BS EN IEC 60193:2019

BSI Standards Publication

Hydraulic turbines, storage pumps and pump-turbines - Model acceptance tests

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National foreword

This British Standard is the UK implementation of EN IEC 60193:2019. It is identical to IEC 60193:2019. It supersedes BS EN 60193:1999, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/15, Hydraulic turbines.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Hydraulische Turbinen, Speicherpumpen und Pumpturbinen - Modellabnahmeprüfungen (IEC 60193:2019)

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European foreword

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- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2020-02-29
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2022-05-30

This document supersedes EN 60193:1999.

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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60041:1991	NOTE	Harmonized as EN 60041:1994
IEC 60609-1:2004	NOTE	Harmonized as EN 60609-1:2005 (not modified)
IEC 60609-2:1997	NOTE	Harmonized as EN 60609-2:1999 (not modified)
IEC 60994:1991	NOTE	Harmonized as EN 60994:1992 (not modified)
ISO 4006:1991	NOTE	Harmonized as EN 24006:1993 (not modified)
ISO 4373:2008	NOTE	Harmonized as EN ISO 4373:2008 (not modified)
ISO 5167-1:2003	NOTE	Harmonized as EN ISO 5167-1:2003 (not modified)
ISO 20456:2017	NOTE	Harmonized as EN ISO 20456 (not modified)[1]

[1] Under preparation. Stage at the time of publication: prEN ISO 20456.

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 62097	2009	Hydraulic machines, radial and axial - Performance conversion method from model to prototype	EN 62097	2009
ISO 2186	2007	Fluid flow in closed conduits - Connections for pressure signal transmissions between primary and secondary elements	-	-
ISO 2533	1975	Standard Atmosphere	-	-
ISO 4185	-	Measurement of liquid flow in closed conduits - Weighing method	EN 24185	1993
-	-		+ AC	1993
ISO 4287	1997	Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters	EN ISO 4287	1998
ISO 8316	-	Measurement of liquid flow in closed conduits - Method by collection of the liquid in a volumetric tank	EN ISO 8316	1995

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HYDRAULIC TURBINES, STORAGE PUMPS AND PUMP-TURBINES – MODEL ACCEPTANCE TESTS

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International Standard IEC 60193 has been prepared by IEC technical committee 4: Hydraulic turbines.

This third edition cancels and replaces the second edition published in 1999. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) update to methods/measuring tools currently used for checking dimensions on both model and prototype;
b) update to requirements of accuracy in the dimensional check procedure as a result of new technology;

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c) merging of tables/sections with redundant information in dimension check in 5.2;
d) update to methods of measuring discharge;
e) update to pressure fluctuation methods and terminology;
f) specification of measuring times for accurate pressure fluctuation analyses in the model;
g) redefine definition for the transposition of pressure fluctuations to prototype;
h) update to surface waviness requirements in prototype;
i) redefining methods/references in clause on cavitation nuclei content (5.7.3.2.2);
j) update to 7.3 and review of methods on radial thrust measurements;
k) update to 7.4 (Hydraulic loads on control components);
l) update and develop methodology in 7.5 for testing in the extended operating range;
m) update to 7.6 concerning index testing;
n) update to methods for measuring roughness;
o) updates to references;
p) updates to figures;
q) revision of sigma definition;
r) reference to new method of transposition in accordance with IEC 62097.

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

FDIS	Report on voting
4/371/FDIS	4/373/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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HYDRAULIC TURBINES, STORAGE PUMPS AND PUMP-TURBINES – MODEL ACCEPTANCE TESTS

1 Scope

This document applies to laboratory models of any type of impulse or reaction hydraulic turbine, storage pump or pump-turbine.

This document applies to models of prototype machines either with unit power greater than 5 MW or with reference diameter greater than 3 m. Full application of the procedures herein prescribed is not generally justified for machines with smaller power and size. Nevertheless, this document may be used for such machines by agreement between the purchaser and the supplier.

In this document, the term "turbine" includes a pump-turbine operating as a turbine and the term "pump" includes a pump-turbine operating as a pump.

This document excludes all matters of purely commercial interest, except those inextricably bound up with the conduct of the tests.

This document is concerned with neither the structural details of the machines nor the mechanical properties of their components, so long as these do not affect model performance or the relationship between model and prototype performances.

This document covers the arrangements for model acceptance tests to be performed on hydraulic turbines, storage pumps and pump-turbines to determine if the main hydraulic performance contract guarantees (see 4.2) have been satisfied.

It contains the rules governing test conduct and prescribes measures to be taken if any phase of the tests is disputed.

The main objectives of this document are:

– to define the terms and quantities used;
– to specify methods of testing and of measuring the quantities involved, in order to ascertain the hydraulic performance of the model;
– to specify the methods of computation of results and of comparison with guarantees;
– to determine if the contract guarantees that fall within the scope of this document have been fulfilled;
– to define the extent, content and structure of the final report.

The guarantees can be given in one of the following ways:

– guarantees for prototype hydraulic performance, computed from model test results considering scale effects;
– guarantees for model hydraulic performance.

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Moreover, additional performance data (see 4.4) can be needed for the design or the operation of the prototype of the hydraulic machine. Contrary to the requirements of Clauses 4 to 6 related to main hydraulic performance, the information of these additional data given in Clause 7 is considered only as recommendation or guidance to the user (see 7.1).

It is particularly recommended that model acceptance tests be performed if the expected field conditions for acceptance tests (see IEC 60041:1991) would not allow the verification of guarantees given for the prototype machine.

A transposition method taking into account the model and prototype wall surface roughness for the performance conversion on pump-turbines, Francis turbines, and axial machines is described in IEC 62097. This method requires model and prototype surface roughness data and is takes into account the shift in n_{ED}, Q_{ED} and P_{ED} factors for determining the transposition of efficiency between model and prototype. However, in the case of Francis machines with semi-spiral casing and axial machines, the transposition method has not been fully validated due to a lack of data. In addition, IEC 62097 does not apply to storage pumps, Pelton turbines, and Dériaz. Therefore, for these and otherwise specifically agreed upon cases where hydraulically smooth flow conditions are assumed on the model and the prototype, the transposition formula and procedure given in Annex D and Annex I can be applied. Applications and limitations of both this document and IEC 62097 transposition methods are discussed in Annex E.

The method for performance conversion from model to prototype needs to be clearly defined in the main hydraulic performance contract.

This document may also be applied to model tests for other purposes, i.e. comparative tests and research and development work.

If model acceptance tests have been performed, field tests can be limited to index tests (see IEC 60041:1991).

If a contradiction is found between this document and any other document, this document prevails.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62097:2009, *Hydraulic machines, radial and axial – Performance conversion method from model to prototype*

ISO 2186:2007, *Fluid flow in closed conduits – Connections for pressure signal transmissions between primary and secondary elements*

ISO 2533:1975, *Standard atmosphere*

ISO 4185:1980, *Measurement of liquid flow in closed conduits – Weighing method*

ISO 4287:1997, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – terms, definitions and surface texture parameters*

ISO 8316:1987, *Measurement of liquid flow in closed conduits – Method by collection of the liquid in a volumetric tank*

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3 Terms, definitions, symbols and units

3.1 General

For the purposes of this document, the following common terms, definitions, symbols and units apply. Specialized terms are explained where they appear.

Clarification of any term, definition or unit of measure in question shall be agreed to in writing by the contracting parties in advance of the test.

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 General terminology

3.2.1
point
value established by one or more consecutive sets of readings and/or recordings at unchanged operating condition and settings, sufficient to calculate the performance of the machine at this operating condition and these settings

3.2.2
test
collection of points and results adequate to establish the performance of the machine over a specified range of operating conditions

3.2.3
hydraulic performance
all performance parameters attributable to the machine owing to hydrodynamic effects

3.2.4
main hydraulic performance data
subset of the hydraulic performance parameters, i.e. power, discharge and/or specific hydraulic energy, efficiency, steady-state runaway speed and/or discharge

Note 1 to entry: The influence of cavitation shall be considered.

3.2.5
additional data
subset of hydraulic performance data which can be determined for information on the model (see 4.4)

Note 1 to entry: However, the prediction of the corresponding prototype data is less accurate than that achievable for the main hydraulic performance data, owing to application of approximate similarity rules.

3.2.6
guarantee
specified performance data contractually agreed to

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3.2.7
measurand
quantity subjected to measurement

3.2.8
transducer
measuring device, which provides an output quantity with a given relationship to the input quantity

3.2.9
transducer with digitized output
measuring device with built-in electronics to give a digitized output (e.g. serial port RS 232)

3.2.10
multiplexer (MUX)
device for switching two or more signals in order to share the same analogue-to-digital converter, frequency counter or cabling facilities

3.2.11
analogue-to-digital converter (A/D converter)
device that translates continuous analogue signals into discrete digital signals

3.2.12
counter
device that measures frequency, time period or number of pulses

3.2.13
voltage-to-frequency converter (V/F converter)
device that translates with a given relationship voltage levels into frequency

3.2.14
aliasing
when sampling analogue signals with a sampling rate less than twice that of the frequency of the highest frequency signal or noise component ("Nyquist rate"), the sampling process will produce spurious low frequency signals (aliases) that cannot be distinguished from the original signal

3.2.15
computer interface
communication port that enables the computer to control and communicate with other compatible devices

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3.3 Units

The International System of Units (SI, see ISO 80000-4) has been used throughout this document.

All terms are given in SI base units or derived coherent units[1]. The basic equations are valid using these units. This has to be taken into account if other than coherent SI units are used for certain data (e.g. kilowatt instead of watt for power, kilopascal or bar instead of pascal for pressure, min^{-1} instead of s^{-1} for rotational speed, etc.). Temperatures may be given in degrees Celsius since absolute temperatures (in kelvins) are rarely required.

