P	For correction of output
	i, j	Numbering subscripts

For confidence limit V and relative measuring uncertainty τ , subscripts which are identical to symbols for quantities always indicate the confidence limit applicable to the relative measuring uncertainty of this quantity.

See Figure 1 for interpretation of symbols and subscripts.

Quantity	Subscript	Definition
Efficiency	/	Reference value of calculated efficiency
General	–	Average value, mean value
	~	Weighted average value

3.4 Definition of guarantee values and test results

3.4.1 Guidance on guarantee parameters

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

The performance of a steam turbine is described by efficiency and capacity and therefore the guarantees given should cover both. However duplication of these categories should be avoided.

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).

3.4.2 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 are the resulting enthalpy rises

For each specific case a guarantee heat cycle, together with the guarantee terminal parameter, 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 4.4.4).

A practical definition for turbine cycles with single reheat and feed heating according to Figure 1a) is then:

$$\eta_t = \frac{P}{\dot{m}_1(h_1 - h_{11}) + \dot{m}_3(h_3 - h_2) + \dot{m}_{ir}(h_2 - h_8)} \quad (2)$$

P can be P_b , P_g or P_c according to contract specification.

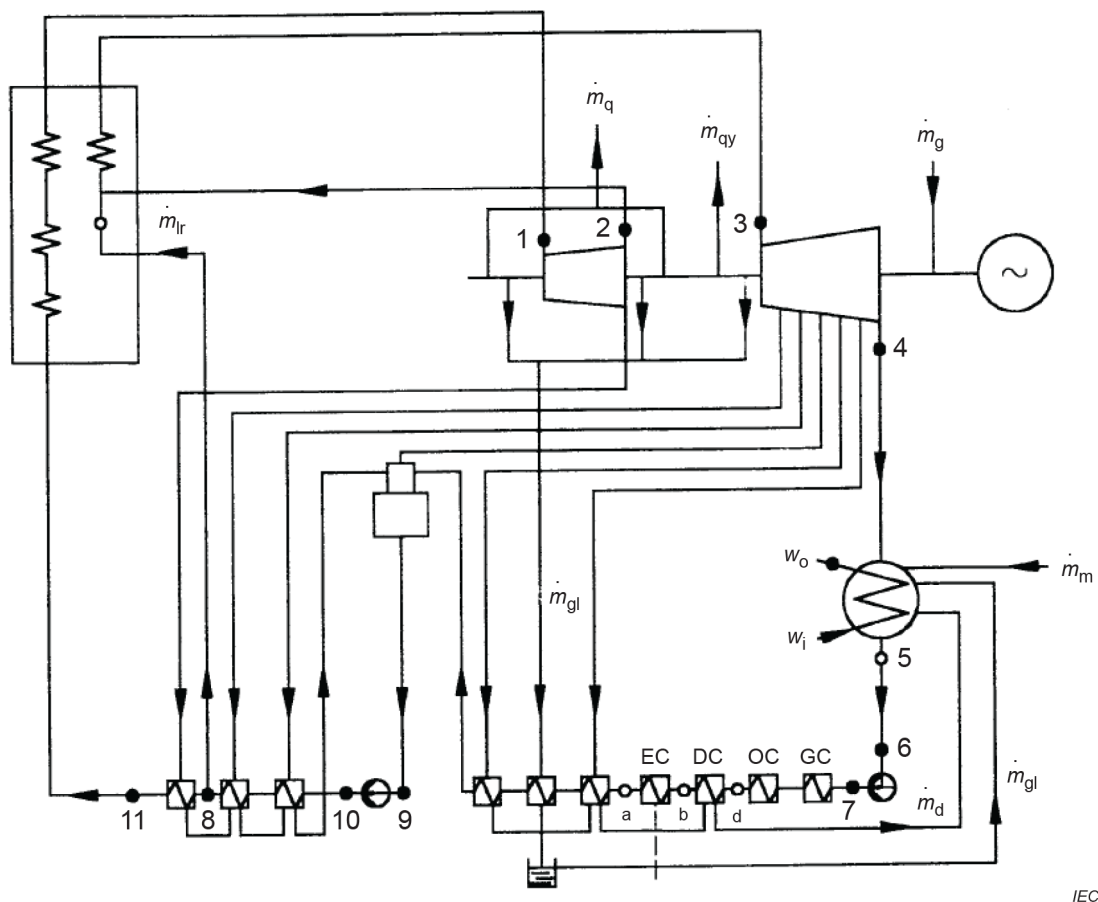


Figure 1a) – Reheating regenerative condensing turbine with feed-water heating

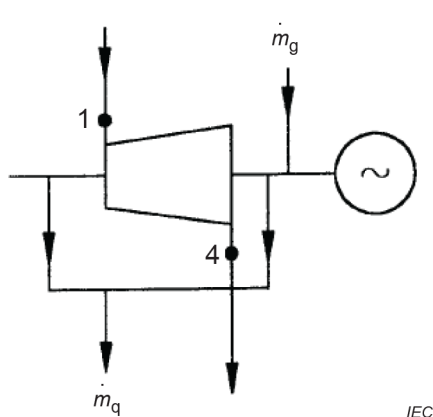


Figure 1b)– Straight condensing or back-pressure turbine without feed-heating

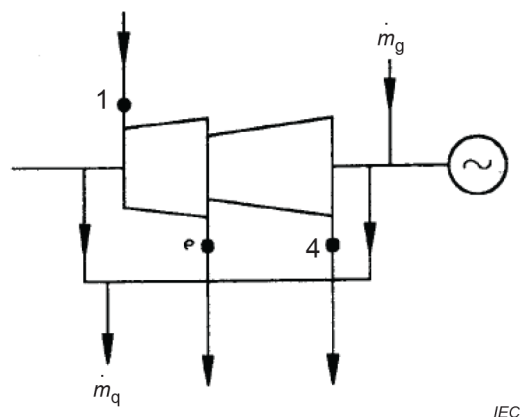


Figure 1c)– Extraction condensing or back-pressure turbine without feed-heating

Figure 1 – Diagrams for interpretation of symbols and subscripts

Any additional heat and/or mass flows added to or subtracted from the cycle e.g., 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 7). Losses are not included in this definition, but treated according to 6.2.3.4.

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 will 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 procedures according to 7.6.2.

3.4.3 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 3.2).

3.4.4 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 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:

$$\eta_{td} = \frac{P}{\dot{m}_1 \Delta h_{s1,4}} \quad (5)$$

P can be P_b , P_g or P_c according to contract specification.

where:

$\Delta h_{s1,4}$ is the isentropic enthalpy drop between initial steam condition at point 1 and pressure at point 4

3.4.5 Steam rate

The steam rate traditionally has been used (and is still used) as a performance criterion for turbines as described in 3.4.4. 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).

$$SR = \frac{\dot{m}_1}{P} = \frac{1}{\eta_{td} \Delta h_s} \quad (6)$$

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 3.2).

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.

3.4.6 Main steam flow capacity

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

Where there are further induction steam flows to the turbine, the maximum flow rate of initial and induction steam flows with all regulating valves wide open under specified steam conditions (usually the steam conditions according to the definition of the other guarantee values) defines the maximum flow capacity of the turbine.

3.4.7 Power output

The power output of the turbine can be guaranteed for the maximum flow capacity or at a specified steam flow or thermal load.

Power output at a specified steam flow or thermal load is similar to an efficiency or steam rate guarantee. If an efficiency, steam rate or heat rate guarantee is given, an additional guarantee of power output at a specified steam flow would lead to a double guarantee and should be avoided.

3.4.8 Guarantee values for extraction and mixed-pressure turbines¹

For mixed-pressure turbines and single or multiple-extraction turbines with or without regulated extraction pressure(s), in all cases without regenerative feed-heating, the guarantee values are most appropriately defined as thermodynamic efficiency in the following generalized way:

$$\eta_{td} = \frac{P}{\sum(\dot{m}_j \Delta h_{sj})} \quad (7)$$

P can be P_b , P_g or P_c according to contract specification.

where $\dot{m}_j$ and Δh_{sj} are the steam flow rate and isentropic enthalpy drop respectively for each consecutive section of the turbine.

