

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

The European Standard EN 60193:1999 has the status of a  
British Standard

ICS 27.140

# National foreword

This British Standard is the official English language version of EN 60193:1999. It is identical with IEC 60193:1997. It supersedes BS EN 60995:1995 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/15, Hydraulic turbines, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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English version

**Hydraulic turbines, storage pumps and pump-turbines  
Model acceptance tests  
(IEC 60193:1999)**

Turbines hydrauliques, pompes  
d'accumulation et pompes-turbines  
Essais de réception sur modèle  
(CEI 60193:1999)

Hydraulische Turbinen,  
Speicherpumpen und Pumpturbinen  
Modellabnahmeprüfungen  
(IEC 60193:1999)

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European Committee for Electrotechnical Standardization  
Comité Européen de Normalisation Electrotechnique  
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### Foreword

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with the EN have to be withdrawn (dow) 2002-12-01

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

Annexes designated "informative" are given for information only.

In this standard, annexes B, F, G, K, L, M and ZA are normative and annexes A, C, D, E, H, J, N and P are informative.

Annex ZA has been added by CENELEC.

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### Endorsement notice

The text of the International Standard IEC 60193:1999 was approved by CENELEC as a European Standard without any modification.

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

## 1 General rules

### 1.1 Scope and object

#### 1.1.1 Scope

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

This standard 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 standard may be used for such machines by agreement between purchaser and supplier.

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

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

This standard 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.

#### 1.1.2 Object

This International Standard 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 1.4.2) 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 standard 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, which fall within the scope of this standard, 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.

Moreover additional performance data (see 1.4.4) can be needed for the design or the operation of the prototype of the hydraulic machine. Contrary to the requirements of clauses 1 to 3 related to main hydraulic performance the information of these additional data given in clause 4 is considered only as recommendation or guidance to the user (see 4.1).

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

This standard 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, clause 15).

If a contradiction is found between this standard and any other standard, this standard shall prevail.

## 1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60041:1991, *Field acceptance test to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines*

IEC 60609:1978, *Cavitation pitting evaluation in hydraulic turbines, storage pumps and pump-turbines*

IEC 60609-2:1997, *Cavitation pitting evaluation in hydraulic turbines, storage pumps and pump-turbines – Part 2: Evaluation in Pelton turbines*

IEC 60994:1991, *Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines)*

IEC 61364:1999, *Nomenclature of hydraulic machinery*

IEC 61366 (all parts), *Hydraulic turbines storage pumps and pump-turbines – Tendering documents*

ISO 31-3:1992, *Quantities and units – Part 3: Mechanics*

ISO 31-12:1992, *Quantities and units – Part 12: Characteristic numbers*

ISO 468:1982, *Surface roughness – Parameters, their values and general rules for specifying requirements*

ISO 1438-1:1980, *Water flow measurement in open channels using weirs and Venturi flumes – Part 1: Thin-plate weirs*

ISO 2186:1973, *Fluid flow in closed conduits – Connections for pressure signal transmissions between primary and secondary elements*

ISO 2533:1975, *Standard atmosphere*  
Addendum 1: 1985

ISO 4006:1991, *Measurement of fluid flow in closed conduits – Vocabulary and symbols*

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

ISO 4373:1995, *Measurement of liquid flow in open channels – Water level measuring devices*

ISO 5167-1:1991, *Measurement of fluid flow by means of pressure differential devices – Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*

ISO 5168:1978, *Measurement of fluid flow – Estimation of uncertainty of a flow-rate measurement*

ISO 6817:1992, *Measurement of conductive liquid flow in closed conduits – Method using electromagnetic flowmeters*

ISO 7066-1:1997, *Assessment of uncertainty in the calibration and use of flow measurement devices – Part 1: Linear calibration relationship*

ISO 7066-2:1988, *Assessment of uncertainty in the calibration and use of flow measurement devices – Part 2: Non-linear calibration relationships*

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

ISO 9104:1991, *Measurement of fluid flow in closed conduits – Methods of evaluating the performance of electromagnetic flow-meters for liquids*

VIM:1993, *International vocabulary of basic and general terms in metrology (BIPM-IEC-ISO-OIML)*

### **1.3 Terms, definitions, symbols and units**

#### **1.3.1 General**

For the purpose of this International Standard 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.

##### **1.3.1.1 point**

A *point* is 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

##### **1.3.1.2 test**

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

**1.3.1.3 hydraulic performance**

all performance parameters attributable to the machine due to hydrodynamic effects

**1.3.1.4 main hydraulic performance data**

a subset of the hydraulic performance parameters, i.e. power, discharge and/or specific hydraulic energy, efficiency, steady-state runaway speed and/or discharge. The influence of cavitation must be considered.