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

3.4 Definition of terms, symbols and units

3.4.1 List of terms and definitions by topic

Subclause	Title
3.4.2	Subscripts and symbols
3.4.3	Geometric terms
3.4.4	Physical quantities and properties
3.4.5	Discharge, velocity and speed terms
3.4.6	Pressure terms
3.4.7	Specific energy terms
3.4.8	Height and head terms
3.4.9	Power and torque terms
3.4.10	Efficiency terms
3.4.11	General terms relating to fluctuating quantities
3.4.12	Fluid dynamic and scaling terms
3.4.13	Dimensionless terms
3.4.14	Terms relating to additional performance data

[1] $N = kg \cdot m \cdot s^{-2}$ $Pa = kg \cdot m^{-1} \cdot s^{-2}$ $J = kg \cdot m^{2} \cdot s^{-2}$ $W = kg \cdot m^{2} \cdot s^{-3}$

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3.4.2 Subscripts and symbols

Subclause	Term	Definition	Subscript or symbol
3.4.2.1	High-pressure[a)] reference section	The high-pressure section of the machine to which the performance guarantees refer (see Figure 1)	1
3.4.2.2	Low-pressure[a)] reference section	The low-pressure section of the machine to which the performance guarantees refer (see Figure 1)	2
3.4.2.3	High-pressure measuring sections	High-pressure sections of the machine used for measurement Note 1 to entry: Whenever possible, these sections should coincide with section 1; otherwise the measured values shall be adjusted to section 1 (see 6.5.2.1.3)	1', 1''.
3.4.2.4	Low-pressure measuring sections	Low-pressure sections of the machine used for measurement Note 1 to entry: Whenever possible, these sections should coincide with section 2; otherwise, the measured values shall be adjusted to section 2 (see 6.5.2.1.3)	2', 2''.
3.4.2.5	Specified	Subscript denoting values of quantities such as rotational speed, discharge etc. for which other quantities are guaranteed	sp
3.4.2.6	Maximum/minimum	Subscript denoting maximum or minimum values of any term	max min
3.4.2.7	Limits	Contractually defined values: – not to be exceeded – to be reached	 //// ☐ or ////
3.4.2.8	Prototype	Subscript denoting values related to the full-size machine	P
3.4.2.9	Model	Subscript denoting values related to the model	M
3.4.2.10	Model at constant Reynolds number	Subscript denoting values related to a model and referred to a constant value of Reynolds number	M*
3.4.2.11	Reference	Subscript denoting values related to a specified reference condition	ref
3.4.2.12	Optimum	Subscript denoting the best efficiency point	opt
3.4.2.13	Ambient	Subscript referring to surrounding atmospheric conditions	amb
3.4.2.14	Plant	Subscript denoting values related to the operating conditions of the prototype in the plant	pl
3.4.2.15	Runaway	Subscript referring to runaway conditions	R
3.4.2.16	Runner blade	Subscript referring to the runner blade of a machine.	B
3.4.2.17	Pelton deflector	Subscript referring to the Pelton deflector of a machine.	D
3.4.2.18	Guide vane	Subscript referring to the guide vane of a machine.	G
3.4.2.19	Pelton needle	Subscript referring to the Pelton needle of a machine	N
3.4.2.20	Axial	Subscript referring to a component of force or torque	a
3.4.2.21	Radial	Subscript referring to a component of force or torque	r
3.4.2.22	Cartesian coordinates	Subscript referring to machine coordinates	x, y, z
3.4.2.23	Theoretical value	Subscript referring to theoretical value	th
3.4.2.24	Hydraulic	Subscript referring to hydraulic value	h

[a)] 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.

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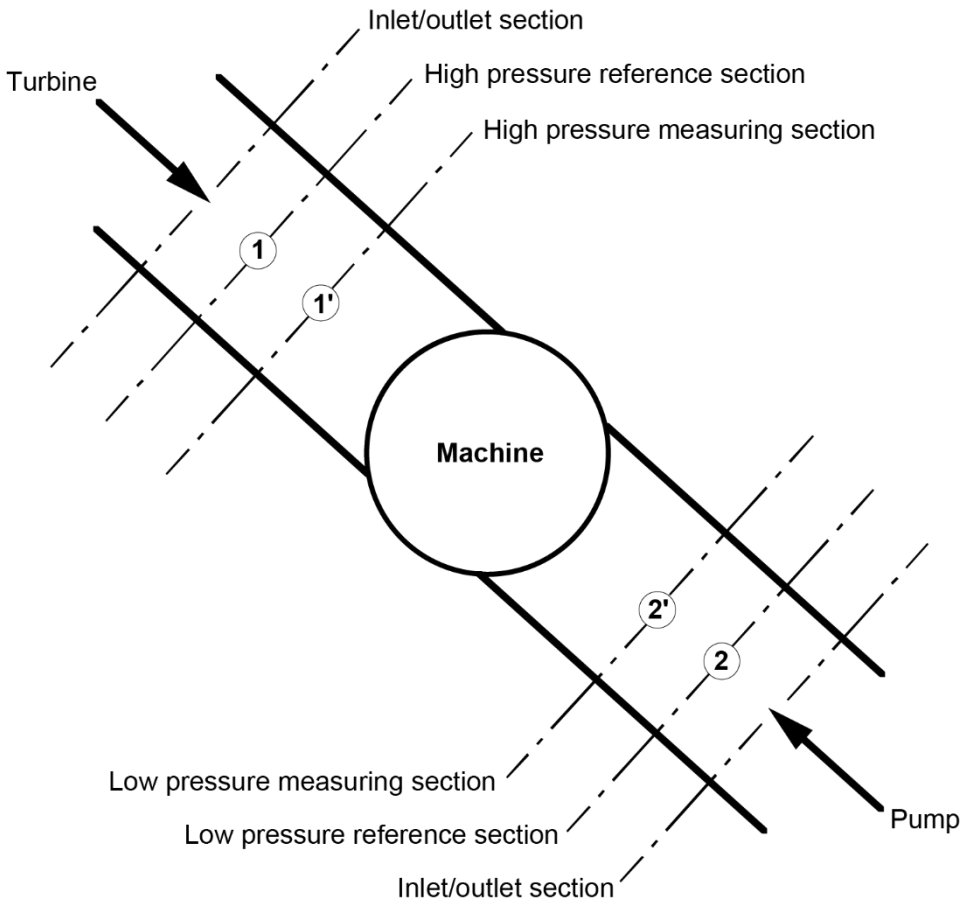
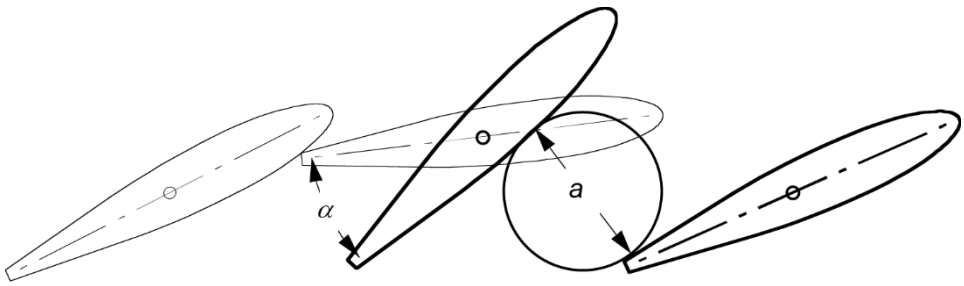


Figure 1– Schematic representation of a hydraulic machine



Closed position: $\alpha = 0°$ or $a = 0$ mm

Figure 2 – Guide vane opening and angle

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3.4.3 Geometric terms

Subclause	Term	Definition	Symbol	Unit
3.4.3.1	Area	Net cross-sectional surface normal to general flow direction	A	m^2
3.4.3.2	Surface area	Total area of a surface (of the runner, flow passages, etc.)	S	m^2
3.4.3.3	Guide vane opening	Average shortest distance between adjacent guide vanes (at a specified section if necessary) (see Figure 2)	a	m
3.4.3.4	Guide vane angle	Average vane angle measured from closed position (see Figure 2)	α	°
3.4.3.5	Needle stroke (impulse turbine)	Average needle stroke measured from closed position	s	m
3.4.3.6	Runner/impeller blade angle	Average runner/impeller blade setting measured from a reference position	β	°
3.4.3.7	Reference diameter	Reference diameter of the hydraulic machine (see Figure 3)	D	m
3.4.3.8	Runner outlet/impeller inlet width	Average shortest distance between two adjacent blades of runner/impeller (see Figure 14 and Figure 15)	a_1, a_2	m
3.4.3.9	Bucket width	Inside maximum width of runner bucket of a Pelton turbine (see Figure 3)	B	m
3.4.3.10	Length scale ratio	The ratio of representative prototype to model lengths; in normal cases this is the reference diameter of the machine Note 1 to entry: In cases where it is difficult to verify this reference, then another significant length may be taken	λ_L	-
3.4.3.11	Level	Elevation of a point in the system above the specified reference datum (usually mean sea level)	z	m
3.4.3.12	Length	Relevant linear size of a component of the machine	L	m
3.4.3.13	Arithmetic roughness	Arithmetic mean deviation of the assessment profile	Ra	μm

