

Rules for steam turbine thermal acceptance tests —

Part 2: Method B: Wide range of accuracy for various types and sizes of turbines

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British Standard

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee MCE/13, Steam turbines, upon which the following bodies were represented:

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

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National foreword

This British Standard has been prepared by Technical Committee MCE/13 and is the English language version of EN 60953-2:1995 *Rules for steam turbine thermal acceptance tests — Part 2: Method B Wide range of accuracy for various types and sizes of turbines*, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 953-2:1990 published by the International Electrotechnical Commission (IEC).

It supersedes BS 752:1974 and BS 5968:1980, which are withdrawn.

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

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

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

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

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

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

EN 60953-2 was produced as a result of international discussion in which the United Kingdom took an active part.

The drawings on pages 24 and 25 constitute Amendment No. 1 to BS EN 60953-2 and are the result of the standard becoming a print on demand item.

The amendment consists of the removal of two A3 circuit diagrams on pages 24 and 25 and their replacement by the two A4 sheets. There are no changes to the text or re-pagination.

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

Cross-references

Publication referred to	Corresponding British Standard
IEC 34-2:1972	BS 4999 <i>General requirements for rotating electrical machines</i> Part 102:1987 <i>Methods for determining losses and efficiency from tests (excluding machines for traction vehicles)</i>
IEC 41:1991 ^a	BS EN 60041:1995 <i>Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines</i>
ISO 31-3:1992	BS 5775 <i>Specification for quantities, units and symbols</i> Part 3:1993 <i>Mechanics</i>
ISO 5167-1:1991 ^b	BS 1042 <i>Measurement of fluid flow in closed conduits</i> Part 1: <i>Pressure differential devices</i> Section 1.1:1992 <i>Specification for square-edged orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full</i>

^a Revision of IEC 41:1963 to which normative reference is made in the text.

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

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, the EN title page, pages 2 to 100, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

English version

Rules for steam turbine thermal acceptance tests
Part 2: Method B
Wide range of accuracy for various types and sizes of
turbines

(IEC 953-2:1990)

Règles pour les essais thermiques de réception
des turbines à vapeur
Partie 2: Méthode B
Précision de divers degrés pour multiples
modèles et tailles de turbines
(CEI 953-2:1990)

Regeln für wärmetechnische Abnahmemessung
an Dampfturbinen
Teil 2: Methode B
Weiter Genauigkeitsbereich für
unterschiedliche Bauarten und Baugrößen von
Dampfturbinen
(IEC 953-2:1990)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Foreword

The text of the International Standard IEC 953-2:1990, prepared by IEC TC 5, Steam turbines, was submitted to the formal vote and was approved by CENELEC0 as EN 60953-2 on 1995-05-15 without any modification.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard (dop) 1996-07-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1996-07-01

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Appendix B, Appendix F, Appendix G and Annex ZA are normative and Appendix A, Appendix C, Appendix D and Appendix E are informative. Annex ZA has been added by CENELEC.

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Introduction

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

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

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

1) *Basic philosophy and figures on uncertainty*

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

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

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

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

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

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

2) *Main differences between Methods A and B*

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

3) *Guiding principles*

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

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

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

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

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

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

4) *Instruments and methods of measurement*

a) Measurement of electrical power

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

b) Flow measurement

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

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

In Method B standardized pressure-difference devices are normally applied for flow measurement. Calibration is recommended where a reduction of overall measuring uncertainty is desirable. Double or multiple measurement of primary flow is recommended for the reduction of measuring uncertainty and a method for checking the compatibility is described.

c) Pressure measurement

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

d) Temperature measurement

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

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

e) Steam quality measurements

Methods A and B are identical.

5) *Evaluation of tests*

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

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

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

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

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

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

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

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

7) Proposals for application

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

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

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

1 Scope and object

1.1 Scope

The rules given in this standard are applicable 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 shall take place are included.