For example, for a single extraction turbine (either back-pressure or condensing), according to Figure 1c), this results in:

$$\eta_{td} = \frac{P}{\dot{m}_1 \Delta h_{s1,e} + (\dot{m}_1 - \dot{m}_e) \Delta h_{se,4}} \quad (8)$$

In the case of an extraction or mixed-pressure turbine, however, it is necessary to specify in addition to the values of output, initial steam flow rate and thermodynamic efficiency, the pertinent flow rate value(s) of extraction steam flow(s) and secondary steam flow(s). This applies at each load subject to guarantee.

Guarantee values for mixed-pressure or extraction turbines with regenerative feed-heating can be defined, if more practicable, as thermal efficiency also. In this case, too, the pertinent flow rate value(s) of secondary steam and extraction steam flow(s) is (are) necessary for a complete guarantee definition.

3.4.9 Thermal Load Capacity (for Nuclear applications)

The maximum thermal load capacity of the steam turbine may be guaranteed under specified steam conditions to verify that the steam turbine can be operated with the maximum steam generator thermal load. Care has to be taken that the boundary conditions and the definition of the thermal load are consistent with the scope of supply.

4 Guiding principles

4.1 Advance planning for test

The parties to any test under these rules shall reach agreement, when the plant is being designed, as to the testing procedure, the interpretation of guarantees, the number, location and arrangement of measuring points and measuring devices, valves and piping arrangements. 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

¹ Mixed pressure turbines – several inlets at different pressures during the expansion.

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.

The parties interested in the test shall reach agreement at a date as early as practicable on the measuring accuracy desired for the acceptance tests. This accuracy, with due consideration of the cost of the acceptance test, shall be in reasonable relationship with the significance of the plant.

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 as far as practicable that no unaccounted-for flow enters or leaves the test cycle or bypasses any cycle component.
- 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, if necessary.
- g) Method of determining steam quality, including sampling technique as required. The recommended methods are given in 5.7.
- h) Method in order to determine steam turbine internal leakage flows shall be defined and agreed by both parties (values of the heat balance diagram or conducting a temperature variation test, see Annex E).

4.2 Preparatory agreements and arrangements for tests

- a) Before the test the parties to the tests shall reach an agreement as to the test program, the specific objectives of the tests, the measuring methods and the method of operation with due regard to 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 measurements (see 4.5).
- 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 instrument should be located during the test at a position with an environment as close as practicable to the environment for calibration. This may be accomplished by locating the instruments in a controlled environment for the test.

- 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 to the test 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 rate.

- g) Agreement shall be reached as to the method of calibration of instruments, and 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) Agreement shall be reached if an independent expert may be employed to represent the interests of both parties equally.
- j) Agreement shall be reached on the minimum number of operating and recording personnel that is required.
- k) It is recommended to use the latest available definition of the properties of water and steam. However, the application shall be consistent between the calculation of the guarantees and the evaluation of the test results. Refer to 6.2.4.

4.3 Planning of the test

4.3.1 Time for acceptance tests

The acceptance tests shall be performed at the operating plant or, by mutual agreement, on the test bed of the manufacturer. Acceptance tests on site shall be carried out, if practicable, within eight weeks after the first synchronization (see 4.5), due consideration should be given to any significant delay between first steam admission and first synchronization. In any event, except with written agreement to the contrary, the acceptance test shall take place within the guarantee period specified in the contract.

It is the intent during this period prior to the acceptance test 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 tests as soon as practicable.

4.3.2 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.

4.4 Preparation of the tests

4.4.1 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 condensers, feedheaters, pipes and valves have been eliminated.

Prior to the acceptance tests, the opportunity shall be given to the manufacturer and or the supplier 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 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 bypass part or all of the turbine expansion stages for temperature-matching purposes during start-up.

4.4.2 Condition of the steam turbine

The condition of the steam turbine depends on the effects of ageing² (see 7.9), of partial damage³ and of deposits⁴.

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 4.5.

The absence of partial damage and/ or deposits shall be confirmed before the test (see also 4.4.1).

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.

4.4.3 Condition of the condenser

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

The condition of the condenser shall be checked for example by opening the water boxes or measuring the terminal temperature difference. In the case of deposits⁴, the condenser shall be cleaned prior to the acceptance tests or the parties concerned by the test may agree on a suitable correction.

The air tightness of the components under vacuum can be assessed by conducting a vacuum decay test. An allowable decay rate shall be agreed between the parties of the tests.

² Ageing means deterioration during correct operating and shutdown conditions in a manner such that the performance of the turbine is adversely influenced.

³ Partial damage: damage and variations in the clearance of the blading, of balance pistons and shaft glands, valve spindle wear: leakages in the valve glands and seats.

⁴ Deposits: salts or metal on the steam side, slime, ashes, bacteria, algae, etc., on the cooling medium side.

4.4.4 Isolation of the cycle

4.4.4.1 General

The accuracy of test results depends to a large extent on effective 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 expressed in percent of initial steam flow at full load shall not exceed 0,4 times the relative measuring uncertainty of the test result (expressed in percent) (see 6.2.3.4). The maximum permissible leakage value is 0,6 % of the full load steam flow. If the maximum value is exceeded, then the test can be accepted only by mutual agreement of the parties to the test. Water storage in the condenser hotwell, 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 6.2.3.3 and 6.2.3.4).

4.4.4.2 Isolation of equipment and flows

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

- a) Large-capacity storage tanks.
- b) Evaporators and allied equipment such as evaporator condenser and evaporator preheaters.
- c) Bypass systems and auxiliary steam lines for starting, if compatible with safe operation.
- d) Bypass lines for condensate primary flow-measuring devices.
- e) Turbine sprays.
- f) Drain lines should be isolated in accordance with normal design requirements.
- g) Interconnecting lines to other units.
- h) Demineralizing equipment.

Isolation of de-mineralizing 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.

4.4.4.3 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 measured or estimated, if they are not isolated from the system.

- 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).

4.4.4.4 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 that 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.

4.4.5 Checks for leakage of condenser and feed water heaters

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

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

4.4.6 Cleanliness of the steam strainers

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

4.4.7 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 these checks shall be recorded in the test report.

4.5 Comparison measurements

For comparison measurements, only those variables are taken into account which are essential to establish the condition of the steam turbine. For the comparison, it is advisable to measure the internal efficiency, the pressure and temperature at the extractions, power output, opening of governing valves, the gland leakage flows, and the LP turbine exhaust pressure of the condenser terminal difference (depending on the guarantee) as well as the vibration level of the steam turbine rotor at suitable points.

The measuring uncertainty of comparison measurements should not be larger than that of the acceptance tests.

The type and scope of the comparison measurements as well as the costs shall be agreed upon by the purchaser and the supplier (see 4.1).

The parties interested in the acceptance test shall participate in the comparison measurements.

The reference measurement shall be made immediately after the first synchronization, at partial load if necessary. Check measurements may be made:

- a) before the acceptance test or during the preliminary test;
- b) after blade washing;
- c) before and/or after an inspection.

The measurements taken during the acceptance test can normally be evaluated as a final check measurement.

Should the result of a check measurement point towards a deposit which can be removed by blade washing, the supplier may require of the purchaser that the steam turbine be washed. If the check measurement sufficiently agrees with the reference measurement after the washing, the acceptance test may be carried out. Should the check measurement not agree sufficiently with the reference measurement, the parties to the contract should then decide either to eliminate the defect or to carry out the acceptance test. If the tests proceed, the comparison measurements shall be included in the test report.

If the result of the reference measurement differs considerably from the expected values according to the guarantee, remedial measures may be agreed upon by the purchaser and the supplier.

4.6 Settings for tests

4.6.1 Load settings

The guarantee may be given and the tests carried out either on the basis of specific valve opening, a specific power output or initial steam mass flow or, for nuclear power stations and for gas turbine combined cycle power stations, a specified thermal heat input. In the planning of the test programme the load settings shall be consistent with the guarantee.

The acceptance tests for partial arc admission turbine with guarantees based on the locus of the valve points shall be conducted at valve points.

Tests at valve points tend to result in more repeatable test conditions. Test valve point loads and flows will probably not occur at the exact values expected by the manufacturer. Therefore it shall be permissible to adjust the operation conditions within the maximum deviations compared to the "Valve point" load point to ensure the specified valve opening is reached.

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.

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.

In addition, the position of the LP control valves of extraction turbines should be brought to a "valve point", if practicable, by adjusting the extraneous steam flow. Similarly, the "valve points" of the secondary initial steam control valves of double pressure turbines can be achieved by adjustment of the secondary steam flow, if practicable.