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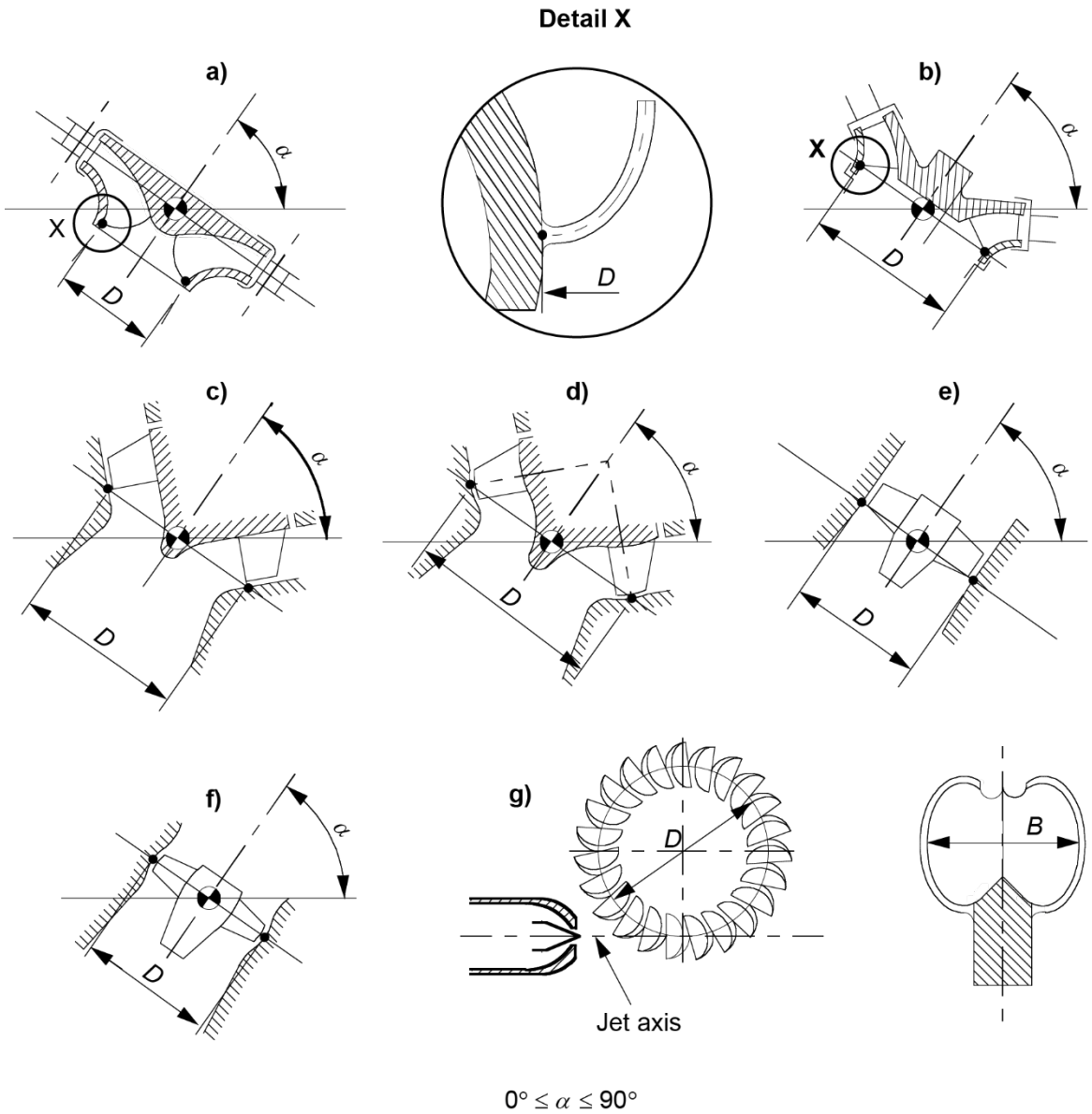

a) Radial machines, such as Francis turbines, radial (centrifugal) pumps and pump-turbines; for multistage machines: low-pressure stage.

b) Diagonal (mixed-flow, semi-axial, Dériaz) machines with fixed runner/impeller blades and with runner/impeller band.

c) Diagonal (mixed-flow, semi-axial, Dériaz) machines with fixed runner/impeller blades, without runner/impeller band.

d) Diagonal (mixed-flow, semi-axial, Dériaz) machines with adjustable runner/impeller blades.

e) Axial machines, such as propeller turbines, tubular turbines[2], axial pumps and pump-turbines with fixed runner/impeller blades.

f) Axial machines, such as Kaplan turbines, tubular turbines[2], axial pumps and pump-turbines with adjustable runner/impeller blades.

g) Pelton turbines.

Figure 3 – Reference diameter and bucket width

2 The term "tubular turbines" includes bulb, pit, rim generator and S-type units.

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3.4.4 Physical quantities and properties

Subclause	Term	Definition	Symbol	Unit
3.4.4.1	Acceleration due to gravity	Local value of gravitational acceleration at the place of testing (see 5.7.2); theoretical values as a function of altitude and latitude are given in Table B.1	g	$m \cdot s^{-2}$
3.4.4.2	Temperature	Thermodynamic (kelvin) Degree Celsius $\theta = \Theta - 273{,}15$	Θ θ	K °C
3.4.4.3	Volume	Quantity of three-dimensional space an object/substance occupies	V	m^3
3.4.4.4	Density	Mass per unit volume a) Density of water ρ is commonly used instead of ρ_w b) ensity of distilled water Values for distilled water ρ_{wd} are given in 5.7.3.1.3 and in Table B.2 c) Density of air Values for air are given in 5.7.4.1 and in Table B.5 d) Density of mercury Values for mercury are given in 5.7.5 and in Table B.7	 ρ, ρ_w, ρ_{wa} ρ_{wd} ρ_a ρ_{Hg}	$kg \cdot m^{-3}$
3.4.4.5	Vapour pressure (absolute)	Absolute partial pressure of saturated vapour in a medium where liquid and gaseous phases of a body are in thermodynamic balance Note 1 to entry: The vapour pressure depends only on the temperature. Values for distilled water are given in 5.7.3.4 and in Table B.4	p_{va}	Pa
3.4.4.6	Dynamic viscosity	A quantity characterizing the mechanical behaviour of a fluid (see ISO 80000-4)	μ	Pa·s
3.4.4.7	Kinematic viscosity	Ratio of the dynamic viscosity to the density of a fluid Note 1 to entry: Values for distilled water as a function of temperature are given in 5.7.3.3 and in Table B.3	ν	$m^2 \cdot s^{-1}$
3.4.4.8	Surface tension	A quantity characterizing the mechanical behaviour of the interface between two fluids (see ISO 80000-4)	σ^*	$J \cdot m^{-2}$

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3.4.5 Discharge, velocity and speed terms

Subclause	Term	Definition	Symbol	Unit
3.4.5.1	Discharge	Volume of water per unit time passing through any section in the system	Q	$m^3 \cdot s^{-1}$
3.4.5.2	Mass flow rate	Mass of water flowing through any section of the system per unit time. Both ρ and Q shall be determined at the same section and at the conditions existing in that section Note 1 to entry: The mass flow rate is constant between two sections if no water is added or removed	(ρQ)	$kg \cdot s^{-1}$
3.4.5.3	Measured discharge	Volume of water per unit time flowing through any measuring section, e.g. 1' (see 3.4.2.3 and 3.4.2.4)	$Q_{1'}$ or $Q_{2'}$	$m^3 \cdot s^{-1}$
3.4.5.4	Discharge at reference section	Volume of water per unit time flowing through the reference section 1 or 2	Q_1 or Q_2	$m^3 \cdot s^{-1}$
3.4.5.5	Corrected discharge at reference section	Volume of water per unit time flowing through the reference section referred to the ambient condition (see 3.4.6.2), e.g. $Q_{1c} = (\rho Q)_1 / \rho_{amb}$ Note 1 to entry: Given the normal conditions of a model test, Q_{1c} may be assumed equal to Q_1	Q_{1c} or Q_{2c}	$m^3 \cdot s^{-1}$
3.4.5.6	Discharge at steady-state runaway speed	Discharge at n_R (see 3.4.5.12)	Q_R	$m^3 \cdot s^{-1}$
3.4.5.7	No-load turbine discharge	Turbine discharge at zero mechanical power at specified speed (usually synchronous) and specified specific hydraulic energy	Q_o	$m^3 \cdot s^{-1}$
3.4.5.8	Leakage discharge	Volumetric loss as illustrated in Figure 6	q	$m^3 \cdot s^{-1}$
3.4.5.9	Mean velocity	Discharge Q divided by area A of the cross-section	v	$m \cdot s^{-1}$
3.4.5.10	Peripheral velocity	Speed at the reference diameter: $u = \pi D n$	u	$m \cdot s^{-1}$
3.4.5.11	Rotational speed	Number of revolutions per unit time	n	s^{-1}
3.4.5.12	Steady-state runaway speed	The steady-state rotational speed at zero mechanical power at specified hydraulic conditions and specified guide vane/blade/needle opening	n_R	s^{-1}
3.4.5.13	Maximum steady-state runaway speed	The highest value of steady-state runaway speed at specified hydraulic conditions (for the prototype, see detailed definition in IEC 60041:1991, 2.3.4.15)	n_{Rmax}	s^{-1}

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3.4.6 Pressure terms

Subclause	Term	Definition	Symbol	Unit
3.4.6.1	Absolute pressure	The static pressure of a fluid measured with reference to a perfect vacuum	p_{abs}	Pa
3.4.6.2	Ambient pressure	The absolute pressure of the ambient air (see 5.7.4.2) Note 1 to entry: Values for standard atmosphere are given as a function of elevation in Table B.6	p_{amb}	Pa
3.4.6.3	Gauge pressure	The difference between the absolute static pressure of a fluid at the reference level of the pressure measuring instrument and the ambient pressure at the place and time of measurement: $p = p_{abs} - p_{amb}$	p	Pa
3.4.6.4	Differential pressure	The difference in pressure between two points or sections of measurement	Δp	Pa

3.4.7 Specific energy terms

In the International System of Units, mass (kg) is one of the base quantities. The energy per unit mass, known as "specific energy", is used in this document as a primary term instead of the energy per local unit weight which is called "head", and was exclusively used in previous publications.