**1.3.1.5 additional data**

a subset of hydraulic performance data which can be determined for information on the model (see 1.4.4). However, the prediction of the corresponding prototype data is less accurate than that achievable for the main hydraulic performance data, due to application of approximate similarity rules.

**1.3.1.6 guarantees**

specified performance data contractually agreed to

**1.3.2 Units**

The international System of Units (SI, see ISO 31-3) has been used throughout this standard.

All terms are given in SI base units or derived coherent units<sup>1)</sup>. 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<sup>-1</sup> instead of s<sup>-1</sup> 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.

---

<sup>1)</sup> N = kg·m·s<sup>-2</sup> Pa = kg·m<sup>-1</sup>·s<sup>-2</sup> J = kg·m<sup>2</sup>·s<sup>-2</sup> W = kg·m<sup>2</sup>·s<sup>-3</sup>

### 1.3.3 List of terms, definitions, symbols and units

#### 1.3.3.1 Subscripts and symbols

| Subclause                                                                                                                                                                                                | Term                                          | Definition                                                                                                                                     | Subscript or symbol                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| 1.3.3.1.1                                                                                                                                                                                                | High pressure <sup>1)</sup> reference section | The high pressure section of the machine to which the performance guarantees refer (see figure 1)                                              | 1                                                     |
| 1.3.3.1.2                                                                                                                                                                                                | Low pressure <sup>1)</sup> reference section  | The low pressure section of the machine to which the performance guarantees refer (see figure 1)                                               | 2                                                     |
| 1.3.3.1.3                                                                                                                                                                                                | High pressure measuring sections              | Whenever possible, these sections should coincide with section 1; otherwise the measured values must be adjusted to section 1 (see 3.5.2.1.3)  | 1', 1" ..                                             |
| 1.3.3.1.4                                                                                                                                                                                                | Low pressure measuring sections               | Whenever possible, these sections should coincide with section 2; otherwise, the measured values must be adjusted to section 2 (see 3.5.2.1.3) | 2', 2" ..                                             |
| 1.3.3.1.5                                                                                                                                                                                                | Specified                                     | Subscript denoting values of quantities such as rotational speed, discharge etc. for which other quantities are guaranteed                     | sp                                                    |
| 1.3.3.1.6                                                                                                                                                                                                | Maximum/minimum                               | Subscript denoting maximum or minimum values of any term                                                                                       | max<br>min                                            |
| 1.3.3.1.7                                                                                                                                                                                                | Limits                                        | Contractually defined values:<br>– not to be exceeded<br>– to be reached                                                                       | $\overline{\quad}$<br>$\square$ or $\overline{\quad}$ |
| 1.3.3.1.8                                                                                                                                                                                                | Prototype                                     | Subscript denoting values related to the full size machine                                                                                     | P                                                     |
| 1.3.3.1.9                                                                                                                                                                                                | Model                                         | Subscript denoting values related to the model                                                                                                 | M                                                     |
| 1.3.3.1.10                                                                                                                                                                                               | Model at constant Reynolds number             | Subscript denoting values related to a model and referred to a constant value of Reynolds number                                               | M*                                                    |
| 1.3.3.1.11                                                                                                                                                                                               | Reference                                     | Subscript denoting values related to a specified reference condition                                                                           | ref                                                   |
| 1.3.3.1.12                                                                                                                                                                                               | Optimum                                       | Subscript denoting the best efficiency point                                                                                                   | opt                                                   |
| 1.3.3.1.13                                                                                                                                                                                               | Ambient                                       | Subscript referring to surrounding atmospheric conditions                                                                                      | amb                                                   |
| 1.3.3.1.14                                                                                                                                                                                               | Plant                                         | Subscript denoting values related to the operating conditions of the prototype in the plant                                                    | pl                                                    |
| 1.3.3.1.15                                                                                                                                                                                               | Runaway                                       | Subscript referring to runaway conditions                                                                                                      | R                                                     |
| <sup>1)</sup> 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. |                                               |                                                                                                                                                |                                                       |

