

Determination of the prototype performance from model acceptance tests of hydraulic machines with consideration of scale effects

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National foreword

This British Standard has been prepared under the direction of the Engineering Sector Board and is the English language version of EN 60995:1994

Determination of the prototype performance from model acceptance tests of hydraulic machines with consideration of scale effects, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 995:1991 published by the International Electrotechnical Commission (IEC) with one common modification. The common modification is indicated by the presence of a sideline in the margin.

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 Publications 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 request.

The terms and definitions contained in the present publication have either been taken from the IEV or have been 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 60995 was produced as a result of international discussion in which the United Kingdom took an active part.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 32, 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.

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Descriptors: Hydraulic turbomachine, model test, scale effect

English version

Determination of the prototype performance from model acceptance tests of hydraulic machines with consideration of scale effects

(IEC 995:1991, modified)

Détermination des performances industrielles des machines hydrauliques à partir des essais sur modèle en considérant les effets d'échelle
(CEI 995:1991, modifiée)

Bestimmung des Leistungsverhaltens von Prototypen hydraulischer Strömungsmaschinen aus Modellabnahmemessungen unter Berücksichtigung von Maßstabseinflüssen
(IEC 995:1991, modifiziert)

This European Standard was approved by CENELEC on 1993-12-08. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

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

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Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 995:1991 could be accepted without textual changes, has shown that some common modifications were necessary for the acceptance as European Standard.

The reference document, together with a common modification prepared by the CENELEC French National Committee, was submitted to the CENELEC members for formal vote.

The text of the draft was approved by CENELEC as EN 60995 on 8 December 1993.

The following dates were fixed:

- latest date of publication of an identical national standard (dop) 1994-12-01
- latest date of withdrawal of conflicting national standards (dow) 1994-12-01

For products which have complied with the relevant national standard before 1994-12-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 1999-12-01.

Annexes designated “normative” are part of the body of the standard. Annexes designated informative are given only for information. In this standard, Appendix A, Appendix B and Appendix C are informative and Annex ZA is normative.

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Section 1. General

1 Introduction

1.1 General remarks

Advances in the technology of hydraulic turbomachines used for hydroelectric power plants indicate the necessity of revising existing codes. The advance in knowledge of scale effects originates from work done by research institutions, manufacturers and a Working Group “Scale effect on performance and efficiency” of the International Association of Hydraulic Research (IAHR).

Scale effects are influenced mainly by Reynolds number but also by other factors partly unknown and therefore rigorous calculation is complicated (see Appendix C and note 2 to Clause 7) or even not yet possible.

The method of calculating prototype efficiencies, as given in this standard, is supported by experimental and theoretical research on flow analysis and has been simplified for practical reasons and agreed as a convention.

The method is based on the present state of knowledge of the scale-up in efficiency from model to homologous prototype.

The application of the method leads to consistent results without ambiguity.

1.2 Basic statements and assumptions

The scale-up of the hydraulic efficiency is based on the dependence of friction losses on Reynolds number Re . Efficiency scale-up formulae based on the ratio of diameter only are therefore eliminated. The exponent of the ratio Re_{uM}/Re_{uP} has been chosen as 0,16.

The ratio of relative scalable losses to total relative losses (loss distribution coefficient V) is referred to a reference Reynolds number and has been agreed on for the different types of machines (see Table I in Clause 7).

The V -coefficients (see Sub-Clause 4.19 and Clause 7) are derived:

- a) from tests at different Reynolds numbers on models with hydraulically smooth surfaces.
- b) from comparison of efficiency tests on prototypes having a surface roughness according to Amendment No. 1 to IEC Publication 193 and to Publication 497 with tests on homologous models. The surface roughness as required by these Publications does not necessarily yield hydraulically smooth flow conditions (see References [1] to [5])¹⁾.

The applied theory is based on hydraulically smooth surfaces. Formulae including roughness corrections are not applied²⁾.

In order to get results without ambiguity it is for contractual purposes conventionally agreed to omit the uncertainty regarding the defined V -values.

The efficiency increase shall be calculated for the optimum point of model efficiencies and shall be applied within the whole range of guaranteed efficiencies.

The hydraulic efficiency at the optimum point used for calculation of efficiency increase shall not be affected by cavitation phenomena.

As long as the geometric similarity of labyrinth seal clearances is within the limits specified in IEC Publication 497 and in Amendment No. 1 to IEC Publication 193, the scale-up of the hydraulic efficiency is not influenced by clearance effects.

Shifting effects on discharge versus specific hydraulic energy between model and prototype are not taken into account.

The mechanical power losses have to be considered separately, see Figure 3.

The scale-up formula is not applicable to impulse turbines (Pelton), see note 2 to Table I in Clause 7.

For further explanations see Clause A.1 of Appendix A.

¹⁾ The figures in square brackets refer to the references given in Appendix C.