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

1.2 Object

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

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

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

1.3 Matters to be considered in the contract

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

Sub-clause

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

2 Units, symbols, terms and definitions

2.1 General

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

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

2.2 Symbols, units

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

Quantity	Symbol	Unit	Examples of multiples and sub-multiples	Other ISO units
Power	P	W	kW	
Flow rate	m	kg/s		
Pressure, absolute	p_{abs}	Pa	kPa	bar ^a
Pressure, gauge	p_e	Pa	kPa	bar ^a
Ambient pressure (barometric)	p_{amb}	Pa	kPa	bar ^a , mbar
Pressure difference	Δp	Pa	kPa	
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	Q	J/s	kJ/s	
Cavitation factor	K	1		
Concentration	C	According to nature of tracer		
Correction factor according to 6.6 a)	F	1		
Correction factor according to 6.6 b)	F^a	1		
Isentropic exponent	k			
Discharge coefficient	C_d			

Quantity	Symbol	Unit	Examples of multiples and sub-multiples	Other ISO units
Flow coefficient	α			
General quantity	x^b			
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.				
^b According to application.				

Relation between Heat Rate and thermal efficiency:

Units used for HR

W/W, kW/kW, kJ/kW · s

kJ/kW · h

kJ/MW · s

kcal/kW · h

BTU/kW · h

Relation

$$HR = \frac{1}{\eta_t}$$

$$HR = \frac{3600}{\eta_t}$$

$$HR = \frac{1000}{\eta_t}$$

$$HR = \frac{859.845}{\eta_t}$$

$$HR = \frac{3412.14}{\eta_t}$$

2.3 Subscripts, superscripts and definitions

Quantity	Subscript	Position or definition
Power	b	At generator terminals
	a	Taken by auxiliaries not driven by the turbine (see 4.2.3); (see also IEC 34)
	g	Net power output: $P_g = P_b - P_a$
	c	At turbine coupling, less power required by turbine auxiliaries, if driven separately (see 4.2.3)
	i	Internal to the turbine
	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

Quantity	Subscript	Position or definition
Make-up water conditions and flow rate Gland steam conditions and flow rates	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
	m	Measurements adjacent to the inlet flange of the condensate system or of the evaporator
	g	Steam supplied to glands from a separate source
Main steam flow rate and concentration Mass flow rate and concentration	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
	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
	R	Recirculated water flow from water separator
Condenser cooling water	w	
	wi	Condenser inlet
	wo	Condenser outlet
	wio	Average value between condenser inlet and outlet
Efficiency	t	Thermal
	td	Thermodynamic
Enthalpy drop	s	Refers to isentropic enthalpy drop
Velocity	throat	At throat of flow-metering nozzle
Static pressure	sat	Saturation pressure of water at pertinent temperature
Concentration	wat	In water phase
	L	In pump loop of BWR
	B	In blow-down water of PWR
	inj	Of injected tracer
	O	At injection point before tracer injection

Quantity	Subscript	Position or definition
Test results and guaranteed values	g	Guaranteed
	c	Corrected
	m	Measured
Correction Factor F or F^*	tot	Product of all individual correction factors
	1, 2, 3	Numbering of individual correction factors
	η	For correction of efficiency
	P	For correction of output
General use	i, j	Numbering subscripts

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.

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

2.4 Definition of guarantee values and test results

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

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

2.4.1

thermal efficiency

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

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

where:

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

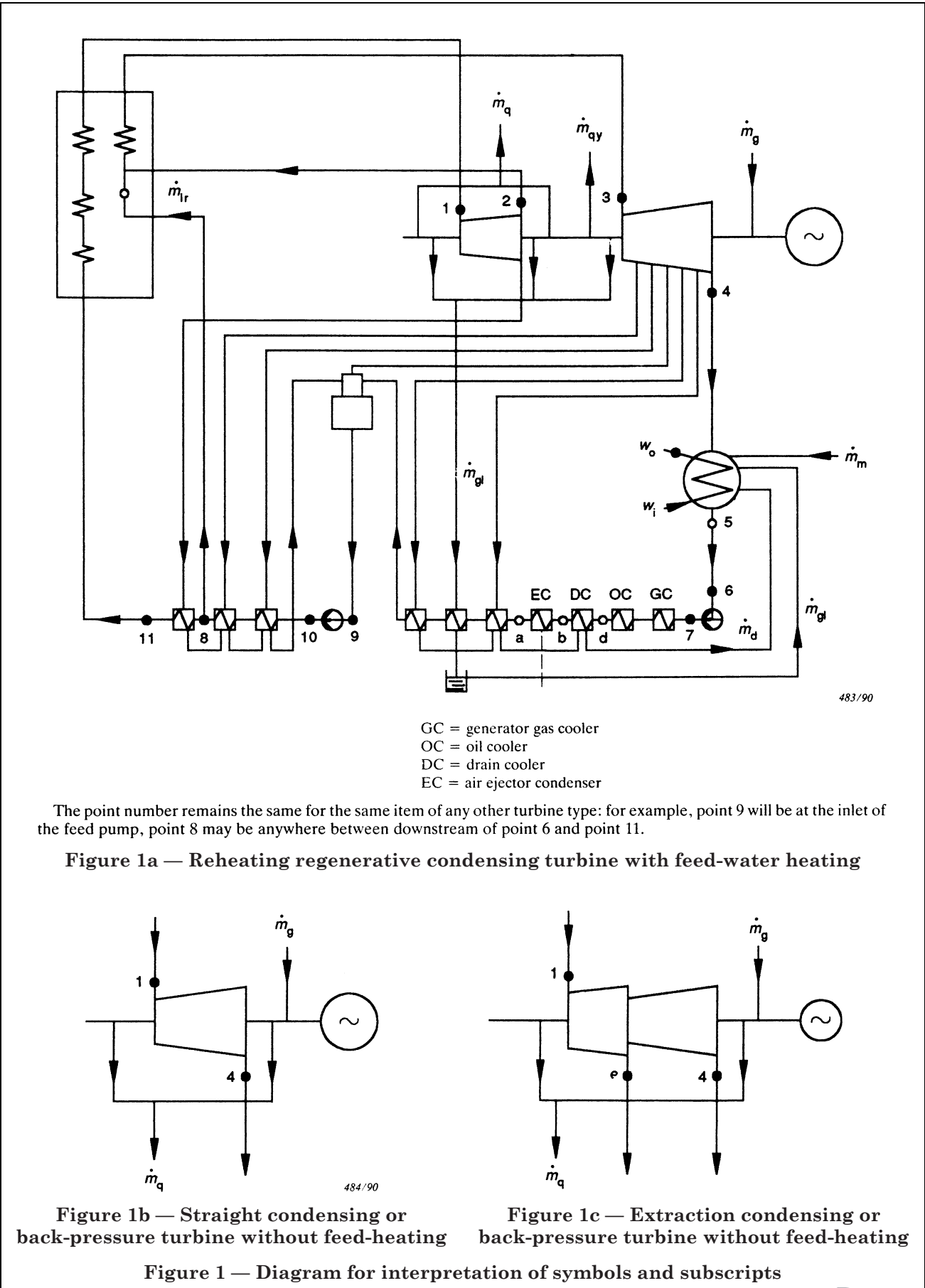
Δh_j are the resulting enthalpy rises

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 3.4.4)

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

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

* According to contract specification.



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 6). Losses are not included in this definition, but treated according to 5.2.3.4

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

this, however, also modifies the thermodynamic character of the definition and the resulting values of the thermal efficiency are not directly comparable with those according to formula (2). Furthermore, the correction procedure will not be avoided altogether in this way, because it is improbable that the values of these additional flows during the test 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 6.6.1

2.4.2

heat rate

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

in a coherent unit system (SI):

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

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

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

2.4.3

thermodynamic efficiency

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

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

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

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

$$\eta_{td} = \frac{P_b \text{ (or } P_g \text{ or } P_c)^*}{\dot{m}_1 \cdot \Delta h_{s1.4}} \quad (5)$$