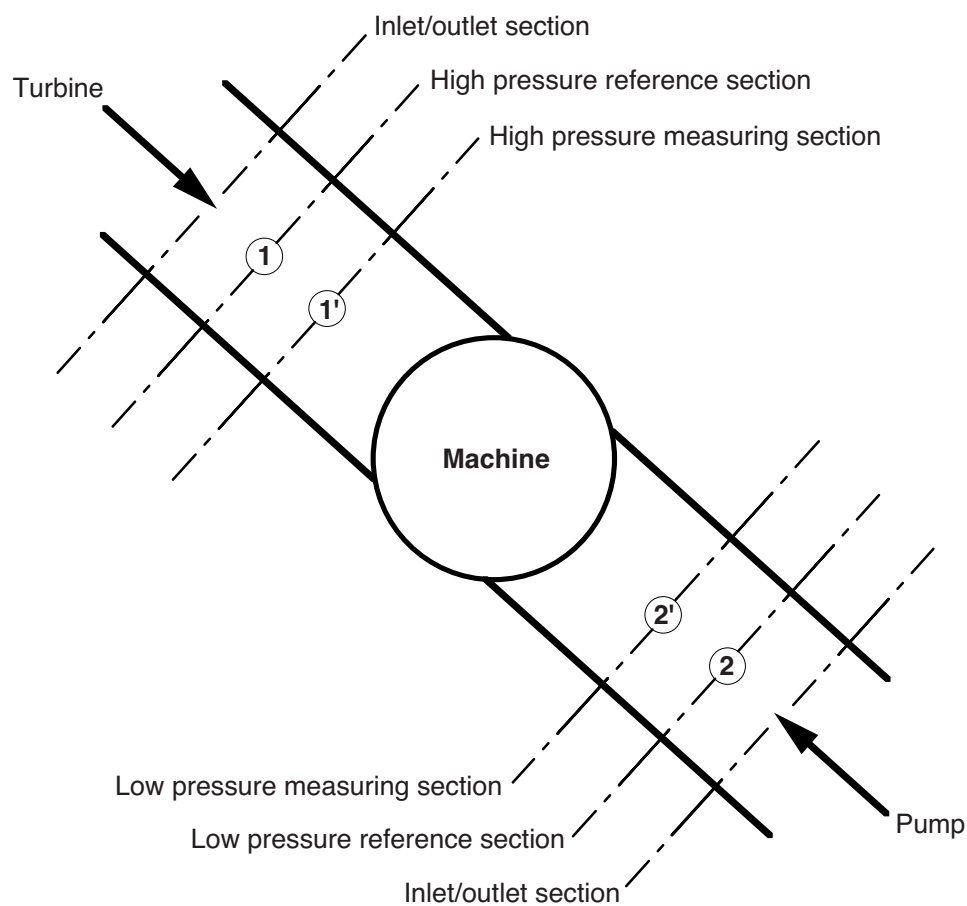
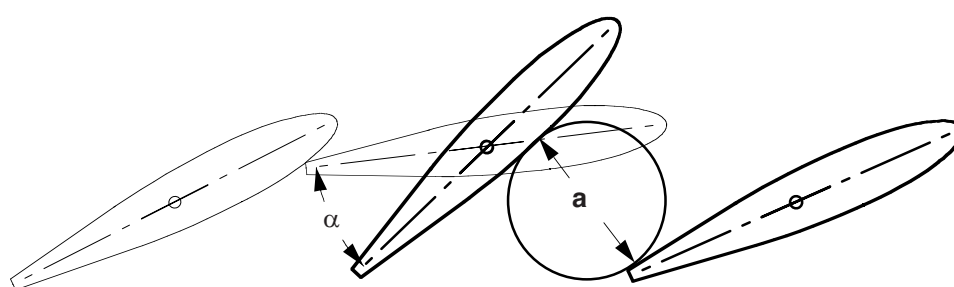


