

Rules for steam turbine thermal acceptance tests —

Part 3: Thermal performance verification tests of retrofitted steam turbines

The European Standard EN 60953-3:2002 has the status of a
British Standard

ICS 27.040

National foreword

This British Standard is the official English language version of EN 60953-3:2002. It is identical with IEC 60953-3:2001.

The UK participation in its preparation was entrusted to Technical Committee MCE/13, Steam turbines, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
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Rules for steam turbine thermal acceptance tests
Part 3: Thermal performance verification tests of
retrofitted steam turbines
(IEC 60953-3:2001)

Règles pour les essais thermiques
de réception des turbines à vapeur
Partie 3: Essais de vérification des
performances des turbines à vapeur
rénovées
(CEI 60953-3:2001)

Regeln für thermische
Abnahmeprüfungen für Dampfturbinen
Teil 3: Thermische
Leistungsangabenüberprüfung für
modernisierte Dampfturbinen
(IEC 60953-3:2001)

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

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Foreword

The text of document 5/130/FDIS, future edition 1 of IEC 60953-3, prepared by IEC TC 5, Steam turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60953-3 on 2001-10-01.

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- latest date by which the EN has to be implemented
at national level by publication of an identical
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- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2004-10-01

This European Standard should be read in conjunction with EN 60953-2.

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annexes H, K and ZA are normative and annexes I, J and L are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60953-3:2001 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

Retrofitting steam turbines in an existing power plant frequently involves an improvement of performance. IEC 60953-1 and IEC 60953-2, which define the rules for steam turbine thermal acceptance tests of a new power plant, do not cater for all the requirements specific to retrofit projects. It has, therefore, been deemed necessary to draw up a supplementary retrofit code (RC) for guidance on the thermal acceptance tests of retrofitted steam turbines.

However, a large number of the provisions and recommendations of IEC 60953-1 and IEC 60953-2 are still applicable to retrofits and, therefore, in order to avoid a repetitive and bulky document, only the retrofit-specific addenda will be found in this RC.

This part of IEC 60953 shall be read in conjunction with IEC 60953-2, and the words 'verification test' should be read in place of 'acceptance test'. IEC 60953-2 is taken as a RS. The structure and clause numbering of this standard follow that of IEC 60953-2. Subclauses found in this standard supersede the whole of the equivalent subclause in the RS. Subclause numbering has been extended whenever new items have been included the numbering following on chronologically. The subclauses of the RS requiring no amendment have not been repeated here.

IEC 60953-2 has been used as reference rather than IEC 60953-1 since it is more versatile and appropriate to retrofits. Although this standard is intended to apply to the retrofit of large condensing steam turbines, it can nevertheless be used for other types and sizes of turbines to define the bases of a specific procedure to be agreed upon by the parties involved.

The fact that IEC 60953-2 has been given preference over IEC 60953-1 does not mean that a less accurate option has been taken. The rules it contains are defined so as to obtain the appropriate testing accuracy for the retrofit project and for the relevant type of guarantee. In some cases, the more stringent rules of IEC 60953-1 are needed to meet these objectives and this is indicated in this standard.

The rules given in this standard cover all hardware change in the steam turbine equipment. Changes to other hardware components (e.g. boiler, feedwater heaters, etc.) are not covered by this code although these changes may affect the thermodynamic cycle.

The purpose of this RC is to cover the retrofit of steam turbine components which influence the efficiency of the power plant and are subject to a performance guarantee. Many different situations are likely to be encountered: for example, the replacement of steam valves, the replacement of part of the turbine blading, of a rotor, of a complete module, etc. The guarantee values will depend on the retrofit considered and are subject to agreement between the parties involved in the contract. This standard helps the parties determine the most appropriate parameters that characterise the retrofit and that could be used as guaranteed values.

A major difficulty in retrofit projects is the choice of parameters to be guaranteed. Although the original manufacturer will generally favour a relative improvement guarantee, another vendor who does not necessarily know all the details of the equipment installed may prefer to have an absolute guarantee value for the retrofitted equipment. This standard gives guidance on the parameters to be guaranteed. Once the guaranteed values are established, they may need to be re-evaluated after a pre-retrofit performance test. This standard provides such rules required for the verification of the guaranteed values.

The many variations of retrofits possible make it difficult to cover all cases comprehensively but a few detailed examples illustrating the application of this standard are presented in the annexes.

The main differences in the main clauses between this standard and the RS are listed below.

Clause 1: Scope and object

Specifically, this standard requires the definitions of new options regarding guarantees. It is possible to guarantee parameters typical of the retrofitted equipment (turbine cylinder efficiency, pressure drop in valve chest, etc.). The RS defines absolute guarantees that are not suitable for specifying improvements between initial and retrofitted equipment, and therefore, relative guarantee values are introduced in this standard.

This standard reviews the contractual provisions, which can vary from one case to another, on account of the wide range of feasible retrofits. These will be subject to an agreement between the parties involved at the time the guarantees are defined i.e. during the formulation of the contract prior to the performance of the verification tests.

Clause 2: Units, symbols, terms and definitions

All the units, symbols, terms and definitions of the RS apply to this RC. The RC, however, includes new concepts and terms associated with the retrofit situation, especially in the definition of guarantees which can be offered, either additionally or in lieu of those of the RS. A guide matrix has been included to allow the parties involved to choose the parameters to be guaranteed, as appropriate to the project.

The guarantees provided by the manufacturer can be

a) Guarantees of absolute values

- Turbine plant thermal efficiency or heat rate;
- turbine thermodynamic efficiency or steam rate or power output at specified steam flow conditions;
- main steam flow capacity and/or maximum power output;
- internal efficiency of turbine sections.

b) Guarantees of relative values

- Improvement of turbine plant thermal efficiency or heat rate;
- improvement of thermodynamic efficiency or steam rate or power output;
- improvement of main steam flow capacity and/or maximum power output;
- improvement of internal efficiency of turbine sections.