These adjustments may result in deviations of the output from the specified value greater than stated in 4.8. In these cases a re-calculation of the guarantee value according to 7.6.2 may be made by agreement of the parties.

If large fluctuations in output or steam flow due to operating conditions are occurring, it is permitted to use a device limiting further opening of valves in order to keep optimum valve positions. The relative positions of the valves shall not differ throughout the test period.

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.

4.6.2 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 condition before a test and arrangements made to measure outward or inward flow that will influence test results.

4.7 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.

4.8 Acceptance tests

4.8.1 Constancy of test conditions

All tests shall be preceded by a period of 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. A typical stabilization period can be 1 to 2 hours.

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 4.8.2.

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

4.8.2 Maximum deviation and fluctuation in test conditions

Except upon agreement to the contrary by the parties, in order to minimize the amount of correction of the results the maximum permissible deviation of the average test condition 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 1.

Should these requirements not be met, the measurement may serve as information only, unless special agreement relating to the influence of the deviating operating conditions is reached.

Table 1 – Maximum deviations and fluctuations⁵ in operating conditions

Variable	Maximum permissible deviation of average of test from that specified
Initial steam pressure	$\pm 5\%$ ^a
Initial steam temperature	$\pm 15\text{ K}$ ^a
Dryness fraction	$\pm 0,005$
Extraction pressure:	
– regulated process	$\pm 5\%$ ^a
– feed heating	See ^b
Exhaust pressure:	
– for back pressure turbines	$\pm 5\%$ ^a
– for condensing turbines	$\pm 25\%$ or $\pm 1,0\text{ kPa}$ whichever is larger, if condenser is not included in guarantee
Extraction flow rate (regulated, feed heating)	$\pm 10\%$
Reheat temperature	$\pm 15\text{ K}$
Isentropic enthalpy drop	$\pm 7\%$
Initial steam flow	$\pm 5\%$
Cooling water flow	$\pm 15\%$ if condenser is included in guarantee
Cooling water inlet temperature	$\pm 5\text{ K}$ if condenser is included in guarantee
Final feed water temperature	$\pm 10\text{ K}$
Speed	$\pm 2\%$ ^c
^a All these items may not lead to a deviation of enthalpy drop of more than $\pm 7\%$. ^b Reasonably small deviations 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 flows suggesting malfunctioning of the heaters, the effect on the overall performance may be serious, and agreement shall then be reached on the course to be followed. ^c This maybe greater for variable speed mechanical drive, if permitted by the technical guarantee of the turbine.	

4.8.3 Duration of test runs and frequency of reading

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

The recommended minimum test period (see 6.1) of an acceptance test is 1 h. This may be reduced by agreement or technical necessity, but should be not less than 30 min. The duration of the capacity tests should be agreed between the parties, but should be not less than 15 min.

Related test data recorded with indicating measuring equipment shall, if practicable, be read at the same time. Since the values measured are not constant, random errors cannot be avoided when taking readings at regular time intervals. The intervals shall be sufficiently short to ensure that these errors do not substantially affect the measuring uncertainty of the whole. This is of vital importance for readings of differential pressure for mass flow measurement and electrical output. For tests of one hour's duration readings at one-minute intervals will satisfactorily fulfil requirements for maximum deviations allowed in Table 1.

⁵ The maximum fluctuation of the variable permitted during each test shall not be greater than half the permissible deviation given in Table 1.
 Fluctuation is defined as the difference between the maximum reading or minimum reading and the average of the test.

If the adoption of longer intervals between readings is necessary a correspondingly longer duration of the test may be required.

The time of the reading should be indicated on the test record. Watches shall be synchronized with each other prior to each test.

4.8.4 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 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. 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.

All observations should begin somewhat before and stop somewhat after the intended test period provided all operating conditions remain constant.

4.8.5 Alternative methods

Alternative methods are presented in these rules for conducting certain details of the test. The test report shall state which alternative has been employed.

4.8.6 Recording of tests

Immediately after each test run each interested party shall receive a set of recorded test data.

4.8.7 Additional measurement

Should a deficiency be found during a test, which is rectified within a relatively short time, the test may be continued. In this event supplementary measurements shall be taken, if necessary, provided always that the correction involved can be calculated sufficiently accurately (e. g., small variations in the terminal temperature difference of the condenser, a heater cut-out or deficiencies of measuring instruments).

If a control valve, which is intended to be closed for the test, opens because of fluctuations in load, or if inadmissibly large fluctuations in test conditions arise during a limited period, this period of the test may subsequently be omitted by mutual agreement of the parties to the test, provided the remaining period fulfils the requirements of 4.8.3. Otherwise the test shall be repeated.

It is recommended that one or more stage pressures and temperatures be observed during the tests, since these may serve as a means of disclosing reasons for any inconsistencies.

4.8.8 Preliminary calculations

Preliminary calculations of corrections and test results shall be conducted immediately after the test in order to confirm the validity of the data taken.

4.8.9 Consistency and number of tests

Should serious inconsistencies arise, either during a test or during the computation of results from a series of tests, the test or tests shall be rejected, in whole or in part, unless otherwise agreed.

The number of test runs conducted at the same test point and used for guarantee comparison is two as a minimum. Neither test shall differ from the average by more than half of the test uncertainty. Any test differing from the average by more than half of the test uncertainty is not taken into account. The corrected test result is the average of the tests fulfilling this criterion.

4.9 Repetition of acceptance tests

Should the acceptance test result be unsatisfactory, the supplier shall be given an opportunity to make modifications and to repeat the test at his own expense. A repetition may also be requested by one of the parties to the contract if justified by doubts about the results.

If the supplier, for reasons which are his responsibility, has made modifications following the acceptance test which make it probable that guarantee values will no longer be met within a reasonable margin, the acceptance tests may be repeated at the request of the purchaser.

5 Measuring techniques and measuring instruments

5.1 Overview

5.1.1 Instrument accuracy requirements

The measuring equipment shall comply with the requirements stated in Table 2 and be of such accuracy that the individual maximum errors do not prevent the desired level of test uncertainty from being achieved.

5.1.2 Measuring instruments

Instruments conforming to any one or more of the following categories are permitted for acceptance tests:

- a) Measuring instruments calibrated by an official authority.
- b) Measuring instruments, which have been calibrated by comparison with measuring instruments officially calibrated by an official authority.
- c) Standardized measuring instruments with known accuracy.
- d) Other approved measuring instruments with known accuracy, the use of which has been agreed upon between the parties to the contract.

Table 2 indicates the available types of instrumentation for acceptance tests. Typical arrangements in a plant are illustrated in Figure 2 and Figure 3.

If transducers are used, they shall have a suitable range and a demonstrable accuracy equivalent to usual instrumentation.

Measuring instruments and transducers may be equipped with devices to enable them to record on a data logging system.

Data logging systems for automatic conversion, correction and recording of measured values may be used. They may also be used for subsequent processing of these values. Their dependability and correctness of operation has to be checked or proven in advance.

5.1.3 Measuring uncertainty

The measurement of each quantity entering into the computation of the test result is liable to some degree of error. The test result is subject to a degree of uncertainty depending on the combined effect of all these errors of measurement.

The measuring uncertainty of the instruments and procedures shall be clearly verified by sufficient general information or, if necessary, by special determination. This particularly applies to remote measuring systems and automatic data-collecting systems.

The uncertainty level for each individual measurement shall be chosen in reasonable relationship with the influence of the reading on the test result.

Data are given in Table 2 for the measuring uncertainty that can be expected for the individual measured variables according to general experience.

The measuring uncertainty of the test results can be calculated from the uncertainties of the individual measurements according to Clause 8.

5.1.4 Calibration of instruments

Instruments requiring calibration shall be calibrated before the test. Certificates shall be available to the parties before the test. The status of the instrument calibration (age of calibration, prior use of instruments, drift, deterioration, etc.) shall be considered in the uncertainty analysis. Any recalibration after the test shall be a matter for agreement between the parties.

5.1.5 Alternative instrumentation

By mutual agreement of the parties to the test, advanced instrument systems such as those using electronic devices or mass-flow techniques, may be used as alternatives to the mandatory instrument requirements, provided that the application of such systems has demonstrated accuracy equivalent to that required by these rules.