The latter term ("head") has the disadvantage that weight is a force which depends on the local value of acceleration due to gravity *g*, which changes mainly with latitude but also with altitude. Nevertheless, the term "head" will still remain in use because it is very common. Therefore, both related energy terms are listed, the specific energy terms in this subclause and head terms in 3.4.8. They differ only by the factor *g*, which is the local value of acceleration due to gravity.

Subclause	Term	Definition	Symbol	Unit
3.4.7.1	Specific hydraulic energy of machine	The energy per unit mass of water available between the high and low-pressure reference sections 1 and 2 of the machine, taking into account the influence of compressibility (see 6.5) $E = \frac{p_{abs1} - p_{abs2}}{\bar{\rho}} + \frac{v_1^2 - v_2^2}{2} + g(z_1 - z_2)$ with $\bar{\rho} = (\rho_1 + \rho_2)/2$ and assuming $g = g_1 = g_2$ Note 1 to entry: The value of ρ_1 and ρ_2 can be calculated from p_{abs1} and p_{abs2} respectively, taking into account θ_1 or θ_2 for both values, given the negligible influence of the difference of the temperature on ρ	E	$J \cdot kg^{-1}$
3.4.7.2	Zero-discharge (shut-off) specific hydraulic energy of the pump	The specific energy of water for a pump at specified speed and specified guide vane and impeller blade settings with high-pressure side shut off	E_0	$J \cdot kg^{-1}$
3.4.7.3	Specific kinetic energy	The specific energy of water in motion: $E_k = \frac{v^2}{2}$	E_k	$J \cdot kg^{-1}$

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Subclause	Term	Definition	Symbol	Unit
3.4.7.4	Suction specific potential energy of the machine	Potential energy per unit mass of water at section 2 corresponding to the difference between the reference level of the machine (see 3.4.8.5) and the piezometric level at section 2: $E_s = g(z_r - z_{2'}) = g(z_r - z_2) - \frac{p_{abs2} - p_{amb}}{\rho_2}$ (see Figure 45)	E_s	$J \cdot kg^{-1}$
3.4.7.5	Net positive suction specific energy	Absolute energy per unit mass of water at section 2 minus the specific energy due to the vapour pressure p_{va} referred to the reference level of the machine: $NPSE = \frac{p_{abs2} - p_{va}}{\rho_2} + \frac{v_2^2}{2} - g(z_r - z_2)$ $= -E_s + \frac{p_{amb} - p_{va}}{\rho_2} + \frac{v_2^2}{2}$ (see Figure 45)	*NPSE*	$J \cdot kg^{-1}$
3.4.7.6	Thoma number	Dimensionless term indicating the conditions of cavitation under which the machine operates Note 1 to entry: It is expressed as the ratio of net positive suction specific energy *NPSE* to a specific hydraulic energy *E* (see 3.4.13.9)	σ	-
3.4.7.7	Cavitation coefficient	Dimensionless term indicating the conditions of cavitation under which the machine operates Note 1 to entry: It is expressed as the ratio of net positive suction specific energy *NPSE* to n^2D^2 (see 3.4.13.10)	σ_{nD}	-
3.4.7.8	Thoma number zero	The lowest value of the Thoma number for which a chosen performance parameter (usually efficiency) remains unchanged as compared to its values at high Thoma number Note 1 to entry: In some cases, the shape of the cavitation curve η_h (σ) is such that the Thoma number zero is difficult to define (see Figure 4)	σ_0	-
3.4.7.9	Thoma number one	The value of the Thoma number for which a drop of one percentage point in efficiency is obtained compared with the efficiency at Thoma number zero Note 1 to entry: In some cases, the shape of the cavitation curve is such that the Thoma number one is difficult to define (see Figure 4)	σ_1	-
3.4.7.10	Defined Thoma number	The value of the Thoma number associated with a defined onset of cavitation, e.g. a specified performance loss	σ_d	-
3.4.7.11	Incipient Thoma number	The value of the Thoma number associated with the beginning of visible runner/impeller cavitation usually detected by observation (see Figure 4)	σ_i	-
3.4.7.12	Plant Thoma number	The value of the Thoma number at the operating conditions of the prototype (see Annex K)	σ_{pl}	-
3.4.7.13	Specific hydraulic energy loss	The specific hydraulic energy dissipated between any two sections	E_L	$J \cdot kg^{-1}$

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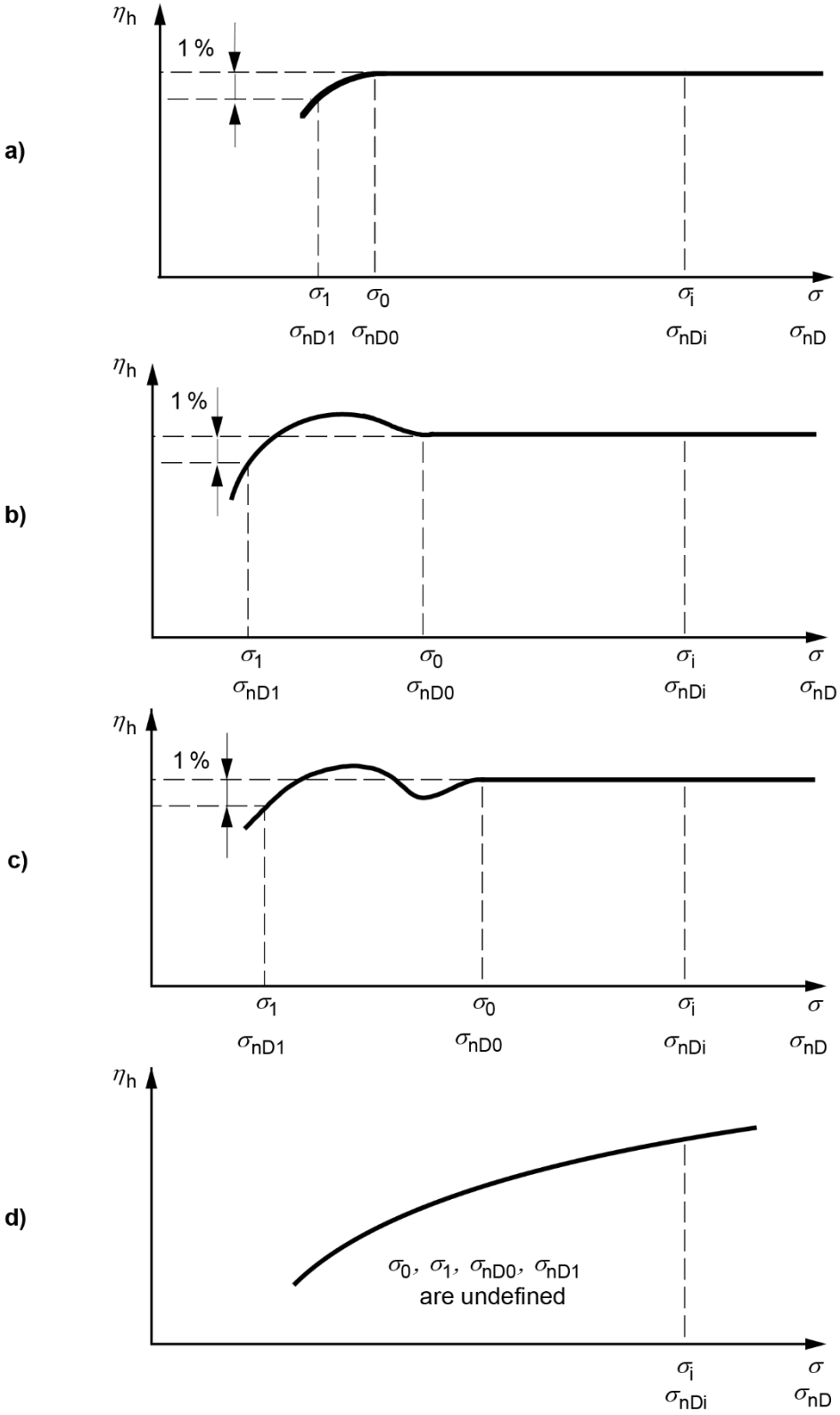

a) Monotonic change in efficiency (for example, for a Francis turbine in the region of optimum efficiency)

b) Efficiency overshoot (for example, for a Francis turbine at full-load operation)

c) Efficiency oscillation, (for example, Francis turbine with inlet cavitation at full-load operation)

d) Monotonic decrease in efficiency (for example, tubular turbine)

Figure 4 – Determination of σ_0 and σ_1 for typical cavitation curves

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3.4.8 Height and head terms

Subclause	Term	Definition	Symbol	Unit
3.4.8.1	Turbine or pump head	Specific energy per local unit weight of water at any section $H = \frac{E}{g}$	H	m
3.4.8.2	Zero discharge (shut-off) head of pump	Specific energy per local unit weight of water for a pump at specified speed and specified guide vane and impeller blade settings with high-pressure side shut off $H_0 = \frac{E_0}{g}$	H_0	m
3.4.8.3	Suction height	Specific energy per local unit weight of water at section 2 corresponding to the difference between the reference level of the machine (see 3.4.8.5) and the piezometric level at section 2 $Z_s = \frac{E_s}{g}$	Z_s	m
3.4.8.4	Net positive suction head	Specific energy per local unit weight of water at section 2 minus the specific energy due to the vapour pressure p_{va} referred to the reference level of the machine (see Figure 45) $NPSH = \frac{NPSE}{g}$	$NPSH$	m
3.4.8.5	Reference level of the machine	Elevation of a point of the machine taken as reference for the setting of the machine (see Figure 5)	z_r	m
3.4.8.6	Cavitation reference level	Elevation of a point of the machine taken as reference for cavitation evaluation during model tests (see 5.3.5.2)	z_c	m
3.4.8.7	Reference level of the pressure measuring instrument	Elevation of a pressure measuring device (see Figure 38)	z_M	m
3.4.8.8	Reference height of pressure measuring instrument	Distance between the reference levels of the machine and the instrument (see Figure 38) $Z_{rM} = z_r - z_M$	Z_{rM}	m