*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

2.4.4

steam rate

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

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

steam rate values expressed in other units can be converted to thermodynamic efficiency values after determination of the relevant Δh_s value taking into account the appropriate conversion factors (see 2.2) since numerical steam rate values depend also on initial steam and exhaust conditions, they are not comparable for turbines with different specified conditions. Therefore, thermodynamic efficiency is used in these rules

2.4.5

main steam flow capacity

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

2.4.6

maximum power output

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

2.4.7

guarantee values for extraction and mixed-pressure turbines²⁾

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:

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

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:

$$\eta_{td} = \frac{P_b \text{ (or } P_g \text{ or } P_c)^*}{\dot{m}_1 \cdot \Delta h_{s1,c} + (\dot{m}_1 - \dot{m}_e) \Delta h_{s2,c}} \quad (8)$$

*According to contract specification.

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

²⁾ Mixed pressure turbines — several inlets at different pressures during the expansion.

3 Guiding principles

3.1 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 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 4.7.

3.2 Preparatory agreements and arrangements for tests

- a) Before the test the parties to the tests shall reach an agreement as to the test programme, the specific objectives of the tests, the measuring methods and the method of operation with due regard to 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 3.5).
- d) Agreement shall be reached on such matters as the means of securing constancy of steam conditions and output.
- e) Instruments liable to failure or breakage in service should be duplicated by reserve instruments, properly calibrated, which can be put into service without delay. A record of such change of instrument during a test shall be clearly made on the observer's record sheet.

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

- f) The determination of the enthalpy of steam superheated less than 15 K, or of the quality of steam containing moisture, may be made only when the parties 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) An independent expert may be a party to all agreements.

j) Agreement shall be reached on the minimum number of operating and recording personnel that is required.

3.3 Planning of the test

3.3.1 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 weeks³⁾ after the first synchronization (see 3.5.). In any event, except with written agreement to the contrary, the acceptance test shall take place within the guarantee period specified in the contract.

3.3.2 Direction of acceptance tests

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

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

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

3.3.3 Cost of acceptance tests

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

3.4 Preparation of the tests

3.4.1 Condition of the plant

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

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

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

³⁾ It is the intent during this period to minimize performance deterioration and risk of damage to the turbine. Enthalpy drop tests or preliminary tests should be made during this period to monitor HP and IP turbine section performance. However, these tests do not provide LP section performance and for this reason it is imperative to conduct the acceptance tests as soon as practicable.

3.4.2 Condition of the steam turbine

The condition of the steam turbine depends on the effects of ageing⁴⁾ (see 6.9), of partial damage⁵⁾ and of deposits⁶⁾.

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

The absence of partial damage and/or deposits shall be confirmed before the test (see also 3.4.1).

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.

3.4.3 Condition of the condenser

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

The condition of the condenser shall be checked by opening the water boxes or measuring the terminal temperature difference. In the case of deposits⁶⁾, the condenser shall be cleaned by the purchaser prior to the acceptance tests at the request of the supplier or the parties concerned by the test may agree on a suitable correction.

3.4.4 Isolation of the cycle

The accuracy of 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 should not exceed the relative measuring uncertainty of the test result (expressed in percent) multiplied by 0.4 (see 5.2.3.4). 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 5.2.3.4).

3.4.4.1 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 pre-heaters.
- 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 on stop, intercept and control valves.
- g) Interconnecting lines to other units.
- h) Demineralizing equipment.

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

⁴⁾ Ageing means deterioration during correct operating and shutdown conditions in a manner such that the performance of the turbine is adversely influenced.

⁵⁾ 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.

⁶⁾ Deposits: salts or metal on the steam side, slime, ashes, bacteria, algae, etc., on the cooling water side.

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

3.4.4.2 *Flows which shall be determined if not isolated*

The following extraneous flows which enter or leave the cycle in such a manner as to cause an error in the flows through the turbine shall be 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).

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

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

- a) Double valves and tell-tales.
- b) Blank flanges.
- c) Blank between two flanges.
- d) Removal of spool piece for visual inspection.
- e) Visual inspection for steam blowing to atmosphere — such as safety valves.
- f) Closed valve which is known to be leak-proof (test witnessed by both parties) and not operated prior to or during the test.
- g) Temperature indication (only acceptable under certain conditions — mutual agreement necessary).
- h) Accurate measurements of levels in any tanks which should be isolated from the system.
- i) Very important isolating valves (for example, HP and LP bypass valves) should be inspected and, if necessary, sealed prior to the test.