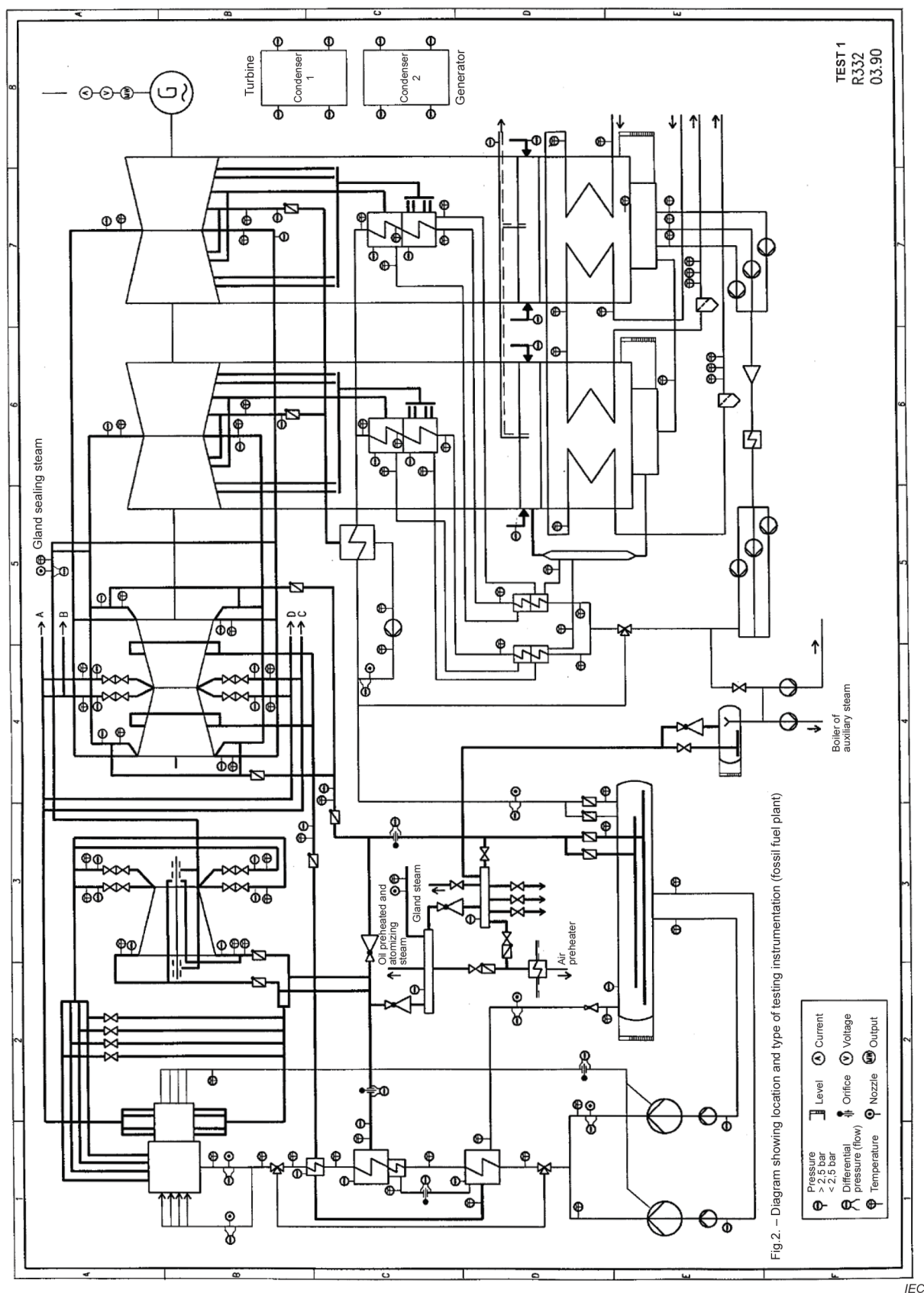
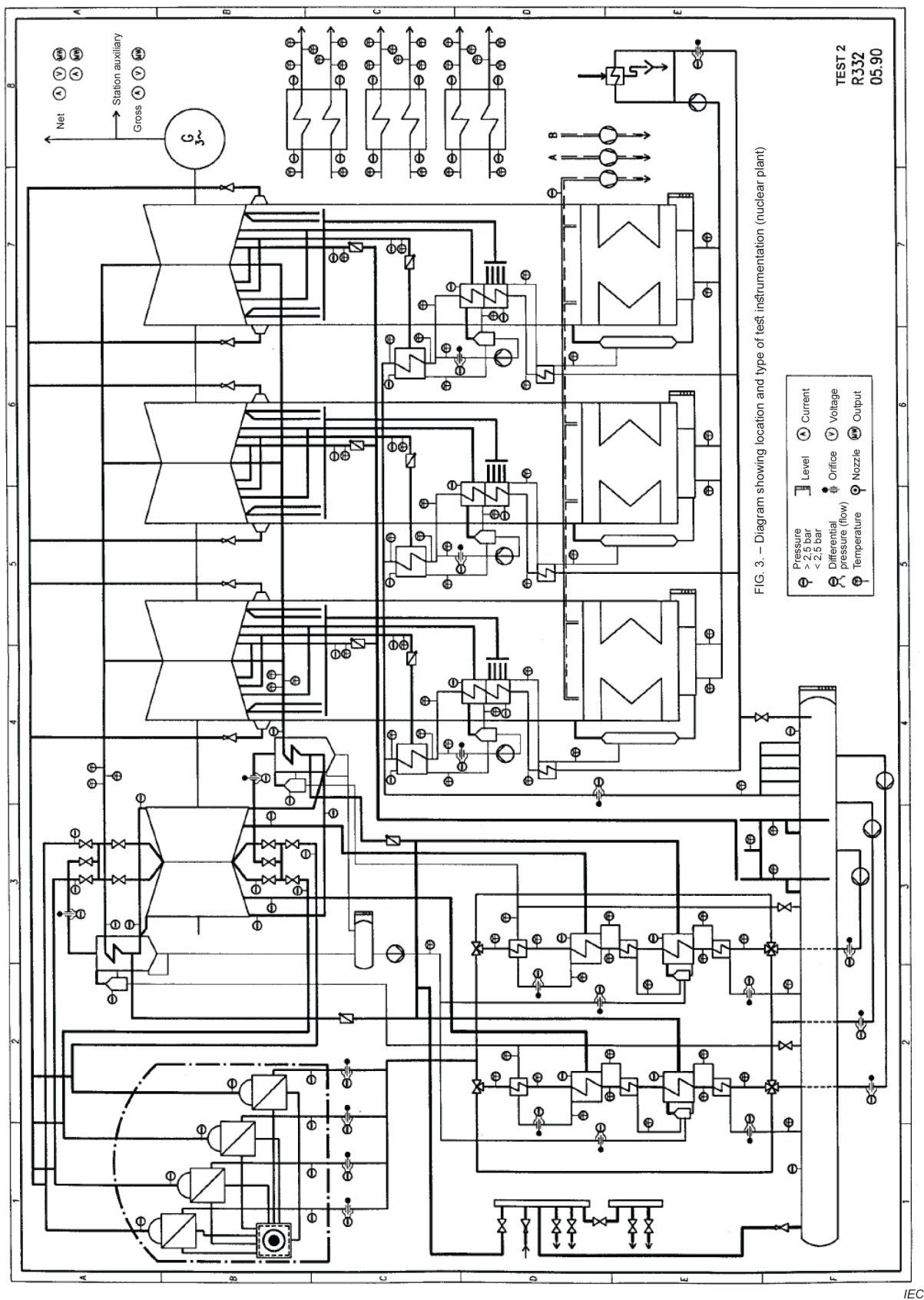


Figure 2 – Diagram showing location and type of test instrumentation (fossil fuel plant)



IEC

Figure 3 – Diagram showing location and type of test instrumentation (nuclear plant)