Clause 3: Guiding principles

The majority of the guiding principles contained in the RS are also applicable to the retrofit situation. Amendments or addenda to this clause mainly cover the precautions to be taken when tests are to be run before and after the retrofit, and address the reference to be taken when a guarantee on improvement in performance is offered.

Special attention is directed to the problems of isolation of the cycle, and allowable deviations of measured quantities which can greatly affect the interpretation of results.

Clause 4: Measuring techniques and measuring instruments

In the case of retrofit projects, rigid rules cannot be formulated for measuring techniques and instruments. The instruments should be chosen to suit the requirements of the installation and the guarantee value to be verified. Guidance is given in annex J on the sensitivity of the parameters guaranteed to the accuracy of the individual measurements, so that the most appropriate choice of instrumentation can be made.

Since flow is among the most important measurements, this standard gives guidance on the necessity to fit additional flow-measuring devices. Methods which allow simultaneous measurement and comparison of primary flows are recommended. The use of flow measurement methods using tracers as an appropriate alternative for some applications where it is difficult to remove flow meters for conventional calibration is given in annex K.

Clause 5: Evaluation of tests

This standard gives details of the evaluation of additional guarantees applicable to retrofit projects. Specific rules are also given for unaccounted leakages in retrofit applications.

Clause 6: Correction of test results and comparison with guarantee

The methods of correction defined in the RS are also applicable to this standard but are supplemented by specific rules which apply to the new types of guarantee. For delayed testing, guidance is given on ageing considerations.

This clause also covers the validation of the performance values which are used as a reference for determining improvement guarantee values: an amendment to the guarantee value is acceptable when the pre-retrofit tests have revealed that the actual condition of the turbine undergoing retrofit is different from the specified condition.

The retrofit of the steam turbine, or any part of it, may have consequences on the balance of the plant (feedheaters, condenser, boiler). If the retrofit affects conditions beyond the interface, then the manufacturer may be required to indicate the consequences of the modification on adjacent equipment items.

Clause 7: Measuring uncertainty

This clause of the RS is supplemented by provisions for special cases encountered in retrofit projects in annexes I and J. Since these cases can be diverse, it is recommended that an uncertainty calculation be run as early as possible, preferably before proceeding with the retrofit, so as to be able to define what instrumentation is required for the tests. The examples can be used as reference bases.

Annexes:

In this standard, five new annexes (H to L) have been added to the seven existing ones (A to G) of IEC 60953-2.

Annex H deals with uncertainties for retrofit applications and completes the information given in annex F of IEC 60953-2.

Annex I and J give examples of performance and uncertainty calculations for several retrofit applications, within fossil-fuel and nuclear power plants.

Annex K relates specifically to the tracer technique method of measurement of flow for retrofit applications.

Annex L gives suggestions how to determine, for example, the inter- labyrinth flow of combined HP/IP turbines using the "temperature variation method".

RULES FOR STEAM TURBINE THERMAL ACCEPTANCE TESTS –

Part 3: Thermal performance verification tests of retrofitted steam turbines

1 Scope and object

1.1 Scope

This part of IEC 60953, also called "retrofit code" (RC), establishes a supplementary retrofit code for thermal verification tests of retrofitted steam turbines.

The rules given in this standard follow the guidance given in IEC 60953-2, hereinafter called the RS but contain amendments and supplements regarding guarantees and verification of the guarantees by thermal acceptance tests on retrofitted steam turbines.

General principles for the preparation, performance, evaluation, comparison with guaranteed values and the determination of the measurement uncertainties of verification tests are given in this standard.

This standard is applicable only when the retrofit involves some hardware change in the steam turbine equipment. Conversely, any modification on the cycle or any retrofit of other equipment of the power plant (e.g. boiler, feedwater heaters, etc.) is not covered by this standard.

1.2 Object

The purpose of this standard is to establish appropriate guaranteed parameters, to verify these guarantees and to determine measurement uncertainty.

The guarantees with their provisions should be formulated completely and without contradiction (see 2.4 and 2.5 of IEC 60953-2). The verification 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. Deviations shall be identified and agreement reached between the parties before signing the contract. Such matters are dealt with in the following subclauses:

Clause (subclause)	Paragraph	Remark
Introduction	5 and 7	Specific procedure and guarantee value
1	2	Guarantee definition
2.5	All paragraphs	
2.5.1.1	2	
3.1	1 and 4	
3.2	4	
6.1.1	Last paragraph	
6.8	–	Guarantee comparison
6.9.1	–	Deterioration of performance of retrofitted components

1.4 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60953. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However parties to agreements based on this part of IEC 60953 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

IEC 60953-1, *Rules for steam turbine acceptance tests – Part 1: Method A – High accuracy for large condensing steam turbines*

IEC 60953-2, *Rules for steam turbine thermal acceptance tests – Part 2: Method B – Wide range of accuracy for various types and sizes of turbines*

2 Units, symbols, terms and definitions

2.2.1 Symbols and units for this standard

Quantity	Symbol	Unit	Examples of multiples and submultiples	Other ISO units
Efficiency (general)	η	1		
Wetness correction factor	WCF	1		
Leaving loss (isentropic equivalent)	LL	J/kg	kJ/kg	
Flow-passing-capacity	FPC	m ²		
Valves wide open	VWO			

2.3.1 Subscripts and superscripts for this standard

Quantity	Subscript	Position or definition
Efficiency	cyl	Global or overall cylinder isentropic efficiency (2.4.8.1, 2.4.8.2)
	cyl-dry	Overall cylinder efficiency on a dry basis (2.4.8.2)
	cyl-wet	Overall cylinder efficiency on a wet basis (1.1.1)
	cyl-HP	HP cylinder efficiency (1.1.1)
	cyl-IP	IP cylinder efficiency (1.1.1)
	cyl-LP	LP cylinder efficiency (1.1.1)
Enthalpy	UEEP	Useful energy end-point (2.4.8.2)
	ELEP	Expansion line end-point (1.1.1)
Enthalpy drop	s	Isentropic from cylinder inlet to outlet
	's	Refers to that part of the expansion in the wet region (1.1.1)
Component performance	tp	Steam conditions at terminal point (2.4.8.3)
	in	Steam condition at inlet to component (2.4.8.3)
	out	Steam condition at outlet from component (2.4.8.3)
Mass flow rate ¹⁾	loss	Mass flow balances (5.2.5)
	make-up	Mass flow balances (5.2.5)
¹⁾ Some mass flow rate and enthalpy subscripts are defined in the text itself (e.g. 5.2.5.1).		