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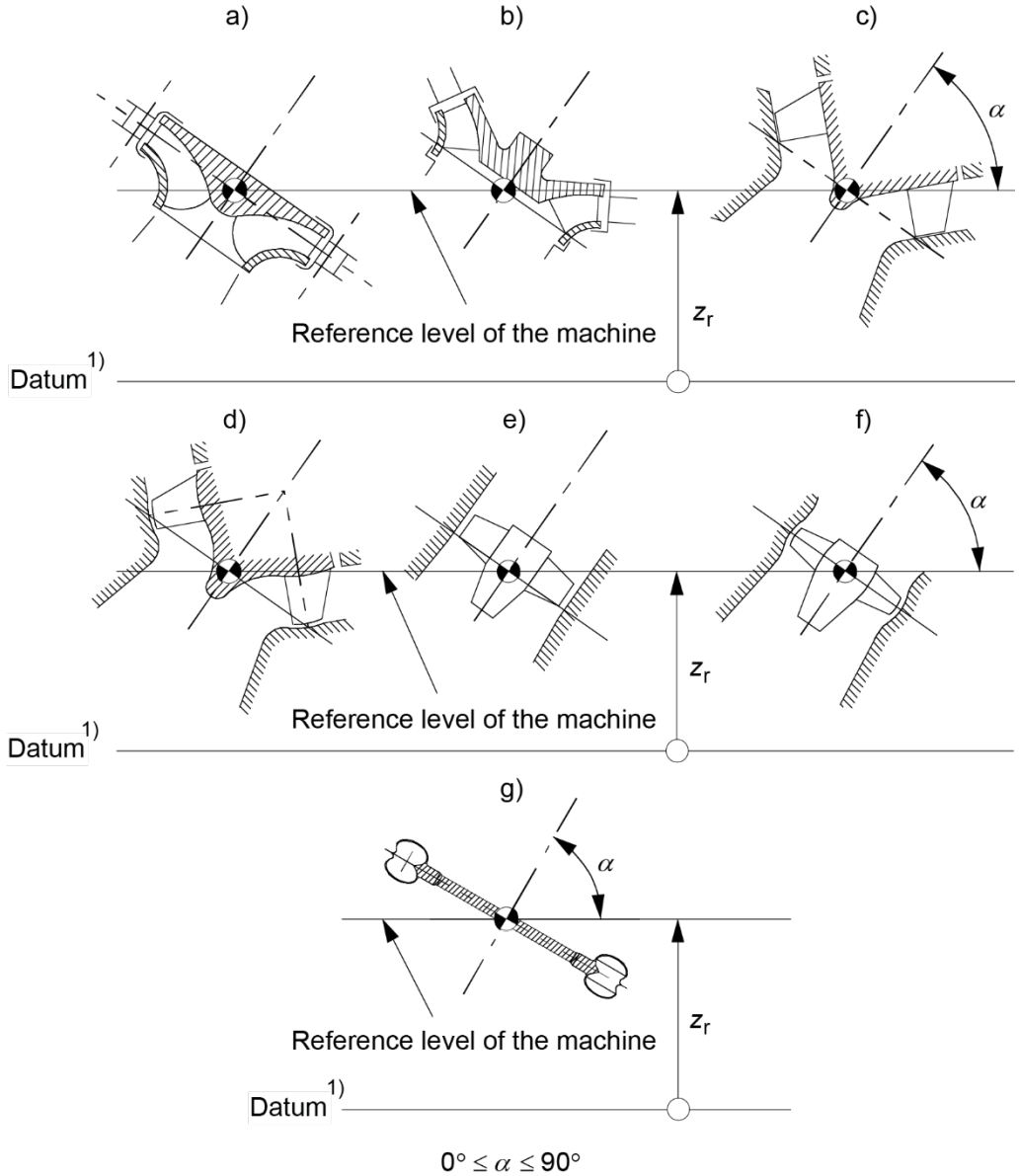

1) See 3.4.3.11

a) Radial machines, such as Francis turbines, radial (centrifugal) pumps and pump-turbines; for multistage machines: low-pressure stage

b) Diagonal (mixed-flow, semi-axial, Dériaz) machines with fixed runner/impeller blades and with runner/impeller band

c) Diagonal (mixed-flow, semi-axial, Dériaz) machines with fixed runner/impeller blades, without runner/impeller band

d) Diagonal (mixed-flow, semi-axial, Dériaz) machines with adjustable runner/impeller blades

e) Axial machines, such as propeller turbines, tubular turbines[3], axial pumps and pump-turbines with fixed runner/impeller blades

f) Axial machines, such as Kaplan turbines, tubular turbines[3], axial pumps and pump-turbines with adjustable runner/impeller blades

g) Pelton turbines

Figure 5 – Reference level of machine

3 The term "tubular turbines" includes bulb, pit, rim generator and S-type units.

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3.4.9 Power and torque terms

Subclause	Term	Definition	Symbol	Unit
3.4.9.1	Hydraulic power	The hydraulic power available for producing power (turbine) or imparted to the water (pump) $P_h = E(\rho Q)_1$	P_h	W
3.4.9.2	Mechanical power of the machine (power)	The mechanical power delivered by the turbine shaft or to the pump shaft, assigning to the hydraulic machine the mechanical losses of the relevant bearings and shaft seals (see Figure 6)	P	W
3.4.9.3	Mechanical power of runner(s)/impeller(s)	Mechanical power transmitted through the coupling of the runner(s)/impeller(s) and the shaft (see Figure 6)	P_m	W
3.4.9.4	Mechanical power losses	Mechanical power dissipated in guide bearings, thrust bearings and shaft seals of the hydraulic machine (see Figure 6)	P_{Lm}	W
3.4.9.5	Zero discharge (shut-off) power of the pump	Pump power at specified speed and at specified guide vane and impeller settings with high-pressure side shut-off	P_0	W
3.4.9.6	Shaft torque	Torque applied to the shaft of the hydraulic machine and corresponding to the mechanical power of the machine (see 3.4.9.2)	T	N·m
3.4.9.7	Runner/impeller torque	Torque transmitted through the coupling of the runner/impeller and the shaft and corresponding to the mechanical power of runner/impeller (see 3.4.9.3)	T_m	N·m
3.4.9.8	Friction torque	Friction torque in guide bearings, thrust bearings and shaft seals of the hydraulic machine (see 3.4.9.4)	T_{Lm}	N·m

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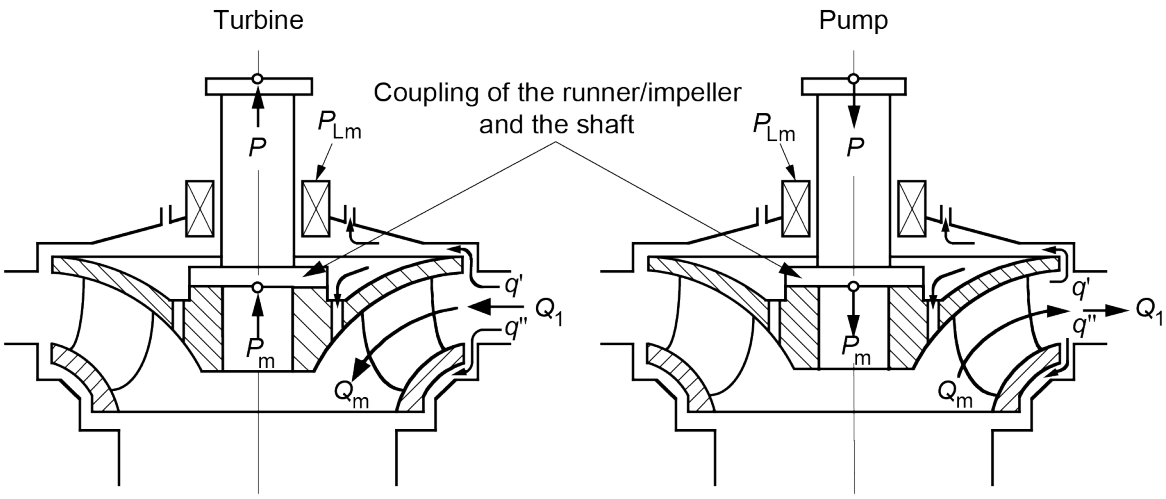

$q = q' + q''$	Leakage discharge	$q = q' + q''$
$Q_1 = Q_m + q$	Discharge at section 1	$Q_1 = Q_m - q$
$P_h = E(\rho Q)_1$	Hydraulic power	$P_h = E(\rho Q)_1$
$P = P_m - P_{Lm}$	Mechanical power of the machine	$P = P_m + P_{Lm}$
$\eta_m = \frac{P}{P_m}$	Mechanical efficiency	$\eta_m = \frac{P_m}{P}$
$\eta_h = \frac{P_m}{P_h}$	Hydraulic efficiency	$\eta_h = \frac{P_h}{P_m}$
$\eta = \frac{P}{P_h}$	Efficiency	$\eta = \frac{P_h}{P}$

NOTES

– The formulae ignore the compressibility of the water.

– For detailed analysis of internal losses, refer to Annex L.

– The disk friction losses and leakage losses (volumetric losses) are considered as hydraulic losses in the formula for hydraulic efficiency. The disk friction losses are the friction losses of the outer surfaces of the runner/impeller not in contact with the flow Q_m passing the runner/impeller blades.