**Figure 1– Schematic representation of a hydraulic machine**

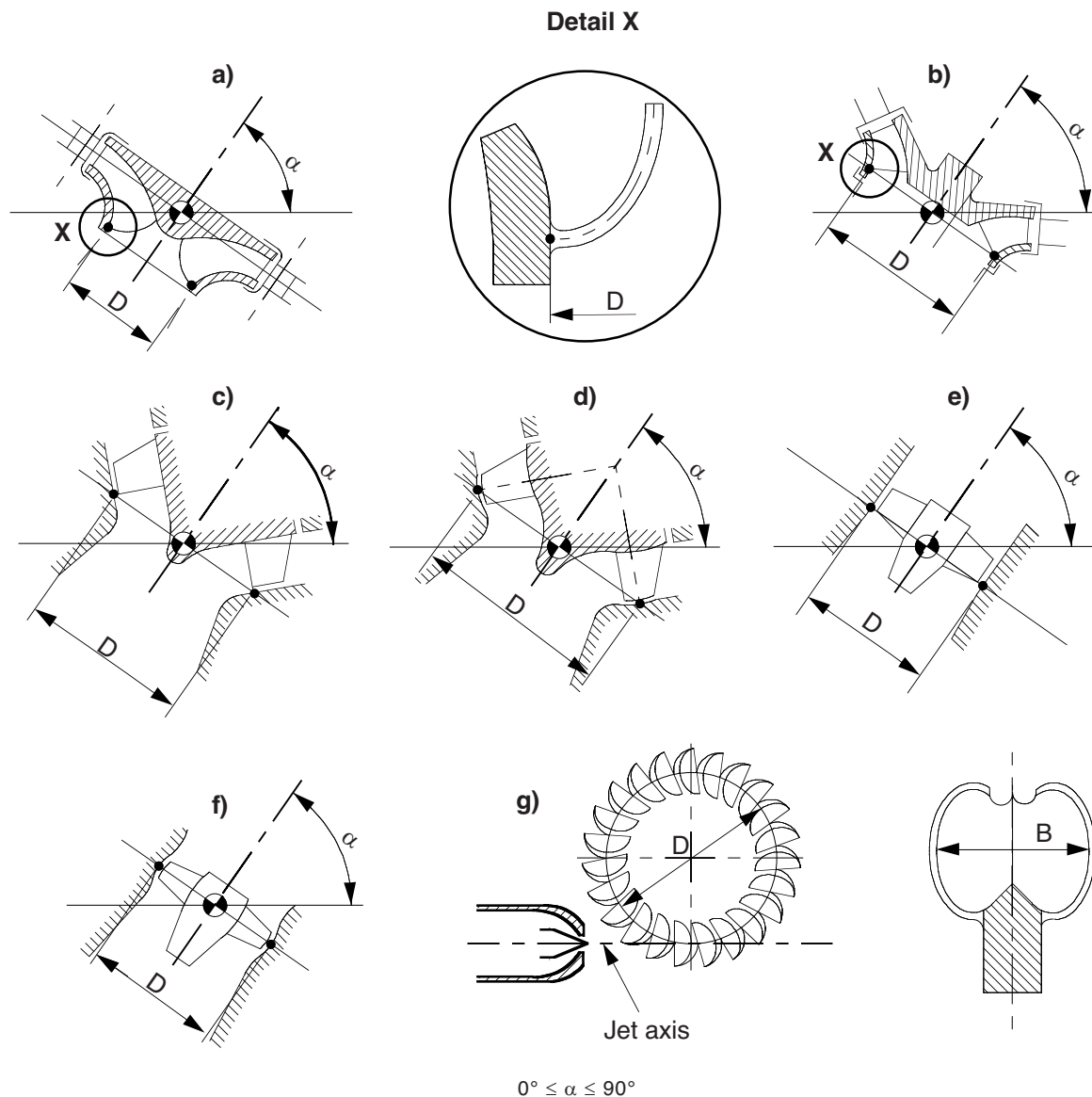


Closed position:  $\alpha = 0^\circ$  or  $a = 0$  mm

**Figure 2 – Guide vane opening and angle**

### 1.3.3.2 Geometric terms

| Subclause  | Term                               | Definition                                                                                                                                                                                                                   | Symbol      | Unit           |
|------------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|----------------|
| 1.3.3.2.1  | Area                               | Net cross sectional area normal to general flow direction                                                                                                                                                                    | A           | m <sup>2</sup> |
| 1.3.3.2.2  | Guide vane opening                 | Average shortest distance between adjacent guide vanes (at a specified section if necessary) (see figure 2)                                                                                                                  | a           | m              |
| 1.3.3.2.3  | Guide vane angle                   | Average vane angle measured from closed position (see figure 2)                                                                                                                                                              | $\alpha$    | °              |
| 1.3.3.2.4  | Needle stroke (impulse turbine)    | Average needle stroke measured from closed position                                                                                                                                                                          | s           | m              |
| 1.3.3.2.5  | Runner/impeller blade angle        | Average runner/impeller blade setting measured from a reference position                                                                                                                                                     | $\beta$     | °              |
| 1.3.3.2.6  | Reference diameter                 | Reference diameter of the hydraulic machine as given in figure 3                                                                                                                                                             | D           | m              |
| 1.3.3.2.7  | Runner outlet/impeller inlet width | Average shortest distance between two adjacent blades of runner/impeller (see figures 14 and 15)                                                                                                                             | $a_1, a_2$  | m              |
| 1.3.3.2.8  | Bucket width                       | Inside maximum width of runner bucket of a Pelton turbine (see figure 3)                                                                                                                                                     | B           | m              |
| 1.3.3.2.9  | Length scale ratio                 | The ratio of representative prototype to model lengths; in normal cases this is the reference diameter of the machine. In cases where it is difficult to verify this reference, then another significant length may be taken | $\lambda_L$ | -              |
| 1.3.3.2.10 | Level                              | Elevation of a point in the system above the specified reference datum (usually mean sea level)                                                                                                                              | z           | m              |