Table 2 – Acceptable instrumentation and uncertainties for acceptance tests

Measured Variable	Measuring Instrument / Method	Accuracy Class	Range	Acceptable Measuring Uncertainty	Remarks
Pressure	Instrument calibrated for test		For all pressures	0,1 % to 0,3 %	
Differential pressure	Differential pressure instrument calibrated for test		For all differential pressures	0,1 % to 0,3 %	
Temperature	Thermocouples calibrated		$t \leq 300 \text{ }^{\circ}\text{C}$	1 K	
			$t > 300 \text{ }^{\circ}\text{C}$	0,3 %	
	Resistance thermometer calibrated		$t \leq 100 \text{ }^{\circ}\text{C}$	0,2 K	
			$t > 100 \text{ }^{\circ}\text{C}$	0,2 %	
Primary flow	Standardized differential pressure devices			0,75 % to 1,5 % ^a (flow coefficient)	ISO 5167
	Calibrated flow devices			0,2 % to 0,4 % ^a (flow coefficient)	
	Calibrated ultrasonic meter – USMP (as defined in 5.3.2.3)			0,35 % to 0,5 % ^a (mass flow)	ISO 122242
Cooling water flow	Ultrasonic flow meter			2 % to 3 %	
	Heat balance			3 % ^b	
	other flow measuring devices			3 %	
Electrical output	Two-wattmeter method Instrument transformers individually tested	0,2 %		0,1 % to 0,5 %	
	Instruments calibrated for test at test load	0,2 %			
	Three-wattmeter method Instrument transformers individually tested	0,2 %		0,1 % to 0,5 %	
	Instruments calibrated for test at test loads	0,2 %			
	Station instrument	0,1 to 0,5 %			
Auxiliary Power	Clamp-on current meter	0,5 %			
	Clamp-on power meter	0,5 %			
Current	Ammeter	0,2 %			
Voltage	Voltmeter	0,2 %			
Mechanical output	Torsion dynamometer or thermodynamic method for pump			approximately 2 %	
Speed	Frequency from electrical output measurement			0,01 %	
	Manual tachometer		Range of calibration	1,0 %	
	Manual revolution meter		Range of calibration	0,5 %	
	Electronic revolution meter		Range of calibration	0,1 %	

Measured Variable	Measuring Instrument / Method	Accuracy Class	Range	Acceptable Measuring Uncertainty	Remarks
Ambient pressure	Precision barometer Absolute pressure transducer			±0,02 kPa (if gauge pressure device is used for back pressure measurement) ±0,05 kPa to 0,2 kPa (if absolute pressure devices is used for back pressure measurement)	
^a The accuracy of the primary flow measurement is decisive for the measuring uncertainty of the test result according to Table 6 and the flow device shall be chosen accordingly. ^b The CW flow uncertainty of the Heat Balance method should be determined for each specific case taking particular reference of the CW outlet temperature measurement uncertainty.					

5.2 Measurement of power

5.2.1 Determination of mechanical turbine output

The mechanical output of the steam turbine can be determined by one of the following four techniques:

- By measuring the output at the generator terminals (see 5.2.4) and adding the generator losses.
- By measuring torque and speed.
- By establishing an energy balance of the steam turbine.

The output is derived from the algebraic sum of all energy flows passing through the energy balance envelope established around the steam turbine⁶.

- By establishing an energy balance of a driven machine (e.g. compressor, pump).

The output is derived from the algebraic sum of all energy flows passing through the energy balance envelope around the driven machine⁶.

5.2.2 Measurement of boiler feed pump power

For a complete evaluation and for correction of the test results according to the guarantee definition, it is normally necessary to measure the power consumed by boiler feed pumps. It corresponds to the increase in the enthalpy of the water⁷, and possibly the power consumed by the hydraulic couplings and speed changers if the pumps are driven directly from the mainshaft, or by an auxiliary steam turbine driven by a bleed from the main turbine.

If the boiler feed pump is driven by an auxiliary turbine, delivered under the responsibility of the manufacturer of the main turbine, and fed by steam from the main turbine or is driven direct from the main shaft, it is, according to the guarantee values, normally necessary to measure the power consumed by the pump, corresponding to the increase of the enthalpy of the water and the mechanical losses, and possibly the power consumed by the hydraulic couplings and speed changers.

⁶ Insignificant energy flows, for example, heat dissipated to the environment due to conduction and radiation, can in most cases be estimated with sufficient accuracy and need not be measured.

⁷ In many cases, mechanical losses and heat losses of the pump can be neglected.

If the use of a dynamometer (see 5.2.1) is not practicable, the pump power is best determined from the rise in specific enthalpy across the pump multiplied by the mass flow.

Since the temperature rise across the pump is small, a high degree of precision is needed in the temperature measurement (e.g. multiple thermocouples connected in series or resistance thermometers in differential connection). In the absence of precise measurements, values of pump efficiency supplied by the manufacturer may be used in conjunction with the measured flow and pressure rise, but unless they are based on tests over the full range of load, they may be open to question.

Sealing water flow and/or injection water flow has to be duly considered in the determination of the mass flow.

The power losses in the pump bearings, the hydraulic coupling and the gear drive are equivalent to the heat picked up in the oil cooling water. Radiation losses are generally negligible.

If more than one pump is in service, it may not be practicable to measure the water flow or the mechanical losses in the bearings, couplings and gear drives individually. However, the total power consumed by the boiler feed pumps in service is all that is needed for an acceptance test.

The power consumed by a pump driven by a rotating electrical machine can be determined from the power consumed by the motor, having regard to the efficiency of the latter according to information supplied by the manufacturer, and from the measurement of the power consumed by the bearings, the hydraulic coupling and the gear drive.

If the auxiliary turbine driving the pump is outside the responsibility of the supplier of the main turbine, it may be sufficient to measure the flow rate and the condition of the bled steam.

5.2.3 Determination of electrical power of a turbine generator

The net power of a turbine generator is defined by the following formula:

$$P_g = P_b - P_a \quad (9)$$

Where an auxiliary of the turbo-generator is driven by an electric motor, the power P_a is the power delivered to the motor. This applies whether the power is derived from the generator terminals downstream of the point where P_b is measured or from a separately generated supply⁸.

Where an auxiliary of the turbo-generator is driven by other means, for example, a pump or exciter driven by a prime mover, the power P_a is the power input to the coupling.

Where excitation is derived from the generator terminals at a point downstream of the point where the power P_b is measured or from some other source, P_a is the power input to the excitation equipment.

When the turbine generator, condensing and feed water heating plant are guaranteed as a combined unit, the power requirements of the condenser and feed water heating auxiliaries shall be treated in accordance with the terms of the contract.

⁸ This does not refer to IEC 60034-2.

5.2.4 Measurement of electrical power

For a three-phase generator with the neutral directly earthed (grounded) or with the four-line system, the unit power shall be measured by the three-wattmeter method.

For a three-phase generator with neutral earthed (grounded) through resistance, reactance, or transformer with resistance, the unit power may be measured by the two-wattmeter method, but preferably by the three-wattmeter method. In all instances watt meters are preferred in place of watthour meters.

A double measurement of the electrical power, if practicable, including the duplication of voltage and current transformers, has advantages for improvement of accuracy.

5.2.5 Electrical instrument connections

The instrument transformers shall be connected into the lines from the generator as near to the generator terminals as practicable and on the generator side of any external connections by which power can enter or leave the generator circuit.

The leads to the meters shall be arranged in such a manner that they will not influence the meter readings by reason of inductance or any other such cause. Inductance may be eliminated by braiding the wires of each pair of conductors for at least 1m from the position where the instruments are located. It is desirable to check the whole arrangement of meters for stray fields, not only from the instrument leads but also from any other source.

The calibration of the transformers shall be made wherever practicable with the same impedance of the instruments and the wiring as in the tests.

The wiring influence of the voltage circuit shall not cause a significant error in measurement of the power output which will be compared with the guarantee. The choice of cross-sectional area of the wiring shall take into account the length of the wire, the influence of the voltage transformers and the resistance of safety fuses in the circuit. The errors due to wiring resistance (including fuses) shall always be taken into account.

5.2.6 Electrical instruments

Polyphase portable precision watt meters, or polyphase portable precision watthour meters shall be used with appropriate voltage and current transformers for measuring electrical output.

Portable ammeters, voltmeters and watt meters shall be included in the measuring circuits to establish that the generator load conforms to rated conditions during the tests and to measure the current, voltage and power factor.

For the environmental conditions of the instrumentation see 4.2 point e) (second paragraph).

The recording time of watthour meters shall be measured in a manner such that any inaccuracy will not exceed 0,03 %. Watthour meter readings shall be recorded during the test at regular intervals (at least every 5 min).