3.4.5 Checks for leakage of condenser and feedwater heaters

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

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

3.4.6 Cleanliness of the steam strainers

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

3.4.7 Checking of the test measuring equipment

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

3.5 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, the gland leakage flows, and the condenser terminal difference 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 3.3.3).

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

The reference measurement shall be made immediately after the first start-up, 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.

3.6 Settings for tests

3.6.1 Load settings

The acceptance tests for a turbine with partial arc admission shall be conducted at “valve points”, which are those positions of the control valves where the total throttle effects are minimized.

The output at a “valve point” may only deviate from the specified value within the limits stated in **3.8.2**.

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 **3.8**. In these cases a re-calculation of the guarantee value according to **6.6.1** 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.

3.6.2 Special settings

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

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

3.7 Preliminary tests

Preliminary tests may be run for the purpose of

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

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

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

3.8 Acceptance tests

3.8.1 Constancy of test conditions

All tests shall be preceded by a period 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.

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

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

3.8.2 Maximum deviation and fluctuation in test conditions

Except upon agreement to the contrary by the parties, the maximum permissible deviation of the average test 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 I.

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.

3.8.3 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 5.1) 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 I. Pressures and temperatures for the determination of thermodynamic properties may be read at longer intervals, that is, from 3 min to 5 min according to amount and type of fluctuations.

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 to the observers through signals from a main clock. It may alternatively be taken from the observers' watches, which shall be synchronized with each other prior to each test.

Table I — Maximum deviations and fluctuations^a in operating conditions

Variable	Maximum permissible deviation of average of test from that specified
Initial steam pressure	$\pm 5\%$ ^b
Initial steam temperature	$\pm 15\text{K}$ ^b
Dryness fraction	± 0.005
Extraction pressure (regulated)	$\pm 5\%$ ^b
Exhaust pressure:	See ^d
— for feed heating	$\pm 5\%$ ^b
— for back pressure turbines	$\pm 25\%$ if condenser is not included in guarantee
— for condensing turbines	$\pm 10\%$
Extraction flow rate	$\pm 15\text{ K}$
Reheat temperature	$\pm 7\%$
Isentropic enthalpy drop	$\pm 5\%$ after correction for specified conditions
Output or initial steam flow	$\left. \begin{array}{l} \pm 15\% \\ \pm 5\text{ K} \\ \pm 10\text{ K} \\ \pm 2\% \end{array} \right\} \text{ if condenser is included in guarantee}$
Cooling water flow	
Cooling water inlet temperature	
Final feed water temperature	
Speed	$\pm 2\%$ ^c

^a The maximum fluctuation of the variable permitted during each test shall not be greater than half the permissible deviation given in Table I except for the output which may vary by $\pm 3\%$.

^b All these items may not lead to a deviation of enthalpy drop of more than $\pm 7\%$.

^c If permitted by the technical guarantee of the turbine.

^d 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.

3.8.4 Reading of integrating measuring instruments

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

3.8.5 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.

3.8.6 Recording of tests

Each observer shall record his actual observations. All records shall be made with carbon copies, at least in duplicate, or by mutual agreement be photo-copied immediately after each test-run. Immediately after the test each interested party shall receive a complete set of records.

3.8.7 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).

Should a control valve which ought to be closed at test load open because of fluctuations in load, or should 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 3.8.3. Otherwise the test has to 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.

3.8.8 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.

3.8.9 Consistency 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.

3.9 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.

4 Measuring techniques and measuring instruments

4.1 General

4.1.1 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 officially calibrated measuring instruments 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 II 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 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.

4.1.2 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 has to 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 II 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 7.

4.1.3 Calibration of instruments

Instruments requiring calibration shall be calibrated before the test. Certificates shall be available to the parties before the test. Any recalibration after the test shall be a matter for agreement between the parties.