2.3.2 Definitions for this standard

For the purpose of this part of IEC 60953-3, the definitions given in IEC 60953-2 and the following definitions apply.

2.3.2.1

turbine retrofit

change of turbine hardware to improve thermal performance

2.3.2.2

retrofit code (RC)

the code presented in this standard, for 'thermal performance verification tests of retrofitted steam turbines'

2.3.2.3

reference standard (RS)

IEC 60953-2

2.3.2.4

absolute guarantee

guarantee on the retrofitted equipment, independent of the performance of the original equipment

2.3.2.5

relative guarantee

guarantee on the improvement due to the retrofitted equipment

2.3.2.6

baseline test

full test conducted before the issue of the retrofit specification, in order to define the reference heat balance of the power plant

NOTE This test is not covered by this standard

2.3.2.7

pre-retrofit test

test performed before the retrofit work in order to define the reference values for relative guarantees

2.3.2.8

post-retrofit test

test associated with pre-retrofit test in order to verify the relative guaranteed values. It uses the same instrumentation as the pre-retrofit test

2.3.2.9

thermal acceptance test

full test conducted according to any national or international standard in order to determine an absolute overall performance guarantee of new plants

NOTE This test is not covered by this standard.

2.3.2.10

absolute post-retrofit test

test after retrofit in order to verify an absolute component or overall guarantee

2.3.2.11

verification tests

all types of tests intended to verify the performances of the retrofitted equipment. They should be either pre-retrofit and post-retrofit tests, absolute post-retrofit tests or full thermal acceptance tests

2.3.2.12

test allowance

agreed contract allowance on the measured and corrected performance value to allow for test uncertainty, ageing and other conditions which may be specific to a particular retrofit project

2.3.2.13

thermal power

heat supply to the cycle from external sources

2.4.8 Component efficiency

This standard recognizes that it is likely that specific components rather than the complete machine will be retrofitted. Therefore, guarantee values relevant to the particular turbine modifications, such as cylinder efficiency and component pressure loss, are sometimes more appropriate. Typical definitions of component performance are given below and examples are presented in annex I.1.

2.4.8.1 Cylinder isentropic efficiency – expansion in superheated region

The cylinder isentropic efficiency gives, as reference, a measurable indication of the bulk efficiency of steam expansion in terms of the actual enthalpy drop compared with the ideal enthalpy drop. When the steam is superheated at inlet (in) and outlet (out), the corresponding enthalpies can be derived directly from pressure and temperature measurements (see figure 1).

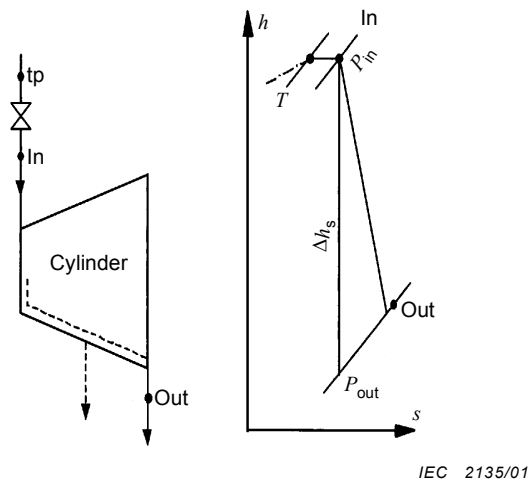


Figure 1 – Isentropic efficiency of the HP cylinder

Cylinder isentropic efficiency: $\eta_{\text{cyl}} = \frac{h_{\text{in}} - h_{\text{out}}}{\Delta h_s}$

The condition at “in” is preferably after the inlet valves to distinguish between valve pressure loss (see 2.4.8.3) and cylinder efficiency. The condition at “out” usually includes returned and mixed ‘balance-piston’ leakage where measurements are taken before the bulk cold reheat steam is routed back to the boiler.

Special care should be paid to the pressure measurements downstream of the inlet valves. Preferably, the pressure should be measured in the inter-connection lines between the valves and the turbine body or, if the turbine has an inlet spiral, at the inlet of the spiral. Pressure measurements in the valve bodies should be avoided. For cases where it is not possible to measure the pressure after the valves the guarantee should be from before valves to turbine exhaust and an agreed pressure drop used through the valve.

Other small complications such as cooling – steam injection and inter-cylinder gland leakage, though usually not included, may, by agreement, be included with an appropriate modification of the efficiency formula.

2.4.8.2 Cylinder isentropic efficiency – expansion involving wet region

For cylinders operating in the wet region, the determination of enthalpy presents a major difficulty and special techniques such as tracers have to be applied. The cylinder isentropic efficiency, η_{cyl} , is defined as above but includes implicit wetness effects.

The efficiency on a dry basis, indicating the aerodynamic quality of the blade path, may, for information purposes, be represented by:

$$\eta_{\text{cyl-dry}} = \eta_{\text{cyl}} / \{(x_{\text{in}} + x_{\text{out}})/2\}.$$

This expression assumes, as is common, that the effect of moisture on section efficiency is 1 % efficiency per 1 % change in moisture content (for example only). The case where the inlet condition is dry and the outlet condition is wet is dealt with in I.1.1.