5.2.7 Instrument transformers

Instrument current and potential transformers of appropriate rating and accuracy characteristics, specially intended for test purposes and individually tested, should be used. If reduction of overall measuring uncertainty is desired, values of ratio and phase-angle corrections for the conditions of loading equivalent to the test instruments and leads used during the test shall be obtained by a recognized test procedure to cover the range of test values of current and voltage (see ANSI/IEEE C57.13). Instrument transformers shall be used which have no burden other than that of the test instruments and leads. Otherwise, it has to be confirmed that the permissible burden is not exceeded. When using digital power analysers, additional burden for current and voltage transformer need not be applied when the burden is within the tested range.

Burden shall be determined from instrument nameplate data and by measurement of lead resistance, or by measurement of the volt-amperes or secondary impedance, and must be constant during the test. Protective relay devices or voltage regulators shall not be connected to the instrument transformers used for the test. Normal station instruments may be connected to the test transformer if the resulting total burden is known and is within the range of test data.

5.3 Flow measurement

5.3.1 Determination of flows to be measured

In an acceptance test the flows to be measured can be divided into two categories:

Primary flows:

Flows which are in direct relation to the power output and which must be measured with a corresponding degree of precision (see 8.4).

To verify the accuracy of measurement of the primary flows, it is recommended that they be measured simultaneously in at least two different locations, and the readings compared.

Secondary flows:

Flows which are necessary for the operation of the plant and which shall be taken into account in the adjustment of the measured values of the primary flows in order to determine the turbine initial steam and reheat steam flows.

5.3.2 Measurement of primary flow

5.3.2.1 General

The measurement of primary flow may be made:

- a) by means of standardized or calibrated differential pressure flow meters (see ISO 5167 series) for water and steam.
- b) by means of calibrated ultrasonic flow meters (see ISO 12242) for water.

The usual method of determining flows is by means of differential pressure devices.

5.3.2.2 Differential pressure devices for measuring primary water or steam flow

Standardized or calibrated differential pressure devices may be used to measure flow. A choice can be made from among the following recommended devices:

- a) sharp-edged orifice plate according to ISO 5167-2.
- b) nozzle according to ISO 5167-3.

The type and diameter ratios of the differential pressure devices shall be selected with due considerations of the resulting measuring uncertainty.

During the passage of the water through the orifices and nozzles either the pressure shall remain not less than 250 kPa above the saturation pressure which corresponds to the measured temperature or the temperature of the flow shall remain not less than 15 K below the saturation temperature corresponding to the lowest absolute pressure in the measuring device.

Two separate tapping pairs shall be provided at the differential pressure device.

To reduce deterioration of the calibrated flow devices, the inner surface shall not corrode during or after calibration. The primary element, $4 \times D$ inlet pipe length and $1 \times D$ outlet pipe length shall be made from non-corrosive material.

5.3.2.3 Ultrasonic transit-time meters for primary water flow measuring

For the purpose of this document, the ultrasonic flow meter (USM) is described as:

- 1) A transit time type flow meter complying with the requirements of ISO 12242 and additional guidance given in this document. The transducers shall be non-refracted see ISO 12242 4.3.2. and the sensor arrangement shall be chordal multipath as described in ISO 12242 4.3.3. Figure 5 with at least 3 parallel chords.
- 2) The geometrical length of each acoustic path between the wetted transducer faces shall be precisely measured with a known accuracy. The geometrical path length is required for diagnostic functions once the flowmeter is in operation and can be used to check its integrity. Information about the geometrical path lengths shall be shared between the test parties.
- 3) The USM body shall be part of a meter run as one package (USMP – USM package, including meter tubes, flow conditioner or flow straightener, flow computer and thermowell), an example arrangement is given in Figure 4. To achieve the desired meter performance a flow conditioner or flow straightener shall be included as a part of the meter run which shall be designed considering the following:
 - a) With the same internal diameter as meter body section;
 - b) Minimum straight length of the USMP upstream of the USM is $10 D$ and at least $5 D$ downstream the USM body;
 - c) Inner surface upstream and downstream of the USM shall be smooth, free from rust, scale and blisters;
 - d) Inside diameter measured at four points at any cross section shall not differ by more than 1 %;
 - e) The upstream pipe section (or for the length of $5.D$) shall be bored ($D \pm 0,25\text{mm}$) with minimum removal of metal for entire length of the pipe section, tapered at $3,5^\circ$ to the remaining pipe diameter;
 The internal bore diameter in the flow section of at least $5 D$ upstream the flowmeter body should be cylindrical within ($D \pm 0,25\text{mm}$) of the diameter of the flowmeter body section.
 - f) A flow conditioner or flow straightener complying with ISO 5167-1, Annex C shall be used with a minimum straight length between downstream face of a flow conditioner or flow straightener and the USM of $5.D$;
 - g) Flanged or welded assembly of the USMP may be used. There should be no internal diameter stage at the flange or weld junction. The internal diameter of the upstream piping before the USMP should not be smaller than the USMP.

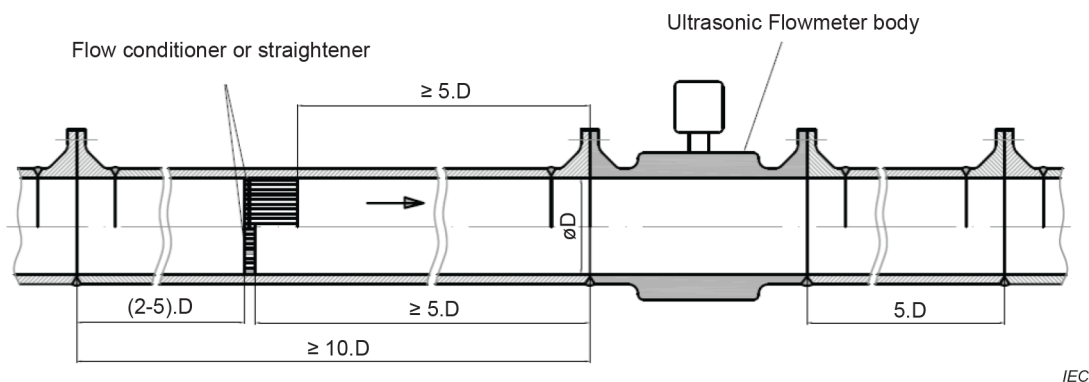


Figure 4 – USM with flow conditioner or flow straightener.

The following details shall be agreed by test parties:

- Minimum number (≥ 3) of ultrasonic paths and path arrangement;
- Electronics, automatic compensation of time delay t_0 (see ISO 12242, 4.4), number of measurements per second;
- Any effect of Waveguide, if waveguides or similar temperature decreasing and sound conducting constructions are utilized in the flowmeter for high temperatures;
- Design of meter run upstream length, type and location of flow conditioner or flow straightener and any straight length, total pressure loss of meter run;
- Number of calibration points, Reynolds number range of calibration.

The USM shall be manufactured, calibrated and installed according to ISO 12242 to ensure that accuracy class of the USM is compliant with the requirements given in Table 2.

As a minimum, the following measurements shall be provided for diagnostic purposes (see 10.4.5 of ISO 12242):

- non-linearized average axial flow velocity through the meter;
- flow velocity for each ultrasonic path (or equivalent for evaluation of the flowing velocity profile);
- speed of sound along each ultrasonic path;
- average speed of sound;
- averaging time interval;
- percentage of accepted pulses for each ultrasonic path;
- signal-to-noise ratio and gain control;
- status and measurement quality indicators;
- alarm and failure indicator;
- optionally, the linearized average axial flow velocity.

The meter shall be supplied with a facility for storing these values in a data file. The data shall be recorded together with volumetric flow (and mass flow if possible) throughout the test and shall be made available to all parties to the test.

Measuring flow uncertainty shall be calculated according to ISO 12242.

All additional effects – differences of calibration against installation, changes in flowrate viscosity, medium density determination etc. shall be added to calibration uncertainty.

5.3.3 Installation and location of flow measuring devices

5.3.3.1 Installation and location of differential pressure devices

The minimum requisite lengths of straight piping upstream and downstream of the orifice or nozzle are influenced by the configuration of the piping before and after the straight sections; for particulars see the ISO standard quoted.

In special circumstances where rotational flow can be expected or when the required straight lengths are not available, application of flow straighteners shall be considered. The incorrect use of flow straighteners may lead to errors. If a flow straightener is used and straight pipe length is not sufficient, the measuring element shall be calibrated with the complete straight piping section upstream and downstream, the flow straightener included.

It is advisable that one of the flow-measuring devices be located in the system at a point where the temperature is typically less than 160 °C to minimize temperature effects, that is, thermal expansion correction and any distortion of the primary element.