Figure 6 – Flux diagram for power and discharge

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3.4.10 Efficiency terms

Subclause	Term	Definition	Symbol	Unit
3.4.10.1	Hydraulic efficiency	a) Turbine: ratio of mechanical power of runner to the hydraulic power $\eta_h = \frac{P_m}{P_h}$ b) Pump: ratio of hydraulic power to the mechanical power of the impeller $\eta_h = \frac{P_h}{P_m}$ See Figure 6	η_h	-
3.4.10.2	Mechanical efficiency	a) Turbine: ratio of mechanical power of the machine to the runner $\eta_m = \frac{P}{P_m}$ b) Pump: ratio of mechanical power of the impeller to the machine $\eta_m = \frac{P_m}{P}$ See Figure 6	η_m	-
3.4.10.3	Efficiency	a) Turbine: ratio of mechanical power of the machine to the hydraulic power $\eta = \frac{P}{P_h} = \eta_h \cdot \eta_m$ b) Pump: ratio of hydraulic power to the power of the machine $\eta = \frac{P_h}{P} = \eta_h \cdot \eta_m$ See Figure 6	η	-
3.4.10.4	Weighted average efficiency	Calculated from the formula $\eta_w = \frac{w_1\eta_1 + w_2\eta_2 + w_3\eta_3 + \ldots}{w_1 + w_2 + w_3 + \ldots}$ where η_1, η_2, η_3, … are the values of efficiency at specified operating conditions and w_1, w_2, w_3 … are their agreed weighting factors respectively	η_w	-

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3.4.11 General terms relating to fluctuating quantities

IEC 60994 provides a reference for terms relating to fluctuating quantities. Terms relevant to this document, some of which are illustrated in Figure 7, are listed below:

Subclause	Term	Definition	Symbol	IEC 60994:1991 reference
3.4.11.1	Discrete quantity	Quantity represented by a sequence of its momentary values	X	
3.4.11.2	Discrete quantity *n*	Value of the quantity *n*	X_n	
3.4.11.3	Number of samples	Total number of discrete quantities	N	
3.4.11.4	Number of samples in a time window	Total number of discrete quantities used in the time window duration	N_w	
3.4.11.5	Mean value	The algebraic sum of the discrete quantities divided by the number of samples $\bar{X} = \frac{1}{N}\sum_1^N X_n$	$\bar{X}$	2.3.3.1
3.4.11.6	Fluctuation of quantity	Oscillatory variation of a quantity X referred to its mean value during a time interval Δt previously selected	$\tilde{X}(t)$	2.3.1.5
3.4.11.7	Maximum value	The maximum value in a chosen time interval	X_{max}	
3.4.11.8	Minimum value	The minimum value in a chosen time interval	X_{min}	
3.4.11.9	Standard deviation (effective value referred to the mean)	The root-mean-square value of the deviation of a set of numbers from the mean value $\tilde{X}_{eff} = \sqrt{\frac{1}{N}\sum_1^N (X_n - \bar{X})^2}$	$\tilde{X}_{eff}$	2.3.3.2
3.4.11.10	Root-mean-square value	The square root of the mean value squared $X_{rms} = \sqrt{\frac{1}{N}\sum_1^N X_n^2}$	X_{rms}	2.3.3.3
3.4.11.11	Peak-to-peak value	The difference between the maximum and minimum values $\Delta X_{pp} = X_{max} - X_{min}$	ΔX_{pp}	2.3.2.11
3.4.11.12	Peak-to-peak value with a 97 % confidence interval	The difference between the maximum and minimum values of a signal is determined using a probability distribution function for a given probability value (e.g. 97 %) Note 1 to entry: This function is estimated by applying statistical counting. The signal values outside of the corresponding confidence interval are excluded.	$\Delta X_{pp,97\ \%}$	
3.4.11.13	Amplitude	Maximum value of a sinusoidal quantity $X(t)$ $A = \frac{1}{2}\Delta X_{pp}$	A	2.3.2.10
3.4.11.14	Time	Physical quantity	t	2.3.2.3
3.4.11.15	Sampling time interval	Time interval between two consecutive samples.	Δt	
3.4.11.16	Frequency	The reciprocal of period s^{-1} (Hz)	f	2.3.2.4
3.4.11.17	Sampling frequency (sampling rate)	Inverse of the sampling time interval $f_s = \frac{1}{\Delta t}$	f_s	

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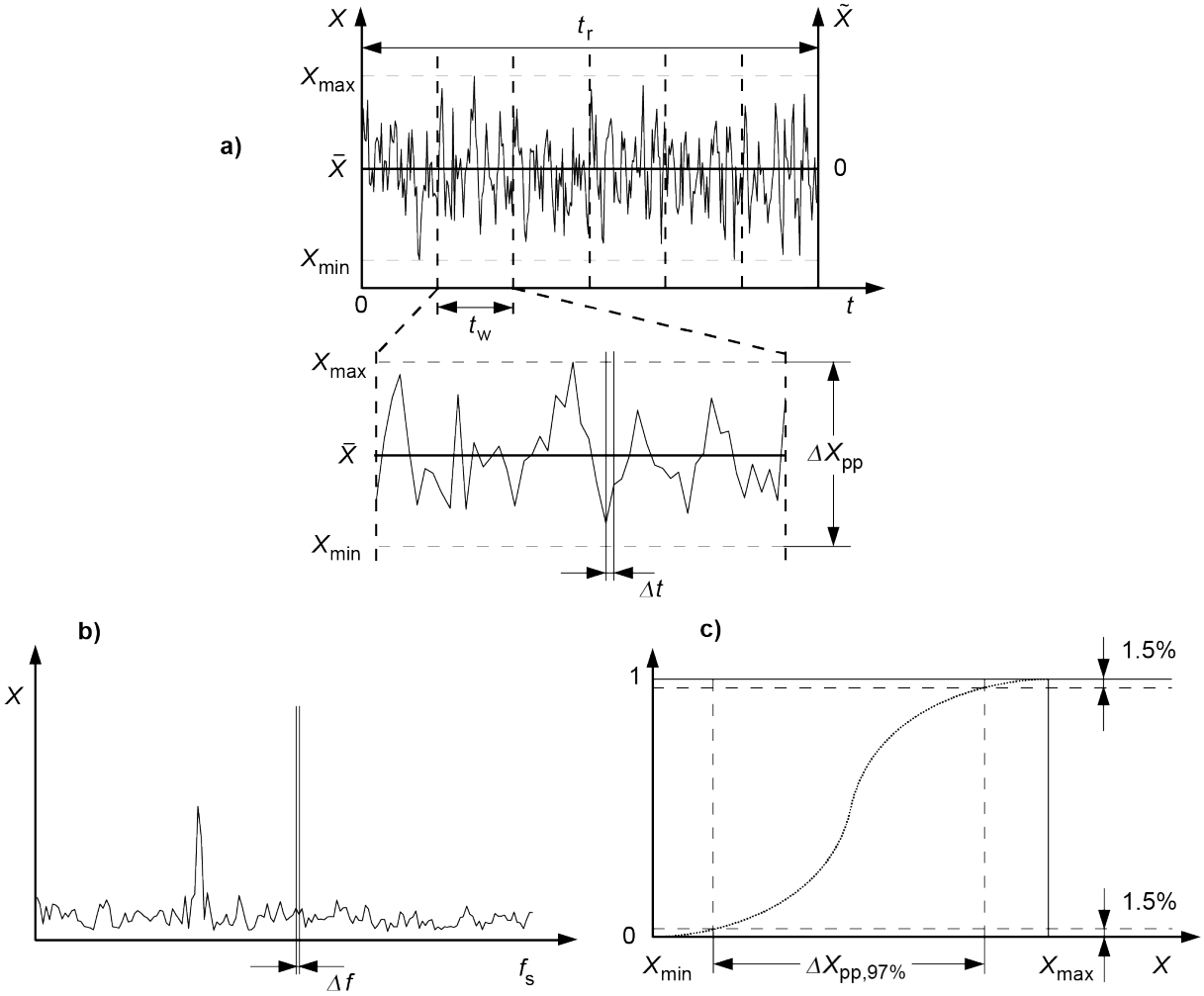
Subclause	Term	Definition	Symbol	IEC 60994:1991 reference
3.4.11.18	Time window duration	Selected time window for frequency analyses by Fourier transform methods $t_w = N_w \Delta t$	t_w	
3.4.11.19	Frequency resolution	Frequency interval between two consecutive values in the discrete Fourier transform $\Delta f = 1/t_w = f_s/N$	Δf	
3.4.11.20	Signal recording time (Acquisition time)	Period of time during which a signal from a transducer is recorded (in seconds).	t_r	2.3.4.14



a) A pressure fluctuation signal over a defined signal recording time (t_r). A minimum of 5 window time lengths (t_w) shall be included in each signal record time duration (see 7.2.1.2.4).

b) The signal transformed into the frequency domain using Fourier analysis. The frequency resolution (Δf) required for each analysis is determined by the speed of rotation of the machine (see 7.2.1.2.4).

c) Using probability distribution, each measure point from Figure 7 a) is cumulated and extreme deviations from the mean fluctuation are removed. A 97 % interval of confidence is illustrated in this figure.