For LP cylinders, where the leaving loss, LL (which is mainly kinetic energy), is a significant quantity and where the internal steam expansion is partly in the wet region, a number of definitions may apply (see clause I.1 and its footnote). However, the overall global efficiency, which can be deduced from a power balance, is again given by the following (see figure 2):

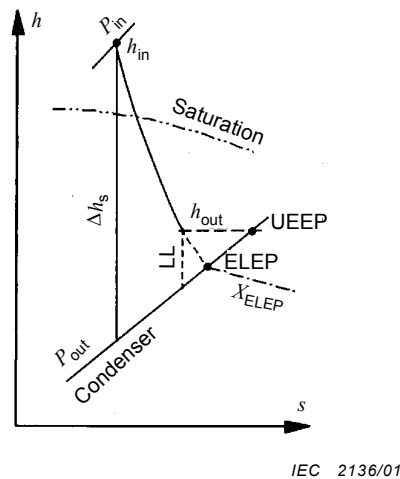


Figure 2 – LP turbine expansion line

$$\text{Cylinder isentropic efficiency } \eta_{\text{cyl}} = \frac{h_{\text{in}} - h_{\text{out}}}{\Delta h_s}$$

where ' h_{out} ' is called UEEP (useful energy end point). This point is in the wet region and is, therefore, usually deduced from a whole cycle power balance calculation. The results of this calculation should be treated with caution, since any undiscovered deficiency in any part of the test cycle may lead to a seriously low deduced value of LP efficiency.

Trial LP expansion lines down to iterative h_{out} values are used in the calculation until:

cylinder internal powers $\Sigma(\text{HP} + \text{IP} + \text{LP})$ – external losses (mechanical, electric, etc.) = generator output

A number of other useful definitions relating particularly to the LP turbine, including wetness and leaving losses, are given in clause I.1 and in 5.2.5.1.

2.4.8.3 Percentage pressure loss in valves and pipes

Pressure losses in transfer components have a significant effect on the overall turbine plant performance. The loss should be quoted for the component in the fully open position and given as a percentage drop compared with the inlet pressure. A typical example is retrofitting the valve system and loop pipes before the HP cylinder, shown in 2.4.8.1, where the pressure falls from p_{tp} , at the terminal point before the valve, to p_{in} , at the measuring point in the cylinder inlet pipes, such that :

$$\text{percentage pressure drop} = \frac{p_{\text{tp}} - p_{\text{in}}}{p_{\text{tp}}} \times \frac{100}{1}$$

2.4.8.4 Flow-passing capacity (FPC) ¹⁾

The increase in output resulting from a cylinder efficiency improvement is usually associated with an unchanged (i.e. constant) flow-passing capacity.

The FPC can be defined as:

$$\text{FPC} = \frac{\dot{m}_{\text{in}}}{\sqrt{p_{\text{in}}/v_{\text{in}}}} \frac{1}{\sqrt{1 - (p_{\text{out}}/p_{\text{in}})^2}}$$

If, alternatively, the FPC is changed instead (or in addition), then the effect on the overall electrical output shall be taken into account by a heat balance calculation. For expansion beyond choked pressure ratio, the above expression simplifies to:

$$\text{FPC} = \frac{\dot{m}_{\text{in}}}{\sqrt{p_{\text{in}}/v_{\text{in}}}}$$

Other methods of calculating FPC can be used by agreement. If the FPC is not as intended then no correction will be allowed for the deviation.

2.5 Guidance on guarantees

In general, the appropriate figures to be used for guarantees are dictated by the ability to verify the actual performance or performance change accurately.

Retrofitting a steam turbine plant usually involves modernization of, at least, one component or cylinder in a complete machine; therefore, it is important to distinguish between the component and the overall performance effects. Additionally, retrofitting the existing machine may be undertaken either by the original equipment manufacturer (OEM) or by other manufacturers. All manufacturers of retrofit equipment are conversant with the absolute efficiency of their new components but it should not be assumed that they will know the performance of the component being replaced or the state of the associated plant. Only the OEM, should be expected to be knowledgeable about the existing equipment and to have confidence in the guarantee as an improvement in performance. The question, therefore, arises as to whether to give absolute or relative performance guarantees.

Since plant purchasers may also favour guarantees of overall plant performance whereas manufacturers prefer to guarantee their individual components, table 1 gives guidance on overall and component guarantees for either absolute or relative situations.

¹⁾ Also called "Swallowing capacity".

Table 1 – Guarantee alternatives

Part of turbine	Dry expansion		Wet expansion	
	Absolute	Relative	Absolute	Relative
Component (η_{cyl} , ΔP)	2.5.1.1 (Recommended)	2.5.2.1 (Recommended)	2.5.1.1 (Discouraged)	2.5.2.1 (Optional)
Overall (heat rate or output)	2.5.1.2 ¹⁾ (Optional)	2.5.2.1 ¹⁾ (Optional) 2.5.2.2 ²⁾ (Discouraged)	2.5.1.2 ¹⁾ (Discouraged) (Except if full steampath for the complete turbine replaced – then "Discouraged" becomes "Recommended")	2.5.2.1 ¹⁾ (Recommended) 2.5.2.2 ³⁾ (Optional)
¹⁾ Depends on acceptance of nominal pre-retrofit overall performance (has to be checked). ²⁾ Less accurate than 2.5.2.1 (Optional). ³⁾ Less accurate than 2.5.2.1 (Recommended).				
NOTE Subclauses indicated in this table refer to the following text.				

The verification of a guarantee on flow-passing-capacity (FPC) depends on the accurate measurement of flows throughout the cycle and, therefore, requires absolute tests.

Considerations of component or overall and absolute or relative performance shall be brought out in the inquiry specification and an agreement shall be reached between parties to the contract.

2.5.1 Absolute guarantees

This RC provides for two types of absolute guarantees and verifications.

2.5.1.1 Direct measurement of absolute performance of replaced component

If the performance is directly measurable, as in the case of cylinders operating entirely in the superheated steam region where cylinder isentropic efficiency can be determined by enthalpy drop tests, then absolute cylinder efficiency is an appropriate figure for guarantee.