- 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) machines with fixed runner/impeller blades and with runner/impeller band.
- c) Diagonal (mixed-flow, semi-axial) machines with fixed runner/impeller blades, without runner/impeller band.
- d) Diagonal (mixed-flow, semi-axial) machines with adjustable runner/impeller blades.
- e) Axial machines, such as propeller turbines, tubular turbines<sup>1)</sup>, axial pumps and pump-turbines with fixed runner/impeller blades.
- f) Axial machines, such as Kaplan turbines, tubular turbines<sup>1)</sup>, axial pumps and pump-turbines with adjustable runner/impeller blades.
- g) Pelton turbines.

**Figure 3 – Reference diameter and bucket width**

<sup>1)</sup> The term "tubular turbines" includes bulb, pit, rim generator and S-type units.

### 1.3.3.3 Physical quantities and properties

| Subclause | Term                        | Definition                                                                                                                                                                                                                                                                                                                                                             | Symbol                                                | Unit                                                                                         |
|-----------|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 1.3.3.3.1 | Acceleration due to gravity | Local value of gravitational acceleration at the place of testing (see 2.5.2); theoretical values as a function of altitude and latitude are given in annex B, table B.1                                                                                                                                                                                               | g                                                     | m s <sup>-2</sup>                                                                            |
| 1.3.3.3.2 | Temperature                 | Thermodynamic<br>Celsius<br>$\theta = \Theta - 273,15$                                                                                                                                                                                                                                                                                                                 | $\Theta$<br>$\theta$                                  | K<br>°C                                                                                      |
| 1.3.3.3.3 | Density                     | Mass per unit volume<br>a) Density of water<br>$\rho$ is commonly used instead of $\rho_w$ . Values for distilled water $\rho_{wd}$ are given in 2.5.3.1.3 and in annex B, table B.2<br>b) Density of air<br>Values for air are given in 2.5.4.1 and in annex B, table B.5<br>c) Density of mercury<br>Values for mercury are given in 2.5.5 and in annex B, table B.7 | $\rho$<br>$\rho_w$<br><br>$\rho_a$<br><br>$\rho_{Hg}$ | kg m <sup>-3</sup><br>kg m <sup>-3</sup><br><br>kg m <sup>-3</sup><br><br>kg m <sup>-3</sup> |
| 1.3.3.3.4 | Vapour pressure (absolute)  | Absolute partial pressure of saturated vapour in a medium where liquid and gaseous phases of a body are in thermodynamic balance. The vapour pressure depends only on the temperature. Values for distilled water are given in 2.5.3.4 and in annex B, table B.4                                                                                                       | $p_{va}$                                              | Pa                                                                                           |
| 1.3.3.3.5 | Dynamic viscosity           | A quantity characterizing the mechanical behaviour of a fluid (see ISO 31-3)                                                                                                                                                                                                                                                                                           | $\mu$                                                 | Pa s                                                                                         |
| 1.3.3.3.6 | Kinematic viscosity         | Ratio of the dynamic viscosity to the density of a fluid. Values for distilled water as a function of temperature are given in 2.5.3.3 and in annex B, table B.3                                                                                                                                                                                                       | $\nu$                                                 | m <sup>2</sup> s <sup>-1</sup>                                                               |
| 1.3.3.3.7 | Surface tension             | A quantity characterizing the mechanical behaviour of the interface between two fluids (see ISO 31-3)                                                                                                                                                                                                                                                                  | $\sigma^*$                                            | J·m <sup>-2</sup>                                                                            |