4.1.4 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.

4.1.5 Mercury in instrumentation

Mercury and compounds of mercury react with component materials and cause environmental problems. The very low vapour pressure of mercury presents a serious health hazard if spillage occurs. The greatest care and strict adherence to all applicable regulations concerning mercury is necessary. If mercury is used the following precautions should be taken:

- a) Keep instrument valves closed except during test runs.
- b) Install quick closing solenoid valves in instrument pressure sensing lines to close automatically on system upsets.
- c) Employ double mercury traps.
- d) Locate the primary flow element in the low temperature part of the feed water cycle of nuclear plants where it is remote from the steam supply system.

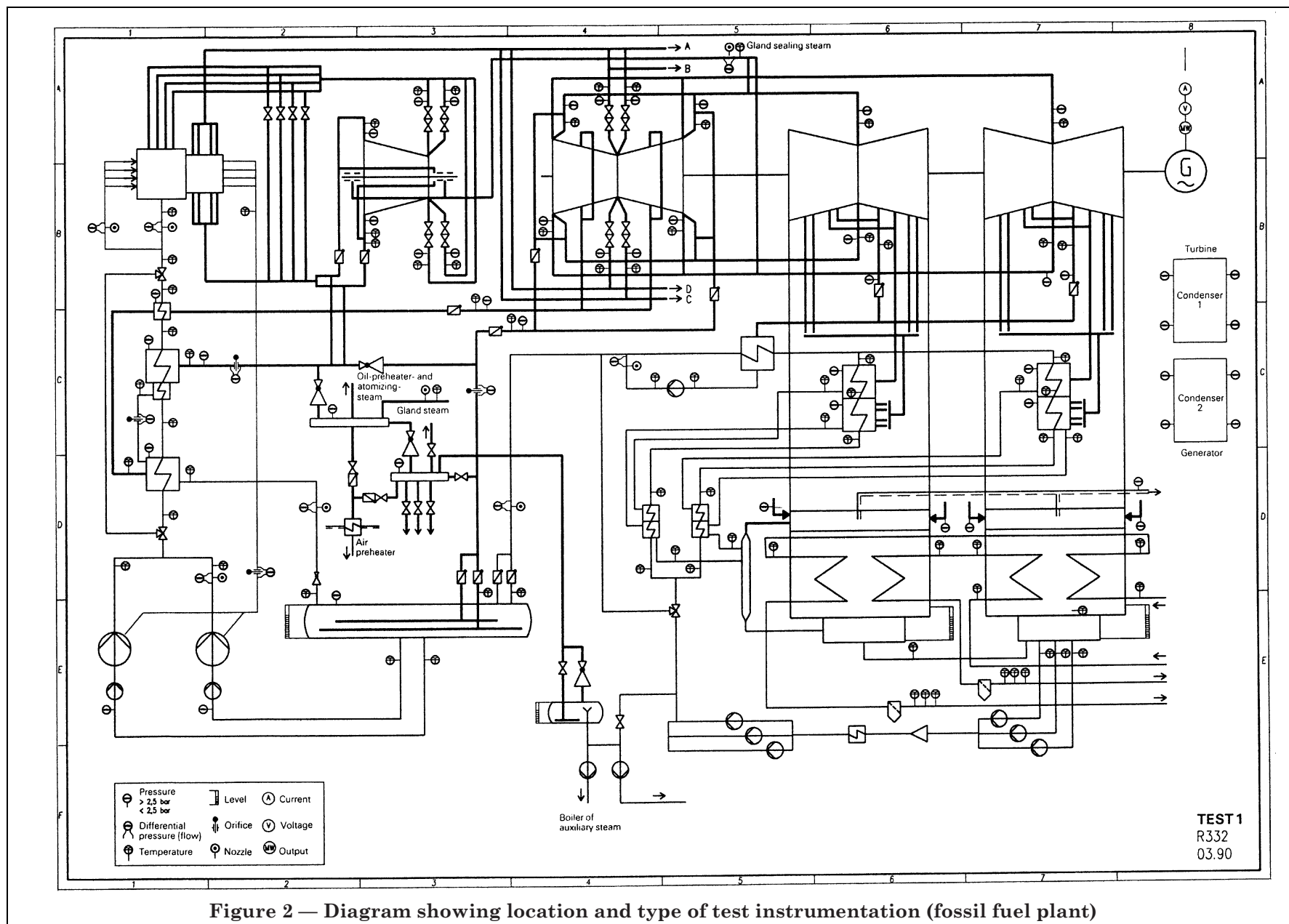


Figure 2 — Diagram showing location and type of test instrumentation (fossil fuel plant)