Figure 7 – Illustration of some definitions related to oscillating quantities

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3.4.12 Fluid dynamics and scaling terms[a)]

Subclause	Term	Definition	Symbol	Unit
3.4.12.1	Reynolds number	Ratio of inertia forces to viscous forces (see 5.3.1): a) Reaction machines $Re = \frac{uD}{\nu}$ b) Impulse turbines $\frac{uB}{\nu}$	Re	-
3.4.12.2	Reference Reynolds number	The value $Re = 7 \times 10^6$	Re_{ref}	
3.4.12.3	Froude number[b)]	Square root of the ratio of inertia forces to gravity forces (see 5.3.1): a) Reaction machines $Fr = \left[\frac{E}{gD}\right]^{1/2}$ b) Impulse turbines $\left[\frac{E}{gB}\right]^{1/2}$	Fr	-
3.4.12.4	Weber number[b)]	Ratio of inertia forces to surface tension forces $We = \left[\frac{\rho L v^2}{\sigma^*}\right]^{1/2}$ (see 5.3.1)	We	-
3.4.12.5	Reference loss distribution coefficient	Ratio of relative scalable loss to relative total loss for reference Reynolds number for the point of optimum hydraulic efficiency $V_{ref} = \frac{\delta_{ref}}{1-\eta_{hM\ opt}}$ Note 1 to entry: See Table D.1 for the values corresponding to the different types of reaction machines	V_{ref}	-
3.4.12.6	Relative scalable loss	Loss in efficiency due to scale effects related to the Reynolds number	δ	-
3.4.12.7	Reference relative scalable loss	Loss in efficiency due to scale effects at the reference Reynolds number (see Annex D) $\delta_{ref} = V_{ref}\left(1-\eta_{h\ ref}\right)$	δ_{ref}	-
3.4.12.8	Relative non-scalable loss	Loss in efficiency that cannot be attributed to scale effects (see Annex D) $\delta_{ns} = \left(1-\eta_h\right) - \delta$	δ_{ns}	-
3.4.12.9	Relative total loss	Sum of scalable and non-scalable losses (see Annex D) $1-\eta_h = \delta + \delta_{ns}$		-
3.4.12.10	Difference of hydraulic efficiency	Difference between the values of hydraulic efficiency at two hydraulically similar operating points measured at different Reynolds numbers (see 5.3.2)	$\Delta\eta_h$	-

a) See ISO 80000-11.

b) Other definitions of these numbers can be found in relevant scientific works.

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3.4.13 Dimensionless terms

Machine performance may be characterized by dimensionless terms based on $E = 1$, $D = 1$ and $\rho = 1$ or on $n = 1$, $D = 1$ and $\rho = 1$.

The units are: H (m); D (m); E (J·kg^{-1}); n (s^{-1}); ρ (kg·m^{-3}); T (N·m); P (W); Q (m^3·s^{-1}).

The relations of these dimensionless terms to other existing definitions are given in Annex A.

Subclause	Term	Definition	Symbol	Relations
3.4.13.1	Speed factor	$\frac{nD}{E^{0,5}}$	n_{ED}	$= \frac{1}{E_{nD}^{0,5}}$
3.4.13.2	Discharge factor	$\frac{Q_1}{D^2E^{0,5}}$	Q_{ED}	$= \frac{Q_{nD}}{E_{nD}^{0,5}}$
3.4.13.3	Torque factor	$\frac{T_m}{\rho_1 D^3 E}$	T_{ED}	$= \frac{T_{nD}}{E_{nD}} = \frac{P_{ED}}{2\pi n_{ED}}$
3.4.13.4	Power factor[1)]	$\frac{P_m}{\rho_1 D^2 E^{1,5}}$	P_{ED}	$= Q_{ED}\eta_{hT}$ (turbine) $= \frac{Q_{ED}}{\eta_{hP}}$ (pump) $= \frac{P_{nD}}{E_{nD}^{1,5}} = P_{nD}n_{ED}^3$ $= 2\pi n_{ED}T_{ED}$
3.4.13.5	Energy coefficient	$\frac{E}{n^2D^2}$	E_{nD}	$= \frac{1}{n_{ED}^2}$
3.4.13.6	Discharge coefficient	$\frac{Q_1}{nD^3}$	Q_{nD}	$= \frac{Q_{ED}}{n_{ED}} = Q_{ED}E_{nD}^{0,5}$
3.4.13.7	Torque coefficient	$\frac{T_m}{\rho_1 n^2 D^5}$	T_{nD}	$= \frac{T_{ED}}{n_{ED}^2} = T_{ED}E_{nD} = \frac{P_{nD}}{2\pi}$
3.4.13.8	Power coefficient[a)]	$\frac{P_m}{\rho_1 n^3 D^5}$	P_{nD}	$= E_{nD}Q_{nD}\eta_{hT}$ (turbine) $= \frac{E_{nD}Q_{nD}}{\eta_{hP}}$ (pump) $= \frac{P_{ED}}{n_{ED}^3} = P_{ED}E_{nD}^{1,5} = 2\pi T_{nD}$
3.4.13.9	Thoma number	$\frac{NPSE}{E}$	σ	$= \frac{Q_{nD}}{E_{nD}} = \sigma_{nD}n_{ED}^2$
3.4.13.10	Cavitation coefficient	$\frac{NPSE}{n^2D^2}$	σ_{nD}	$= \sigma E_{nD} = \frac{\sigma}{n_{ED}^2}$
3.4.13.11	Specific speed	$\frac{nQ^{0,5}}{E^{0,75}}$	N_{QE}	$= n_{ED}Q_{ED}^{0,5} = \frac{Q_{nD}^{0,5}}{E_{nD}^{0,75}}$

a) Reference is made to the mechanical power of the runner/impeller, usually measured on the model.

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3.4.14 Terms relating to additional performance data

For presentation and analysis of additional performance data such as pressure and torque fluctuations, hydraulic thrust, and hydraulic loads on control components, it is recommended to use dimensionless terms as defined hereafter and in 7.2.2 to 7.4. They are identified by the symbol of the measured quantity with subscripts denoting the machine component and the quantities taken as unity; for instance, $T_{G,ED}$ will denote the guide vane torque factor, i.e. the torque acting on the guide vanes based on specific hydraulic energy of the machine and reference diameter equal to unity.

The symbols used to define the measurements are listed below:

Subclause	Term	Definition	Symbol	Unit
3.4.14.1	Force	Influence tending to produce motion or stress on a machine component	F	N
3.4.14.2	Moment	Magnitude of a turning effect produced by a force acting at a perpendicular distance to a given point	M	N·m
3.4.14.3	Pressure	The force per unit area	p	Pa
3.4.14.4	Torque	The axial component of the moment	T	N·m

The dimensionless terms relating to additional performance data are listed below:

Subclause	Term	Definition	Symbol	Unit
3.4.14.5	Torque factor	$T_{ED} = \frac{T}{\rho D^3 E}$	T_{ED}	-
3.4.14.6	Torque coefficient	$T_{nD} = \frac{T}{\rho n^2 D^5}$	T_{nD}	-
3.4.14.7	Force factor	$F_{ED} = \frac{F}{\rho D^2 E}$	F_{ED}	-
3.4.14.8	Force coefficient	$F_{nD} = \frac{F}{\rho n^2 D^4}$	F_{nD}	-
3.4.14.9	Pressure fluctuation factor	$\tilde{p}_E = \frac{\tilde{p}}{\rho E}$	$\tilde{p}_E$	-
3.4.14.10	Pressure fluctuation coefficient	$\tilde{p}_{nD} = \frac{\tilde{p}}{\rho n^2 D^2}$	$\tilde{p}_{nD}$	-

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4 Nature and extent of guarantees related to hydraulic performance

4.1 General

4.1.1 Design data and coordination

The purchaser shall be responsible for specifying the data on which guarantees are based including, for example, reference sections, water levels, specific hydraulic energies (see 3.4.7.1), and specific hydraulic energy losses. The purchaser is also responsible for coordinating efforts to determine interactions between the waterways and the electrical and mechanical parts of the machine.

The purchaser shall arrange for the machine supplier to be provided with data, accurate and sufficient in detail, to cover the following:

– operating water levels in all reservoirs;
– hydraulic losses of each part of the water conduit from intake to outlet;
– design drawings of water conduits associated with the hydraulic machine including valves and gates;
– any information relevant to the water flow in the conduit, such as any results of model tests of the conduits;
– in the case of rehabilitation of existing machines, particular attention is to be paid to the limitations imposed by the existing equipment (for example openings, surface roughness, generator limitations, etc.).

Attention shall be paid to flow conditions at the model inlet and outlet (see 5.1.2.4 and 5.1.3.3). In most cases, it will be sufficient to extend the model just beyond the high and low-pressure reference sections. These sections shall be included for the model tests in order to conform to this document. If the prototype installation is such that there is reason to believe that the total flow pattern through the waterways is not fully represented by the model, the contract shall specify the steps to be taken, which may include specifying the extent of the water passages to be modelled. In some other cases, the validity of the approach conditions shall have been verified by the purchaser through the test of a partial model of the plant prior to the test of the model machine.

4.1.2 Definition of the hydraulic performance guarantees

A contract for both regulated[4] and non-regulated prototype machines shall contain, as a minimum, guarantees covering power, discharge and/or specific hydraulic energy, efficiency, maximum momentary overspeed and maximum/minimum momentary pressure and maximum steady-state runaway speed (reverse runaway speed for a pump), as well as guarantees related to cavitation.

For a pump, the guarantee may also cover the maximum specific hydraulic energy (head) and the power at zero discharge, the latter with the impeller rotating in water and/or air at the specified speed.

The guarantees shall be given for one or more operating points (see 4.2.2). These points belong to performance curves of the machine, which are usually submitted by the supplier. In some cases (e.g. small hydro), a table may be sufficient.

[4] "Regulated" as used in this document refers to the control of the discharge through variations of guide vane opening, needle stroke and/or runner/impeller blade angle.

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The current state of the art permits the verification of some of these prototype guarantees by model test (see 4.2), while others cannot be verified by model tests (see 4.3). Moreover, additional data may be obtained from the model as an indication of the expected prototype operation (see 4.4).

4.1.3 Guarantees of correlated quantities

It is recommended that the contract does not fix more than one guarantee for correlated quantities; for example in the case of a regulated turbine, efficiency shall be guaranteed versus either discharge or power, but not both.

4.1.4 Form of guarantees

Either of the following two forms of guarantees may be applied when the performance of a prototype machine is to be accepted on the basis of a model test:

a) Guarantees for the hydraulic performance of the prototype, computed from model test results with allowance for scale effect. For reaction machines, the scale effect is to be taken into account in accordance with 6.8 and Annex D. For impulse turbines, when it is agreed in the contract, the scale effect should be taken into account in accordance with Annex I.

b) Guarantees for the hydraulic performance of the model referred to a Reynolds number (Reynolds, Froude and Weber numbers for impulse turbines) to be specified in the contract.