The effect of the replaced component on the overall plant performance may then be evaluated, for information purposes, by calculation and this should be agreed upon in the contract. Special care shall be exercised if the component affects the thermodynamic cycle of the plant. Instances of this include different extraction pressures, varied conditions at reheaters and changed swallowing capacities.

There are cases where the replaced component efficiency would have to be determined indirectly from the overall plant performance (e.g. cylinders operating partly in the wet region where enthalpy cannot be determined), with consequent unacceptable loss of accuracy. In such cases, it is recommended that the guarantee be given in terms of the improvement to the overall plant (see 2.5.2).

2.5.1.2 Absolute heat rate after modification

In this case a thermal acceptance test is recommended after modification, according to IEC 60953-1. In appropriate circumstances for small steam turbines also IEC 60953-2 can be permitted. No prior test is made, but previous design data or guarantee tests are used as the

basis to determine the guarantee value including provisions for correction due to cycle or other component performance variations on test, as necessary. Great care is required with the old condition of the associated plant which may hide overall cycle deficiencies and lead, for example, to deduction of an erroneously low level of LP cylinder efficiency. A new baseline test on the complete plant before retrofit can provide clarification on this point.

This alternative can be followed where the modifications are extensive and the plant is subject to thorough inspection. The contractor takes a greater risk in this case and shall satisfy himself that the basis is sound.

2.5.2 Relative tests of performance improvement

The code provides for two types of relative guarantees, particularly relevant to retrofit cases.

2.5.2.1 Improvement tests taking advantage of the same instrumentation

The value to the purchaser of carrying out a performance modernization is reflected directly in the actual improvement achieved (rather than in an absolute level). Therefore verification of guaranteed improvement can be based on pre-retrofit and post-retrofit test, together with the convenient use of the same measuring instruments applied in general accordance with the code. This can apply to both component and overall heat rate improvements.

The guaranteed figure of improvement is based on sound knowledge of the existing plant. Guarantees given on the basis of nominal performance of the existing plant (e.g. original heat balance diagram or original performance tests) are subject to confirmation and amendment as necessary, depending on the results of analysis of the pre-retrofit tests.

To use tests on the overall plant for the replaced component(s), the remainder of the plant should ideally be left in the same condition, from the pre-retrofit to post-retrofit test period. The testing, if done simply and without delay, has the advantage of being less costly, whilst the uncertainty in the improvement result will be reduced due to the use of the same instruments. However the quality of instrumentation shall be carefully selected to be commensurate with clear demonstration of the level of improvement expected.

The plant operating condition, e.g. thermal power, VWO or generator output, before and after, needs to be similar in order to reduce cycle corrections. For example, consider an LP retrofit of a nuclear unit; keeping the thermal reactor power and the valve setting constant for both pre-retrofit and post-retrofit tests simplifies the correction procedure and usually allows the generator power to be the measure of heat rate improvement.

2.5.2.2 Improvement determined from full tests before and after modification

In addition to the verification of performance improvement, the plant purchaser sometimes requires to establish the absolute performance of the modernized unit. This may be achieved by a combination of a full-code pre-retrofit test with a full-code post-retrofit test. This is the most comprehensive method and the operator can benefit from the resulting detailed knowledge of the plant's performance. However there is a possible drawback. If the verification full test is seriously delayed, this requires the replacement of instrumentation with a consequent loss of accuracy. The cost and time to carry out the tests may also be prohibitive in some cases, especially if high accuracy is required to determine a small guaranteed change.

3 Guiding principles

3.1 Advance planning for test

The parties to verification tests of retrofit projects under this standard shall reach an agreement concerning the testing procedure, the interpretation of guarantees, the number, location and arrangement of measuring points and devices, valves and piping arrangements as well as measurement accuracy, with due consideration given to the cost of the verification tests.

In planning the retrofit tests emphasis should be placed on the possibly poor condition of old plants especially with respect to leakages which may have developed over time. Preparations need to take this into account.

The instrumentation shall be selected in such a way that component performance, as defined in the contract, can be verified.

Consideration shall be given to the possible requirements for additional instrumentation tapping points over and above that supplied in the original construction contract. Since the nature of the plant retrofit may be limited to a single component within the power plant cycle, additional measurement points may be required to assess the component performance. Alternatively, corrections to the overall plant performance may be required for changes in other items of the plant which have an impact on the performance of the retrofit component but are not attributable to the retrofit contract (see clause 1.2). However, changes in the process directly related to the exchanged parts should not be corrected for.

The following is a list of typical items upon which an agreement should be reached as early as possible to give the maximum opportunity to make any instrument or plant changes that may be required:

Items a) through g) of 3.1 and a) through j) of 3.2 of the RS apply.

Special care shall be given to the instrumentation calibration requirements.

3.3.1 Time for verification tests

If the verification test is limited to a post-retrofit test, it shall be conducted as soon as possible after the first synchronization of the unit and preferably within eight weeks.

If the verification of performance is based upon comparative measurements before and after the retrofit, the pre-retrofit test shall preferably be conducted as late as possible before the retrofit outage but no sooner than eight weeks. The post-retrofit test shall be conducted as soon as possible after the first synchronization of the unit after the retrofit and preferably within eight weeks.

It is also important to keep changes in the operation parameters between pre- and post-retrofit tests at a minimum in order to limit corrections (see table 2). Situations may occur where accuracy and consistency in the tests are of greater importance than the timing.