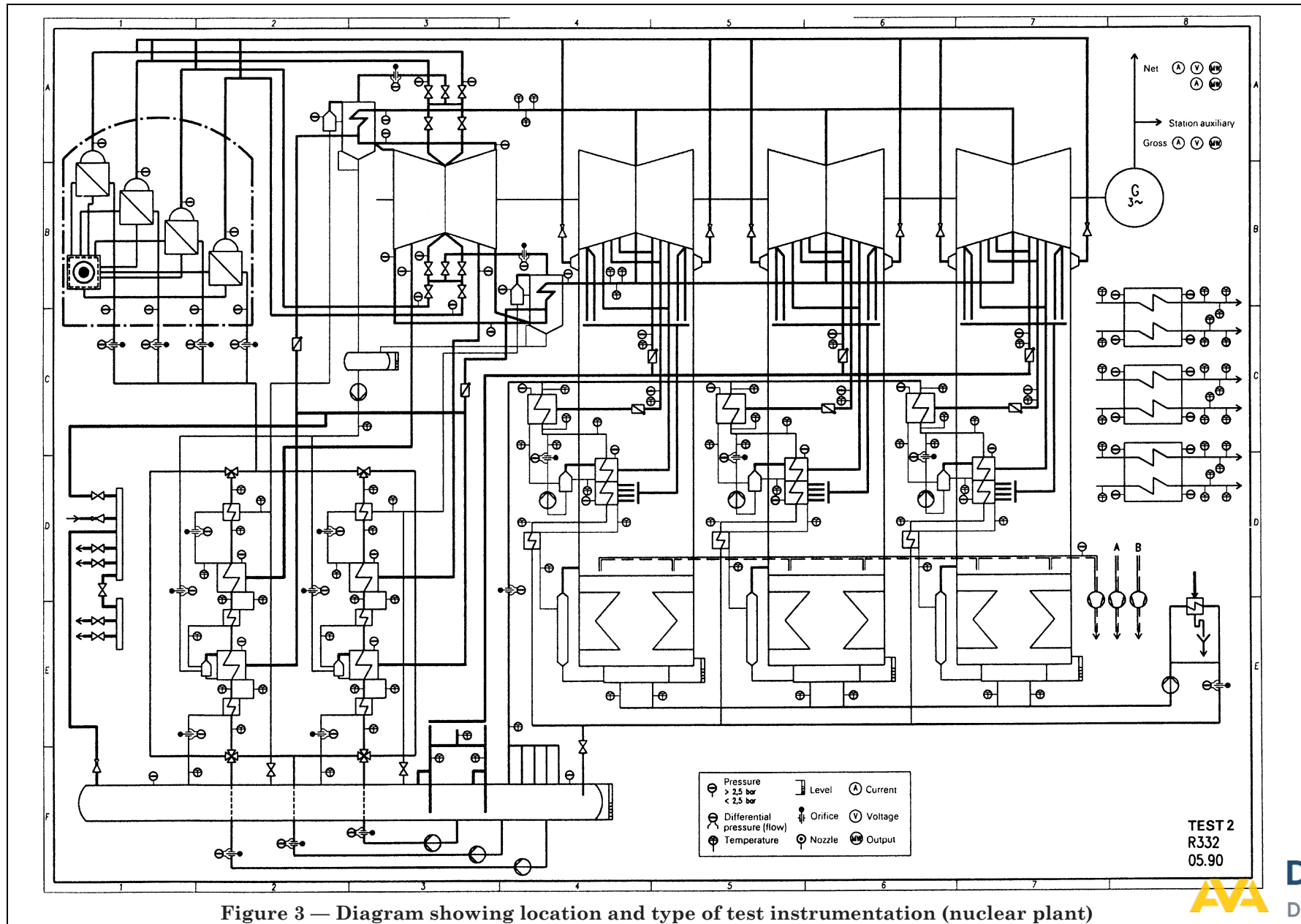


Figure 3 — Diagram showing location and type of test instrumentation (nuclear plant)