In each case, the similitude requirements of 5.3 shall be met.

4.2 Main hydraulic performance guarantees verifiable by model test

4.2.1 Guaranteed quantities for any machine

4.2.1.1 Power

The term power usually refers to the mechanical power of the runner/impeller (see 3.4.9.3). When the mechanical power of the machine (see 3.4.9.2) is guaranteed for the prototype, the mechanical power losses (see 3.4.9.4) are to be taken into account.

4.2.1.2 Discharge and/or specific hydraulic energy

This refers either to the discharge at the reference section (see 3.4.5.4), obtained when operating under specified specific hydraulic energies, or to the specific hydraulic energy obtained when operating with specified discharges.

4.2.1.3 Efficiency

The term efficiency refers to the hydraulic efficiency (see 3.4.10.1) unless otherwise specified. When the prototype efficiency (see 3.4.10.3) is guaranteed, the mechanical power losses (see 3.4.9.4) or the mechanical efficiency (see 3.4.10.2) is to be taken into account.

In reaction machines, the relationship between model and prototype hydraulic efficiencies shall be considered, as explained in Annex D. The currently accepted convention is to apply this relationship to the entire range of guaranteed efficiencies.

4.2.1.4 Steady-state runaway speed and/or discharge

A guarantee for maximum steady-state runaway speed (see 3.4.5.12) or for the reverse runaway speed in case of pumps is required. An additional guarantee for maximum discharge under runaway conditions may be required.

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The no-load discharge for turbine operation shall be determined as part of the characteristic runaway-curve (see Figure 56).

4.2.1.5 Influence of cavitation on hydraulic performance

The contract shall clearly state the hydraulic conditions (specific hydraulic energies and net positive suction specific energies) for which the hydraulic performances are to be guaranteed.

The guarantees of the hydraulic performance of the prototype shall include the influence of cavitation. According to current engineering practice, this influence is determined by the model tests performed in accordance with 5.3.5.2, 5.5.3.6, 6.8.2.3.8 and 6.8.3.2.

The application of the efficiency transposition formula due to the Reynolds number is limited to the range of σ values specified in 6.8.2.4.2. The contract shall specify the procedure to be used if σ_{pl} falls outside this range.

In some cases, the contract may contain an additional clause on cavitation specifying that the measured value of the Thoma number chosen as criterion (σ_d) shall be lower than the plant Thoma number σ_{pl} by a margin (see 6.10.5). The criterion and the margin shall be specified in the contract.

4.2.2 Specific application

4.2.2.1 Regulated turbine (see 6.10.3.1.2)

Guarantee	Criteria
Power	Power to be reached at one or more specified specific hydraulic energies
Discharge	Discharge to be reached at one or more specified specific hydraulic energies
Efficiency	Guarantees may be required for one or more specified specific hydraulic energies as follows: – at one or more specified powers or discharges; or – as weighted average efficiency[a)] over a specified range of powers or discharges
Runaway speed	Guaranteed steady-state runaway speed not to be exceeded when operating under maximum or any other specified specific hydraulic energy. In the case of double-regulated machines, it shall be stated if the guarantee refers to the condition in which the optimum relationship between guide vane opening and runner blade angle is maintained (on-cam condition) or/and to the maximum runaway speed occurring in the worst possible off-cam condition
Cavitation	Guarantees as outlined in 4.2.1.5 may be required for one or more specified specific hydraulic energies, discharges or powers, usually for the corresponding minimum σ_{pl} value
[a)] Weighted efficiencies and a series of individual efficiencies shall not be guaranteed simultaneously	

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4.2.2.2 Non-regulated turbine (see 6.10.3.1.3)

Guarantee	Criteria
Power	Power to be reached and power not to be exceeded over a specified range of specific hydraulic energies[a)]
Discharge	Discharge to be reached and/or not to be exceeded over a specified range of specific hydraulic energies. This guarantee is usually replaced by the corresponding power guarantee
Efficiency	Guarantees may be required for one or more specified specific hydraulic energies as follows: – at one or more specified specific hydraulic energies; or – as a weighted average efficiency[b)] over a specified range of specific hydraulic energies
Runaway speed	Guaranteed steady-state runaway speed not to be exceeded when operating under maximum specific hydraulic energy
Cavitation	Guarantees as outlined in 4.2.1.5 may be required for one or more specified specific hydraulic energies, usually for the corresponding minimum σ_{pl} value
a) For the contractual limits of the power corresponding to the specified specific hydraulic energies, see 6.10.3.1.3. b) Weighted efficiencies and a series of individual efficiencies shall not be guaranteed simultaneously.	

4.2.2.3 Non-regulated/regulated pump (see 6.10.3.1.4)

Guarantee	Criteria
Power	Power not to be exceeded over a specified range of specific hydraulic energies or discharge
Discharge and/or specific hydraulic energy	Discharge over a specified range of specific hydraulic energies or specific energies over a specified range of discharges, including values to be reached and/or not to be exceeded
Efficiency	Guarantees may be required for one or more specified specific hydraulic energies or discharges as follows: – at one or more specified specific hydraulic energies or discharges; or – as a weighted average efficiency[a)] over a specified range of specific hydraulic energies or discharges
Runaway speed	Guaranteed maximum steady-state reverse runaway speed not to be exceeded when operating under maximum specified specific hydraulic energy. In the case of double-regulated machines, it shall be stated if the guarantee is referred to the condition in which the optimum relationship between guide vane opening and impeller blade angle is maintained (on-cam condition) or/and to the maximum runaway speed occurring in the worst possible off-cam condition
Cavitation	Guarantees as outlined in 4.2.1.5 may be required for one or more specified specific hydraulic energies, discharges or powers, usually for the corresponding minimum σ_{pl} value
a) Weighted efficiencies and a series of individual efficiencies shall not be guaranteed simultaneously	

4.3 Guarantees not verifiable by model test

4.3.1 Guarantees on cavitation erosion

The amount of cavitation pitting is to be guaranteed for the prototype only. Evaluation of this guarantee on the prototype shall be carried out in accordance with the recommendations of the IEC 60609 series.

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The model test may reveal some of the potential areas of cavitation erosion by visual inspection during the tests (see 5.5.3.6).

4.3.2 Guarantees on maximum momentary overspeed and maximum momentary pressure rise

Momentary overspeed (including momentary runaway speed) and pressure depend primarily upon water conduit geometry (penstock length, surge tank, etc.), the inertia of the rotating part of the unit and the operating law of the guide vanes. They can therefore not be determined directly by a dynamic test on the model which does not reproduce either the full extent of the applicable waterways, the inertia of the unit or the characteristics of the speed governor. Nevertheless, the steady-state model test data, transferred to the prototype, provide values enabling calculation of the transient phenomena with sufficient accuracy.

4.3.3 Guarantees covering noise and vibration

Determination of prototype noise and vibration by model tests lies outside the scope of this document. This document should be used only as a guide for the modelling of the hydraulic sources of these phenomena (i.e. through determination of the pressure fluctuations or other dynamic loads).

4.4 Additional performance data

Additional data may be obtained from the model:

– pressure fluctuations (see 7.2.2);
– shaft torque fluctuations (see 7.2.3);
– hydraulic thrust, both radial and axial (see 7.3);
– hydraulic torque on guide vanes and adjustable runner/impeller blades or hydraulic forces on needles and deflectors over the full operating range (see 7.4);
– characteristics in four quadrant operation including power and specific hydraulic energy at zero discharge (shut-off conditions) of a pump with impeller rotating in water or air (see 7.5);
– differential pressure measurements in view of prototype index tests (see 7.6);
– cam relationship for optimum performance in the case of double-regulated machines (relation between guide vane and runner/impeller blade openings) (see 6.8).

It may also be specified to determine other additional data, such as velocity or pressure distribution in various components of the machine, etc.

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5 Execution of tests

5.1 Requirements of test installation and model

5.1.1 Choice of laboratory

Any laboratory satisfying the criteria set out in this document concerning general layout, capacity and quality of instrumentation should be deemed suitable. An independent laboratory is sometimes preferable, particularly when comparative tests are required with models from different manufacturers.

5.1.2 Test installation

5.1.2.1 General characteristics of the test circuit

The test circuit shall be such that when cavitation appears in the model, it shall not occur elsewhere to an extent whereby it affects the stability or the satisfactory operation of the installation or of the model performance measurement.

Any entrained gas bubbles in the model shall not affect the functioning of instrumentation, particularly the flow measuring device and the pressure measurement lines.

The circuit shall be designed in such a manner that no leakage or addition of water may occur between the flow measuring instrument and the model. These criteria should be easily verifiable.

5.1.2.2 Capacity of the test installation

The capacity of the test installation (i.e. power, pressure, specific hydraulic energy, discharge and *NPSE*) shall be such that the minimum values for model size and the required test conditions as listed in 5.4.2 can be met.

The operation shall be stable and steady without surging or fluctuating effects (see 5.4.3).

5.1.2.3 Condition of the water

The test water shall be clean, clear and free of any solid material in suspension and any chemical impurities which may have an influence on the water properties such as viscosity and vapour pressure. Free gas and air bubbles should be removed as far as possible before testing (see 5.3.5.2 for recommended level).

The gas content (see 5.7.3.2), including both entrained and dissolved gas, of the water used in the test rig, should be recorded for the test, especially with respect to repeatability of cavitation test results and for comparison purposes.

Experience in closed circuits indicates that dissolved air may produce nuclei in the water and the nuclei content plays a major role in travelling cavitation, e.g. gas bubbles moving through the flow (see 5.3.6.2 for nuclei influence on cavitation). Therefore, this may influence the cavitation pattern and the resulting cavitation characteristics (see 5.3.5 and 5.3.6.2).

Thoma similitude should be fulfilled by using an appropriate specific hydraulic energy or/and nuclei content.

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