**1.3.3.4 Discharge, velocity and speed terms**

| Subclause  | Term                                     | Definition                                                                                                                                                                                                                                                                        | Symbol                             | Unit                           |
|------------|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|--------------------------------|
| 1.3.3.4.1  | Discharge (volume flow rate)             | Volume of water per unit time passing through any section in the system                                                                                                                                                                                                           | Q                                  | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.2  | Mass flow rate                           | Mass of water flowing through any section of the system per unit time. Both $\rho$ and Q shall be determined at the same section and at the conditions existing in that section<br><br>NOTE – The mass flow rate is constant between two sections if no water is added or removed | ( $\rho Q$ )                       | kg s <sup>-1</sup>             |
| 1.3.3.4.3  | Measured discharge                       | Volume of water per unit time flowing through any measuring section, e.g. 1' (see 1.3.3.1.3 and 1.3.3.1.4)                                                                                                                                                                        | Q <sub>1'</sub> or Q <sub>2'</sub> | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.4  | Discharge at reference section           | Volume of water per unit time flowing through the reference section 1 or 2                                                                                                                                                                                                        | Q <sub>1</sub> or Q <sub>2</sub>   | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.5  | Corrected discharge at reference section | Volume of water per unit time flowing through the reference section referred to the ambient condition (see 1.3.3.5.2), e.g.<br><br>$Q_{1c} = (\rho Q)_1 / \rho_{amb}$<br><br>Given the normal conditions of a model test, Q <sub>1c</sub> may be assumed equal to Q <sub>1</sub>  | Q <sub>1c</sub> or Q <sub>2c</sub> | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.6  | Discharge at steady-state runaway speed  | Discharge at $n_R$ (see 1.3.3.4.12)                                                                                                                                                                                                                                               | Q <sub>R</sub>                     | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.7  | No-load turbine discharge                | Turbine discharge at zero mechanical power at specified speed (usually synchronous) and specified specific hydraulic energy                                                                                                                                                       | Q <sub>0</sub>                     | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.8  | Leakage flowrate                         | Volumetric loss as illustrated in figure 6                                                                                                                                                                                                                                        | q                                  | m <sup>3</sup> s <sup>-1</sup> |
| 1.3.3.4.9  | Mean velocity                            | Discharge Q divided by area A of the cross-section                                                                                                                                                                                                                                | v                                  | m s <sup>-1</sup>              |
| 1.3.3.4.10 | Peripheral velocity                      | Peripheral velocity at the reference diameter (see figure 3): $u = \pi D n$                                                                                                                                                                                                       | u                                  | m s <sup>-1</sup>              |
| 1.3.3.4.11 | Rotational speed                         | Number of revolutions per unit time                                                                                                                                                                                                                                               | n                                  | s <sup>-1</sup>                |
| 1.3.3.4.12 | 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 <sup>-1</sup>                |
| 1.3.3.4.13 | 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)                                                                                                                                       | $n_{Rmax}$                         | s <sup>-1</sup>                |

### 1.3.3.5 Pressure terms

| Subclause | Term              | Definition                                                                                                                                                                                                           | Symbol    | Unit |
|-----------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|------|
| 1.3.3.5.1 | Absolute pressure | The static pressure of a fluid measured with reference to a perfect vacuum                                                                                                                                           | $p_{abs}$ | Pa   |
| 1.3.3.5.2 | Ambient pressure  | The absolute pressure of the ambient air (see 2.5.4.2). Values for standard atmosphere are given as a function of elevation in annex B, table B.6                                                                    | $p_{amb}$ | Pa   |
| 1.3.3.5.3 | 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,<br>$p = p_{abs} - p_{amb}$ | $p$       | Pa   |