Table 2 – Maximum deviations and fluctuations ¹⁾ in operating conditions from specified and relative datums

Variable	A Maximum permissible deviation of average of test from that specified	B ⁶⁾ Maximum permissible deviation of average of post-retrofit test from pre-retrofit test
Initial steam pressure	$\pm 5 \% ^{2)}$	$\pm 2,5 \% ^{2)}$
Initial steam temperature	$\pm 15 \text{ K} ^{2)}$	$\pm 7,5 \text{ K} ^{2)}$
Dryness fraction	$\pm 0,005 \%$	$\pm 0,0025 \%$
Extraction pressure (regulated)	$\pm 5 \% ^{2)}$	$\pm 2,5 \% ^{2)}$
Exhaust pressure:		
- for feed heating	See ⁴⁾	See ⁴⁾
- for back pressure turbines	$\pm 5 \% ^{2)}$	$\pm 2,5 \% ^{2)}$
- for condensing turbines	$\pm 10 \% ^{5) 7)}$	$\pm 5 \% ^{5) 7)}$ or 0,3 kPa
Extraction flow rate	$\pm 10 \%$	$\pm 5 \%$
Reheat temperature	$\pm 15 \text{ K}$	$\pm 7,5 \text{ K}$
Isentropic enthalpy drop	$\pm 7 \%$	$\pm 3,5 \%$
Initial steam flow	$\pm 5 \%$	$\pm 2,5 \%$
Cooling water flow	$\pm 15 \%$	$\pm 7,5 \%$
Cooling water inlet temperature	$\pm 5 \text{ K} ^{8)}$	$\pm 2,0 \text{ K} ^{8)}$
Final feed water temperature	$\pm 10 \text{ K}$	$\pm 5 \text{ K}$
Rotational speed	$\pm 2 \% ^{3)}$	$\pm 2 \% ^{3)}$
¹⁾ The maximum fluctuation of the variable permitted during each test should not be greater than half the permissible deviation given in table 2, column A except for the output which may vary $\pm 3 \%$. ²⁾ All these items may not lead to deviation of enthalpy drop by more than $\pm 7 \%$. ³⁾ If permitted by the technical guarantee of the turbine. ⁴⁾ 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 should then be reached on the course to be followed. ⁵⁾ If the test exhaust pressure deviates beyond the permissible limit, the exhaust pressure correction should be derived from tests or calculation by agreement between the parties. ⁶⁾ Column B represents the maximum deviation for those variables which are required to be consistent between the pre- and post-retrofit tests. For the post-retrofit test conditions, which are expected to change as a result of the plant overhaul, column A applies. ⁷⁾ If condenser is not included in guarantee. ⁸⁾ If condenser is included in guarantee.		

One example might be the power output of a nuclear power plant being sensitive to variations of the exhaust pressure. In countries with seasonally varying cooling water conditions, more accurate results may be achieved by keeping deviations in the exhaust pressure small rather than reaching short elapsed time between pre- and post-retrofit tests.

3.4.4.4 Isolation of the cycle

Due to the generally poor condition of valves, particularly in older plants, efforts should be made to assess the leakage at a suitable period of time prior to the test. Particular attention should be focused on primary flow device by-passes, start up by-passes, heater drains, main steam drains, etc., and any auxiliary steam supplies into or out of the cycle.

Where unresolved isolation problems exist on the pre-retrofit test, which alter the guarantee cycle, the test may proceed by agreement between the parties, by ensuring that the same isolation is applied to the verification tests. Additional corrections may need to be applied to the performance evaluation to take account of the effects of cycle changes from that guaranteed. Where possible, suitable corrections should be identified and agreed prior to the post-retrofit test.

3.6.1.1 Fossil plant

Wherever possible, in order to ensure consistency of conditions between pre- and post-retrofit tests, tests shall be conducted with the valves in a wide open condition, or at a valve point for nozzle governed machines. Tests under other specific conditions may be conducted, where mutually agreed.

3.6.1.2 Nuclear plant

Where the thermal power of the steam generator is limited, for example in a nuclear installation, it is preferable to conduct the pre- and post-retrofit tests at constant thermal power. In this way, the net improvement in cycle performance will be indicated by a change in the generated output.

4 Measuring techniques and measuring instruments

4.1.6 Consistency of pre- and post-retrofit tests

If guarantees are made on the basis of relative performance where verification is demonstrated on the basis of pre- and post-retrofit tests, carried out without delay, the repeatability of each test series is vital and best accuracy of the instrumentation may become of secondary importance. The fundamental basis of such a procedure requires replication of the instrumentation and data acquisition system in each test series so that the systematic errors are virtually eliminated. It is therefore required that as many instruments as possible be left installed to reduce the relative error. This applies particularly to the primary flow measurement device. It shall be mutually agreed when to effect calibration (before and/or after the tests). For relative testing the calibration of the primary flow measurements is normally not considered.

Consistency may also be achieved by the use of sufficient duplication of primary instruments to cover for instrument failures. The impact of such a failure in a group of duplicate instruments shall be considered by calculating a weighted mean, based upon the scatter observed in the pre-retrofit test data. Alternatively, if a new instrument is introduced to replace a failure, due consideration shall be given to the assessment of the test uncertainty due to the increased bias error.

4.2.8 Determination of electrical power of pre- and post-retrofit tests

If the required accuracy of a relative verification test allows it, by agreement between the parties to the test, permanent unit fiscal power metering may be used. The permanent instrumentation indication shall have sufficient resolution and the metering system shall have demonstrated repeatability.

When using digital test power analysers, corrections for the burden of current and voltage transformers need not be applied if the circuit load is the same in pre- and post-retrofit tests. Due consideration, however, shall be given to the circuit load, particularly where high impedance power analysers are connected to dedicated test transformers, a suitable load may be added to the circuit.

4.3.1 Determination of flows to be measured

For retrofit verification tests, the flows to be measured can be divided into two categories.

- a) Primary flows: Flows which are directly proportional to the guarantee values and which shall be measured with the corresponding degree of precision (see 7.4 of IEC 60953-2).

The adequacy of existing flow measurement device should be assessed in advance of any test, and improved or modified devices installed if necessary.

In some cases of old plants, it is possible to check the errors in the primary flow measurement by additional flow measurements in two or more different locations. However, the primary flow measurement takes precedence in the event of discrepancy.

- b) 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 turbine initial steam and reheat steam flows. Secondary flows shall be measured where their impact is significant and it is practical to measure. Alternatively, the flows may be calculated by heat balance or from design values.