In order to reduce the possibility of thermal distortion of the flow-measuring device, it is desirable that the pipe and the flanges of the flow section be made of corrosion-resistant material having the same coefficient of expansion as the primary element.

When a flow-measuring device is installed in a vertical run of pipe or pressure taps are connected at different elevations, a correction may be necessary to account for differences in altitude between the two pressure-tapping points and differences in density between the fluid flowing through the flow-measuring device and the fluid in the pressure-tap lines.

To minimize the difficulty of obtaining steady flow, the flow-measuring device should not be located at a pump discharge. Advantage should be taken of the damping effect of any existing heat exchangers and long lengths of pipe in the cycle. The location of the flow-measuring device should also be such that the effects of recirculating and bypassing flows are eliminated. If this is not practicable, extraneous flows shall be measured with sufficient accuracy.

If the feedwater heating cycle includes a deaerator, it is recommended to measure the condensate flow at the deaerator inlet. This eliminates any possibility of low pressure heater leakage recirculating through the flow-measuring device. If the cycle has no deaerator, it is recommended that the flow be measured after it has passed through the low-pressure heaters and before it enters the boiler feed pump. If the drains from the high-pressure heaters join the main condensate flow upstream of the flow-measuring device, it will be necessary to measure the total drain flow from the high-pressure heaters and calculate the extraction steam by heat balance around the heaters to determine the high-pressure heater leakage.

For turbines using wet steam and heaters with pumped-ahead drains, a suitable double flow measurement may be required to determine if any of the heaters leak. The location of the low pressure flow measurement will depend on the cycle arrangement. Heater leakage can also be measured by using the tracer method.

5.3.3.2 Installation and location of ultrasonic flow meters

Installation of the USM must comply with ISO 12242.

The manufacturer shall specify minimum length requirements ($l_{\min}$) and maximum expected deviation (S – percentage maximum deviation in measured flowrate due to upstream fittings) for standardised sets of upstream fittings (perturbations).

Determination of $l_{\min}$ for non-standardised up-stream pipework configuration is in responsibility of the test party responsible for USM installation.

The USM sensitivity on flow disturbances depends, among other things, on the meter's design. Because of the large variety of USM types and flow disturbances, it is not possible to generalise upstream lengths.

The USM is always calibrated together with the actual flow conditioner or flow straightener and meter tube as one package (USMP).

The USMP is calibrated and installed to the pipeline as shortly prior testing as possible, in no case it is installed prior the initial flushing or chemical cleaning of the pipe.

5.3.4 Calibration of primary flow devices for water flow

5.3.4.1 General

If a primary flow device has to be calibrated, this should preferably be done with flow conditions corresponding to the same range of operational conditions that will prevail in the turbine tests.

Calibration is to be conducted preferably with the upstream and downstream piping comprising the flow section to be used in the test, including the flow straightener if used.

It should be demonstrated during calibration that a flow device is capable of repeating selected calibration points with sufficient accuracy. The difference between the expected discharge coefficient according to the applied design standard and the calibration results at each calibration point should be within the expected uncertainty of the discharge coefficient according to the design standard.

After calibration the flow section assembly shall not be disassembled. This could invalidate the calibration. During the time between calibration and installation the flow device shall be preserved and protected to ensure that the integrity of the calibration is maintained.

It is recommended to install calibrated flow devices immediately before the test.

It is recommended to inspect calibrated flow devices immediately before and after the test. They shall be recalibrated after the test if deemed to be necessary.

If it is necessary to extrapolate the calibration an additional uncertainty is introduced which shall be considered in the determination of the measuring uncertainty.

5.3.4.2 Calibration of differential pressure devices for water flow

If a differential pressure device has to be calibrated, this should preferably be done with flow conditions corresponding to the same range of Reynolds numbers that will prevail in the turbine tests.

Laboratory facilities using heated water are capable of achieving values of Reynolds numbers as great as those associated with test condensate at feedwater tank inlet flow conditions of large steam turbine units.

Laboratory facilities using high pressure gas as calibration medium are capable of achieving values of Reynolds numbers as great as those associated with test final feedwater flow conditions of large steam turbine units. Comparison tests have demonstrated good correlation of water and high pressure gas calibration results.

Guidance for extrapolation of throat tap nozzles calibration results can be found in ISO 5167-3. If extrapolation of the discharge coefficient is necessary, an additional uncertainty is introduced which shall be considered in the determination of the measuring uncertainty.

5.3.4.3 Calibration of ultrasonic flow meters

To achieve the uncertainty requirements given in Table 2 for primary flow measurements the device shall be calibrated. The USMP calibration shall be conducted under conditions as described in 8.3 of ISO 12242 and the volume flow shall be calculated in accordance with 4.2 of ISO 12242.

Laboratory flow calibration shall be conducted:

- 1) Over the appropriate range of Reynolds number such that the calibration is not extrapolated when applied to the test. If the Reynolds number on calibration does not encompass the operating Reynolds number, then the method to extrapolate the calibration and corresponding uncertainty of extrapolation shall be agreed between the parties to the test.
- 2) Where possible with the viscosity, temperature and pressure shall be similar to the expected operating condition of the meter.
- 3) With upstream and downstream pipe sections (i.e. the whole meter run – USMP).

5.3.5 Inspection of flow measuring devices

5.3.5.1 Inspection of differential pressure devices

It is recommended that shortly before or after the test all differential pressure devices and their pipe sections used for measurement of primary mass flow be inspected for condition (e.g. roughness), size (e.g. sharpness of edge for orifice plates), and general conformity with the standard required. The outcome of this inspection shall be recorded. If differential pressure devices are not inspected, this shall be duly considered in the evaluation of the test according to 6.2.3.1.

These differential pressure devices shall not be installed prior to the cleaning period before commissioning of the plant. They shall either be fitted after cleaning or they shall be bypassed.

In the case of condensing turbines, it is mandatory that practical arrangements for inspection be provided for at least one differential pressure device for a primary mass flow, preferably the condensate mass flow upstream of the deaerator. At least one differential pressure device has to be inspected after the test if this is required by one party.

5.3.5.2 Inspection of ultrasonic flow meters

5.3.5.2.1 Zero flow checks

It is recommended to perform zero flow checks shortly before and after the tests. The method is described in ISO 12242.

A zero offset (if found) may be indicative of a more fundamental problem with the USM and should be investigated to determine and cause and reduce as far as possible. The user may wish to perform additional diagnostic checks as part of a repeat of the theoretical prediction procedure.

5.3.5.2.2 Visual inspection

It is recommended to perform a visual inspection of all primary flows measured by USMs shortly before or after the tests. Visual inspection may be performed because of found zero offset, or independently. The outcome of this inspection shall be recorded.

In case of condensing turbines, it is mandatory, that at least one primary flow measurement shall be inspected, if required by one party. Practical arrangements shall be provided in advance.

Deposits, rusting or defective internal coating may affect the accuracy of the USM. At least the internal surface and the wall roughness shall be checked using optical (visual) methods by

removing the USMP from the pipeline or by using a borescopic inspection. Details and recommendation of such inspection are described in ISO 12242: If the meter bore is clean and the original machining marks are clearly visible, then there may not be a need or requirement to re-measure.

5.3.6 Differential pressure measurements

The measurement of the differential pressure necessitates particular care. Measuring systems shall be installed with the precautions listed below.

Measuring accuracy for primary flows shall be increased by the use of two independent measuring systems, including two separate taping pairs.

- a) Connecting piping used between the pressure taps and the measuring device shall be not less than 6 mm inside diameter tubing, of material which will minimize resistance damping inside the piping. This tubing should run horizontally at the same elevation as the primary element pressure taps for 1m from the flow-measuring device to cool down to ambient temperature and then slope down continuously without loops to the measuring device. The connecting piping shall be tight.

To reduce the amount of heat transferred to the connection piping when measuring steam flow, condensing pots shall not be used (this is most relevant for high pressure applications).