²⁾ Although various procedures on how to consider the influence of surface roughness on efficiency scaling have been published (see References [1] to [5]), it is presently not possible to agree on such a formula or procedure.

2 Object and scope

This standard supplements IEC Publications 193 (and its Amendment No. 1), 193 A and 497, which are concerned with testing homologous models of hydraulic turbomachines as listed in Table I of Clause 7 and with the use of model results for predicting prototype performance i.e. discharge, specific hydraulic energy (head), power and efficiency.

NOTE For definitions of specific hydraulic energy and head see Sub-clauses 4.12 and 4.13.

Since the method and the procedure for calculating the increase of hydraulic efficiency have been modified in this standard, the contents of the following chapters in IEC Publications 193 and 497 are to be replaced:

In IEC Publication 193:

- Sub-clause 2.2.2 of Chapter III
- Sub-clause 1.1 and Clause 6 of Chapter VI.

In IEC Publication 497:

- Sub-clause 11.3 of Chapter III
- Clause 25 of Chapter VI
- Sub-clause 25.1 of Chapter VI
- Clause 30 of Chapter VI.

Furthermore, Table B.1, Table B.2 and Table B.3 in Appendix B replace Tables I and II in IEC Publication 193 and Tables IA, II and IV in IEC Publication 497.

All other chapters in IEC Publications 193 (and its Amendment No. 1), 193 A, and 497 remain unchanged and are still valid, except some modifications on terms, symbols and units, see Section 2 of this publication.

This standard applies to machines with unit power greater than 5 MW or with reference diameter greater than 3 m. Although the complexity of the procedure involved is not generally justified for machines with smaller power and size, nevertheless this standard may be used for such machines by agreement between purchaser and supplier.

Section 2. Terms, symbols and definitions

3 General

The International System of Units (SI) has been used throughout this standard³⁾. All terms are given in SI Base Units or derived coherent units (for example N instead of $\text{kg} \cdot \text{m} \cdot \text{s}^{-2}$). The equations are only valid using these units.

Any other system of units may be used but only if agreed to in writing by the contracting parties.

4 List of terms

The terms, definitions, symbols, units and subscripts correspond to those listed (in more details) in IEC Publication 41 on field acceptance tests.

SUBSCRIPTS

Term	Symbol
prototype	P
model	M
value referred to a constant Reynolds number	M^3
high pressure reference section (see Sub-clause 4.6)	1
low pressure reference section (see Sub-clause 4.7)	2
hydraulic	h
mechanical	m
reference	ref
optimum (best efficiency point)	opt
non-scalable (independent of Re_u)	ns
The terms “high pressure” and “low pressure” define the two sides of the machine irrespective of the flow direction and therefore are independent of the mode of operation of the machine (see Figure 2).	

³⁾ In IEC Publication 193, the $\text{kg} \cdot \text{m} \cdot \text{s}$ system is used.
In IEC Publication 497, the SI system is principally applied.

Sub-clause	Term	Definition	Symbol	Unit
4.1	Acceleration due to gravity	Local value of g as a function of altitude and latitude (see Appendix B, Table B.1).	g	$\text{m} \cdot \text{s}^{-2}$
4.2	Density	Mass per unit volume. Values for water as a function of pressure and temperature (see Appendix B, Table B.2). In this standard ρ is used instead of ρ_w .	ρ ρ_w	$\text{kg} \cdot \text{m}^{-3}$ $\text{kg} \cdot \text{m}^{-3}$
4.3	Kinematic viscosity	Dynamic viscosity of the fluid divided by its density. Values for water as a function of temperature (see Appendix B, Table B.3).	ν	$\text{m}^2 \cdot \text{s}^{-1}$
4.4	Reference diameter	Reference diameter of the hydraulic machine (see Figure 1).	D	m
4.5	Absolute pressure	The static pressure of the water measured with reference to a perfect vacuum.	p_{abs}	Pa
4.6	High pressure reference section	The high pressure section of the machine to which the performance guarantees refer (see Figure 2).	1	
4.7	Low pressure reference section	The low pressure section of the machine to which the performance guarantees refer (see Figure 2).	2	
4.8	Discharge (Volume flow rate)	Volume of water per unit time flowing through any section in the system.	Q	$\text{m}^3 \cdot \text{s}^{-1}$
4.9	Mass flow rate	Mass of water flowing through any section of the system per unit time. Both ρ and Q must be determined at the same section and at the conditions existing in that section. NOTE The mass flow rate is constant between two sections if no water is added or removed.	$(\rho \cdot Q)$	$\text{kg} \cdot \text{s}^{-1}$
4.10	Mean velocity	Discharge divided by the area.	v	$\text{m} \cdot \text{s}^{-1}$
4.11	Level	Elevation of a point in the system above the specified reference datum (usually mean sea level).	z	m