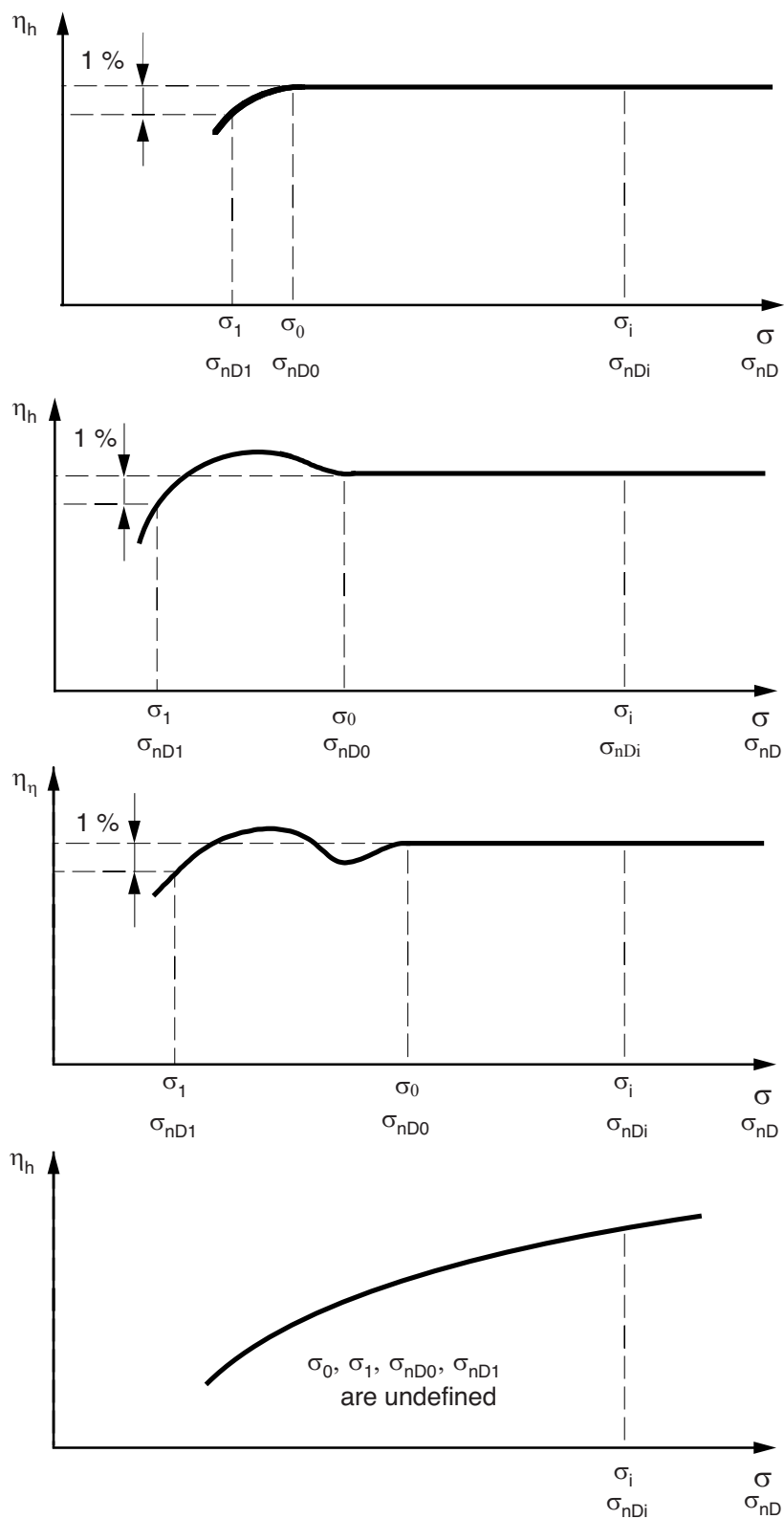
### 1.3.3.6 Specific energy terms

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 standard 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 1.3.3.7. They differ only by the factor  $g$ , which is the local value of acceleration due to gravity.