- b) The connecting lines to the measuring device shall be installed with a continuous downward slope. After venting, time should be allowed for the water legs to form and cool. Special attention has to be paid to the proper formation of water legs at sub-atmospheric pressure.
- c) The length of piping between the flow-measuring device and measuring device should not exceed 7,5 m if practicable. It shall also be uninsulated.
- d) Precautions shall be taken when running the connecting piping to ensure that any temperature difference between the fluid in the two lines connecting the primary element and each measuring device remains negligible. It is recommended that the piping be bundled and run in such a manner as to minimize heat transfer to these pipes from an external source.
- e) The connecting piping shall be well cleaned, preferably by flushing, before the measuring device is connected. The measuring device connections shall include the necessary means for shutting off connecting piping or venting at any time during the test. Sufficient time should be allowed for the water legs in the connecting piping to reach temperature equilibrium.
- f) Special precautions shall be taken to ensure proper venting of the system. The measuring device should be located at a lower elevation than the primary-flow element.
- g) The measuring devices shall be calibrated before the tests. Each calibration shall be done with expected line pressure applied with rising and falling differential pressure. The tests are to be calculated with the rising and falling mean calibrated values.

5.3.7 Water flow fluctuation

Flow measurements shall not be attempted unless the flow is steady or varies only slightly with time (refer to 4.8.2 and Table 1). Variations in the flow shall be minimised before the beginning of a test by adjustment of the control system. Damping devices on the measuring device do not eliminate errors due to fluctuation or pulsations and, therefore, shall not be used. If the fluctuations or pulsations remain excessive after every effort has been made to suppress them, mutual agreement is required before the test can be started.

5.3.8 Secondary flow measurements

5.3.8.1 General

In addition to the primary flow measurements (see above), many secondary flow measurements are required. Because of differences in plant layout and the alternative positions of flow measuring devices, it is not possible to specify the accuracy required in each separate measurement. The parties to the test should decide what secondary flow measurements shall

be made for the type of turbine installation concerned and then arrange for each measuring device to have an accuracy such that the combined effect of all errors in the secondary flow measurements is in appropriate proportion to the error in the test result. Consequently, if standardized measuring devices are used, calibration may not be necessary.

If the secondary flow-measurement is of steam, the steam shall remain superheated in passing through the flow-measuring device. Measurement shall not be attempted if the amount of superheat is less than 15 K at the smallest cross-section of the nozzle or orifice.

5.3.8.2 Extraction steam flows to feed heaters

If the extraction steam is superheated the extraction flow can be determined by heat balance calculation. The accuracy of the result falls off as the temperature rise across the heater diminishes.

A direct measurement by suitable pressure differential devices is possible, if the necessary measuring accuracy can be achieved.

Wet steam extraction flows can be determined from heater drain flow measurements. This can be accomplished by using a standardized or, if necessary, a calibrated flow measuring device with suitable installation conditions.

The heater drain flows can be measured using differential pressure devices except for the lowest pressure heaters with cascaded drains where very little pressure drop is available. In these cases, Venturi tubes or other low head loss primary elements (i.e. calibrated USMP) of the required accuracy should be used. The connecting piping between the transducer and the differential pressure device should be as short as practicable to minimize damping errors due to unsteady flow and care shall be taken to eliminate air bubbles in this piping.

If, for these reasons, transducers are mounted in areas not accessible during operation of the plant, suitable means for a remote operated calibration are required. The calibrating reference should be a secondary standard.

Heater drain flows are often very unsteady; therefore, the transducer output should be observed $\leq$ every 20 s.

In sizing the primary elements to avoid cavitation, the best compromise between Reynolds number, pressure loss, diameter ratio, and deflection should be made without reducing the critical cavitation coefficient "K" below 0,2, where:

$$K = \frac{p_{\text{throat}} - p_{\text{sat}}}{\frac{\rho}{2} \times v_{\text{throat}}^2} \quad (10)$$

The cavitation problem may be reduced by providing a loop seal or increasing the length of the loop seal to put more head on the meter so that the critical cavitation coefficient will be greater than 0,2.

If the heater drain flow is subcooled the cavitation problem is also reduced. The extraction wet steam flow can be determined by a heat balance calculation, if the enthalpy of the extraction steam has been determined by the tracer method (see 5.7.2).

5.3.8.3 HP heater drains

It is very important that the HP heaters shell and emergency drains are checked for leakage (see Annex A).

When the main flow meters are at the deaerator outlet there is a risk of circulating feedwater through the main flow meter through the heater shell.

When the main flow meters are at the deaerator inlet there is a risk of circulating feedwater through the main flow meter through the emergency drains.

To investigate possible leakages the HP heater drain flows can be metered by devices capable of sufficient accuracy and compared with the HP heater drain flows determined by heat balance.

5.3.8.4 Moisture separator and reheater drains

It may not be possible to install a flow-measuring device because the available head is less than that required to avoid cavitation and also for reasons of plant design or operation. In these circumstances, the tracer technique can be used to measure the flow with a sufficient accuracy. In case of measurement with a pressure difference device the recommendation of 5.3.8.2 shall be followed.

5.3.8.5 Boiler feed pump turbine steam supply

Steam consumption of a boiler feed pump turbine is preferably to be measured as condensate if a separate condenser is installed.

In a reheat cycle having a boiler feed pump driven by a turbine supplied with steam from the main turbine at a point up-stream of the reheater, the steam supplied shall be determined to enable the flow through the reheater to be determined.

5.3.8.6 Turbine gland leakages

The gland leakage flows of reheating condensing turbines which do not pass through the reheater but are returned to the system beyond the reheater, have to be determined separately, preferably by measurement, as these flows shall be considered when determining the heat supplied by the reheater.

For the gland flows that are not measured it shall be assumed that they are in proportion to the gland flows that are measured, i.e. a pro rata relationship.

If any glands are provided with leak-offs to atmosphere or to a point that is extraneous to the turbine system, this flow should be measured or determined by means of design data.

5.3.8.7 Desuperheating spray water flow

When spray water from the feed-heating system is used for regulating the reheat steam temperature, the rate of flow of such water shall be measured. Also, if the initial steam temperature is similarly regulated, the rate of flow of spray water to the superheater shall be measured, unless the water is drawn from a position downstream of the final feed heater and the last feed water flow measuring device.

5.3.8.8 Boiler feed pump gland sealing and balance water flow

The amounts of water supplied to the feed pump glands for sealing and/ or cooling purposes and the amounts of leak-off water returning to various parts of the system are liable to be considerable, which may be direct additions to, or subtractions from, the main flow measurement. The number of boiler feed pump water flows to be measured will depend on the

location of the main metering device. Calibrated or standardized measuring devices are required and it should be ascertained at the time of the test that they are in good condition.

5.3.8.9 Stored water changes

Changes in stored water quantities within the test cycle shall be taken into account in the assessment of the condensate/feedwater flows through the system.

Such stored water quantity changes will include those in condenser hot-wells, boiler drums, deaerator storage tanks, feed heater bodies, reserve condensate tank and any storage or drain tanks that cannot be isolated from the system.

Water level changes in all storage vessels should be measured by permanently installed transducers or gauges. Temporarily installed level transducers or gauges may be used.

If the temperature of the water in a vessel is appreciably different from the ambient temperature and an external instrument tubes or a gauge glass is employed, for example, as in the case of a deaerator storage tank, the density of water in the instrument's tube or gauge glass should be used in the conversion of water level change to mass change in the vessel.

Instrument's tube or gauge glasses which are connected to vessels containing hot water should not be blown down within a period of approximately half an hour before taking a reading in order to avoid a false level indication due to a change of temperature in the water column.

Since time is a critical factor in the measurement of the water level changes, the test readings shall be closely synchronized with the signals for commencement and termination of a test.

Stored level changes of each vessel should be derived from internal dimension and stored water level deviation during the test.

Stored level deviation during the test is level difference per time between first and last reading (or average of several readings) of the test. Approximate curves may be alternatively used on condition that continuous and high frequency (compared to test duration) fluctuations are found in the trend of the level measurement during the test.

5.3.8.10 Leakage determination

It will be necessary to use calculated values for internal pump leakages, shaft packing, valve stem leakages, internal turbine leakages and other leakages when it is not practicable to measure these flows.

5.3.9 Occasional secondary flows

5.3.9.1 General

Further secondary flows, which occur relatively rarely, or need not be measured, include the following:

5.3.9.2 Ejector steam

Steam-jet air ejector steam flow can be calculated from the measured pressure and temperature of the steam supply and the known cross-sectional area of the jets. When the steam supply is wet, it may be preferable to use the design flow rates given by the manufacturer.

The amount of steam removed from the condenser by the air removal means is generally negligible. Should it be measured, the method of measurement shall be agreed upon by the parties to the test.