Table II — Acceptable instrumentation for acceptance tests and resulting average uncertainties

Reference	Measured Variable	Measuring Instrument	Accuracy Class	Range	Average Measuring Uncertainty	Remarks
1	Pressure	Deadweight gauge		$P > 2$ bar	± 0.3 %	
2		Transducer calibrated for test		For all pressures	± 0.3 % – 0.5 %	
3		Bourdon gauge calibrated for test	0.3 %	$P > 2$ bar	± 0.3 % – 0.6 %	
4		Bourdon gauge calibrated	0.6 %	$P > 2$ bar	± 1 %	
5		Mercury manometer		$P < 2$ bar	± 1 mm	On length of liquid column
6		Liquid manometer		$P < 2$ bar	± 1 mm	
7	Differential pressure	Liquid manometer		$h > 100$ mm	± 1 mm	
8		Differential pressure transducer calibrated for test		For all differential pressures	± 0.3 % – 0.5 %	
9	Temperature	Thermocouples calibrated		$t \leq 300$ °C	± 1 K	
				$t > 300$ °C	± 0.5 %	
10		Resistance thermometer calibrated		$0 < t \leq 100$ °C	± 0.2 K	
				$t > 100$ °C	± 0.5 %	
11		Mercury-in-glass-thermometer graduated 0.1 °C calibrated	0.10 °C	$t < 100$ °C	± 0.1 K	
12	Primary flow	Standardized differential pressure devices			$0.75 - 1.5^a$	ISO 5167
13		Calibrated differential pressure devices				
14	Cooling water flow	Vane type flow meter		$D > 1\,000$		IEC 41
15	Electrical output	Two-wattmeter method Instrument transformers calibrated for test	0.2 %		0.1 % – 0.2 %	
		Instruments calibrated for test at test load	0.2 %			
16		Three-wattmeter method Instrument transformers calibrated for test	0.2 %		0.1 % – 0.2 %	
		Instruments calibrated for test	0.2 %			
17	Current	Ammeter	0.2 %			IEC 41
18	Voltage	Voltmeter	0.2 %			IEC 41
19	Mechanical output	Torsion dynamometer or thermodynamic method for pump			approximately ± 2 %	
20	Speed	Manual tachometer		Range of calibration	± 1.0 %	
21		Manual revolution meter		Range of calibration	± 0.5 %	
22		Electronic revolution meter		Range of calibration	± 0.1 %	
23	Ambient pressure	Precision barometer			± 0.2 mbar	

^a The accuracy of the primary flow measurement is decisive for the measuring uncertainty of the test result according to Table 3 and the pressure differential device shall be chosen accordingly.

4.2 Measurement of power

4.2.1 *Determination of mechanical turbine output*

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

- a) By measuring the output at the generator terminals (see 4.2.4) and adding the generator losses.
- b) By measuring torque and speed.

Absorption or torsion dynamometers are permissible, provided precautions are taken in their construction and use to ensure accuracy. This includes electric or eddy-current generators, the input of which is measured by the reaction of the stator.

If auxiliary power services of the turbine, such as governor and lubricating oil pumps, are driven from an external energy supply, their power requirements shall be deducted from the turbine output at the coupling in order to determine the net output at the turbine coupling.

- c) 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 turbine⁷⁾.

- d) 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 machine⁷⁾.

4.2.2 *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 water⁸⁾, 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.

If the use of a dynamometer (see 4.2.1) 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.

⁷⁾ 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.

⁸⁾ In many cases mechanical losses and heat losses of the pump can be neglected.