4.3.3.1 Location of an additional primary flow device

By agreement between the parties to the test, a suitable flow device may be added in the high pressure feedwater line after the final feedwater heater. This would give greater accuracy and confidence in the verification. Design details of a high pressure throat tapped nozzle are given in annex B of IEC 60953-2. An example with flow metering at both deaerator inlet and final feedwater is given in annex I.

4.3.4.1 Differential pressure measurements for pre- and post-retrofit tests

Where repeatability of test series is required, the use of electronic pressure transmitters is recommended. They shall have demonstrated long-term repeatability and be of suitable accuracy. To further reduce measurement uncertainty it is suggested that duplicate transmitters be fitted to each pair of device tapings.

4.4.5.1 Calibration of primary flow differential pressure transmitters

When the primary flow device is located in the low pressure part of the feed water system, the transmitter may be calibrated with the low pressure port open to atmosphere and by simultaneously applying a high pressure source to the high pressure side of the device. The transmitter, however, shall be demonstrated as being insensitive to small increases in line static pressure.

When the location of the primary flow device is such that the working pressure of the transmitter is significantly higher than atmospheric pressure, calibration shall be conducted at the working pressure, unless the transmitters have been demonstrated as being independent of high line static pressure. This technique can be achieved by the use of a suitable dual piston dead weight tester.

4.7.7 Use of tracer techniques in retrofit applications

Sometimes the primary and/or secondary flows cannot be measured accurately enough, due to missing or inaccurate flow devices. In such cases, the tracer technique offers a practical alternative (see annex K).

5 Evaluation of tests

5.1 Preparation of evaluation

The evaluation of test results involves a chain of activities all of which contribute to the accuracy of the final result. In the retrofit situation where an improvement has been guaranteed, the guarantee value is determined as being the difference between pre-retrofit test and post-retrofit test measurements. The measurements for both the pre-retrofit test and the post-retrofit test shall be used to calculate the improvement of the turbine performance, due consideration being given to all influencing factors. Keeping the pre- and post-retrofit test operational conditions as close as possible reduces correction uncertainties and simplifies the evaluation. Among the most important factors are cycle isolation and leakage. The measuring uncertainty of the test results shall also be determined (see clause 7 of the RS and annexes H and J of this standard).

From the instrument readings taken during the test, results are calculated in accordance with 2.4 of the RS.

Prior to evaluating the measurements, a time interval which shall constitute the official test period shall be selected from the overall period during which test readings have been taken. This interval shall be equal to at least the period laid down in 3.8.3 of the RS. During this period, for absolute tests, the provisions of 3.8.1 and 3.8.2 of the RS shall be satisfied. For relative tests, table 2 and 3.3.1 of this standard shall apply. Readings of all instruments, including integrating instruments, and corresponding time measurements shall be available for the start and the end of the selected test period (see 5.2.1 of the RS).

In the event of a disturbance occurring during the test, all readings during the disturbed period may be discarded. In doing so, however, evidence shall be provided that, before and after the disturbance, essentially the same steady state conditions existed. If the periods before and after the disturbance are evaluated separately, then the uncertainty of the test results shall not be divided by $\sqrt{n}$, n being the number of test intervals. However, a test may be divided into several test intervals which shall be evaluated separately. However, tests can only be declared as separate if the cycle isolation has been broken and re-established between the tests.

In the event of temporary failure of a measuring instrument during the test, the lost instrument readings may, by mutual agreement, be either construed from other suitable instrument readings or, provided plant operating conditions are adequately stable, they can be replaced by the mean of the instrument readings prior to the start and after the end of the instrument failure. For example the live steam temperature ahead of the turbine can be calculated from the live steam temperature at the boiler outlet, on the basis of the more or less constant difference between the values (see 3.8.7 of the RS).

5.2.2 Correction and conversion of averaged readings

NOTE Replace the existing item d) of RS by the following text.

d) any additional influences (e.g. water legs) (see 4.4.7 in the RS). The importance of these corrections is emphasised at lower pressure levels.

5.2.3.4 Leakages

Leakages shall, as far as is practicable, be identified and eliminated before the test. If any identified leakages cannot be eliminated, their flow rates shall be measured or estimated. These estimates shall be included in the main or secondary flow rate calculations. Unidentified leakages, which result in a loss of working fluid, shall also have their flow rate(s) and position(s) estimated and included, if considered necessary, in the main or secondary flow rate calculations.

The unaccounted leakage during the test(s), expressed in per cent of full load main steam flow, shall not exceed

0,6 %

In addition, the difference between the unaccounted leakages of pre- and post-retrofit tests shall not exceed

0,2 %

of the full load main steam flow, unless otherwise agreed. It is recommended that a preliminary test be performed prior to the pre-retrofit test to determine the actual unaccounted leakages.

Leakages shall, if possible, be estimated and allowed for in the mass flow balance.

Unaccounted leakages shall be apportioned in accordance with table 3. The figures given in table 3 may be changed, if mutually agreed.

Table 3 – Apportionment of unaccounted leakages

Percentage of non-localized leakage to be attributed to	Conventional power station	Nuclear power station
Inlet steam piping and steam generator (including by-pass station)	60 %	30 %
Steam turbine	40 %	70 %

It may be assumed that, of the leakage attributed to a steam turbine with reheat, half occurs before the reheat stage and half after (the second half equally occurring in hot reheat and crossover).

5.2.4 Thermodynamic properties of steam and water

The source of steam properties used for guarantees and the computation of test results shall be agreed by the purchaser and the supplier, and stated in the contract.

It is recommended that the properties should be obtained from the International Association for the Properties of Water and Steam Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97) or tables and charts derived from IAPWS-IF97. IAPWS-IF97 has superseded the 1967 IFC Formulation for Industrial Use.

For any comparison with previous results, it is necessary to use properties from the same source to obtain meaningful information.

5.2.5 Calculation of test results

When retrofitting power plants, a large number of components may be involved, e.g. valves, pumps, heat exchangers, etc. However, the most important components considered in this standard are the turbine parts. Depending on the specific retrofitted turbine component HP, IP or LP and the guaranteed value, the scope of instrumentation will be different (see clause 4). Therefore, this standard does not require specific locations for measuring flows. Nevertheless, the number of flow measurements shall be consistent with the guarantee and required accuracy (see annex J).

The determination of isentropic efficiencies of HP and IP turbines (non-wet cylinders) does not involve any flow measurements but only temperature and pressure measurements.

The determination of heat rate and LP turbine efficiency is more complicated and always involves flow measurements. The evaluation procedure can be divided into two steps:

- flow balances of defined reference volumes;
- energy balances of defined reference volumes.

It is often possible to establish a particular mass flow (e.g. live steam flow) by several methods, by means of mass flow balances over different parts of the system. Additionally, important mass flows (e.g. feedwater flow) can be determined from a number of independently measured mass flows at different locations of the cycle. Using equations (H.7) to (H.10), the weighted mean value and the uncertainty of the feedwater flow can be determined.

The agreement of flow balances is a necessary pre-condition to the calculation of energy balances. In particular when two flow measurements are used (see figure J.1) i.e.

- feedwater directly measured before the boiler;
- feedwater indirectly determined from the main condensate flow measurements and heat balances.

The cause has to be investigated if the difference of the feedwater flows are greater than 0,5 %.

To set up mass flow balance equations, certain auxiliary flows shall be measured and also any variation in the contents of tanks and other storage spaces in the steam/water circuit.

The algebraic sum of the level drops (kg/s) of tanks and other storage spaces in the circuit, during the test period, shall be considered to be equal to the losses from the circuit, provided that no make-up water is fed into the circuit during the tests and no working medium is deliberately removed from the circuit. This yields

$$\dot{m}_{\text{loss}} = \sum_{i=1}^N \dot{m}_i \quad (1)$$

where

$\dot{m}_{\text{loss}}$ is the sum of flow losses;

$\dot{m}_i$ is the level drop (kg/s) of tank i .

If make-up water ($\dot{m}_{\text{make-up}}$) is fed to the circuit, equation (1) becomes equation (2):

$$\dot{m}_{\text{loss}} = \sum_{i=1}^N \dot{m}_i + \dot{m}_{\text{make-up}} \quad (2)$$

The test results provide the basis for comparison with the guarantees. They depend on the test boundary conditions (live steam condition, reheat steam condition, turbine exhaust pressure, etc.) under which they were determined. Before the test results are assessed and used for guarantee comparison, it is essential that they are satisfactorily corrected to guarantee conditions (see clause 6).

The thermal and/or thermodynamic efficiency, the initial steam flow capacity and the output shall be calculated in accordance with the definition of the guarantee values (see 2.4 of the RS).

A definitive value shall be established for each variable as described in 5.1 and 5.2 of the RS. This value shall be used exclusively in further evaluation.

For the determination of measuring uncertainty (see annex H).

5.2.5.1 LP turbine efficiencies

Unlike most HP and IP turbine efficiency, the LP turbine efficiency cannot be determined by direct pressure and temperature measurements because of the wet expansion line end point.

The approach to solve the problem is to use a combination of flow and heat balances by which the shaft load of the HP and IP turbines can be determined. The internal load of the LP turbine is

$$P_{\text{LP}} = P_i - P_{\text{HP}} - P_{\text{IP}} \quad (3)$$

and

$$\dot{m}_{\text{in}} = \sum_{i=1}^N \dot{m}_{ei} + \dot{m}_4 \quad (4)$$

$$P_{\text{LP}} = \sum_{i=1}^N [\dot{m}_{ei} \times \Delta h_{ei}] + \dot{m}_4 \times \Delta h_{\text{UEEP}} \quad (5)$$

where

P_i is the internal power produced by the expansion of the steam;

P_{HP} is the power of the HP turbine;

P_{IP} is the power of the IP turbine;

P_{LP} is the power of the LP turbine;

$\dot{m}_{in}$ is the mass flow at LP inlet;

h_{in} is the enthalpy at LP inlet;

$\dot{m}_{ei}$ is the mass flow at extraction i ;

Δh_{ei} = $h_{in} - h_{ei}$ is the enthalpy drop from LP inlet to extraction i ;

N is the number of extractions;

$\dot{m}_4$ is the exhaust flow;

h_{UEEP} is the useful energy end point (UEEP);

$\Delta h_{UEEP} = h_{in} - h_{UEEP}$ is the enthalpy drop from LP inlet to exhaust.

Two isentropic efficiencies of the LP turbine may be defined as:

$$\eta_{UEEP} = \frac{h_{in} - h_{UEEP}}{\Delta h_s} \quad (6)$$

$$\eta_{ELEP} = \frac{h_{in} - h_{ELEP}}{\Delta h_s} \quad (7)$$

$$h_{UEEP} - h_{ELEP} \text{ is the exhaust loss (non recoverable)} \quad (8)$$

where

h_{ELEP} is the enthalpy of the expansion line end point (ELEP).

The application of equation (5) requires an iterative procedure by which an assumed isentropic efficiency is changed until the calculated internal load agrees with that of equation (5). During the procedure it is essential that the measured extraction enthalpies are considered. The enthalpy of the lowest extractions cannot be directly determined (wet region). Therefore they have to be included in the iteration loop. This procedure requires extensive instrumentation (see figure 2 of the RS) to give acceptable accuracy. See also 2.4.8.

The result of equation (5) is strongly affected by the steam/water cycle. Therefore, steam turbines in cross-compound having a separately driven LP generator result in a simplification. Conversely, steam turbines designed with combined HP/IP turbines lead to a complication due to the existence of internal leakage flows between the HP and IP turbines which cannot be measured directly, but can result in significant inaccuracies in calculated HP and IP internal powers. In most cases the temperature variation method offers a possibility to determine internal leakages (see annex L).