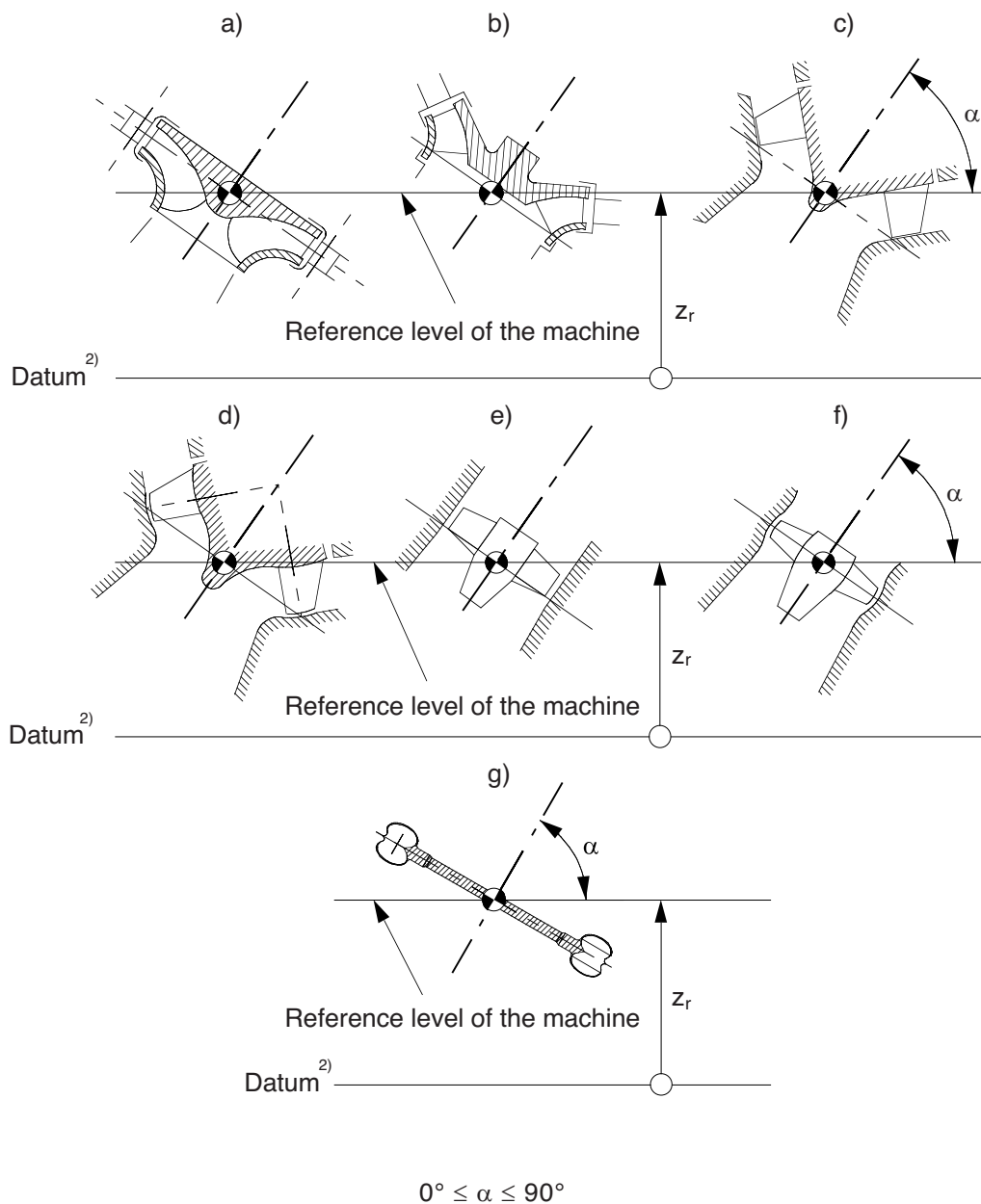
| Subclause                                                                                                                                                                                                                          | Term                                                            | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Symbol         | Unit               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------------|
| 1.3.3.6.1                                                                                                                                                                                                                          | Specific energy                                                 | The energy per unit mass of water at any section                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | e              | J kg <sup>-1</sup> |
| 1.3.3.6.2                                                                                                                                                                                                                          | Specific hydraulic energy of machine                            | <p>Specific energy of water available between the high and low pressure reference sections 1 and 2 of the machine, taking into account the influence of compressibility <sup>1) 2)</sup></p> $E = \frac{p_{abs1} - p_{abs2}}{\bar{\rho}} + \frac{v_1^2 - v_2^2}{2} + (z_1 - z_2)g$ <p>with <math>\bar{\rho} = \frac{\rho_1 + \rho_2}{2}</math> and assuming <math>g = g_1 = g_2</math></p> <p>The value of <math>\rho_1</math> and <math>\rho_2</math> can be calculated from <math>p_{abs1}</math> and <math>p_{abs2}</math> respectively, taking into account <math>\theta_1</math> or <math>\theta_2</math> for both values, given the negligible influence of the difference of the temperature on <math>\rho</math></p> | E              | J kg <sup>-1</sup> |
| 1.3.3.6.3                                                                                                                                                                                                                          | Zero-discharge (shut-off) specific hydraulic energy of the pump | Pump specific energy at specified speed and specified guide vane and impeller blade settings with high pressure side shut off                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | E <sub>o</sub> | J kg <sup>-1</sup> |
| 1.3.3.6.4                                                                                                                                                                                                                          | Suction specific potential energy of the machine                | <p>Specific potential energy at section 2 corresponding to the difference between the reference level of the machine (see 1.3.3.7.6) and the piezometric level at section 2</p> $E_s = g(z_r - z_{2'}) = g(z_r - z_2) - \frac{p_{abs2} - p_{amb}}{\rho_2}$ <p>(see figure 45)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                            | E <sub>s</sub> | J kg <sup>-1</sup> |
| 1.3.3.6.5                                                                                                                                                                                                                          | Net positive suction specific energy                            | <p>Absolute specific energy at section 2 minus the specific energy due to the vapour pressure <math>p_{va}</math> <sup>3)</sup> referred to the reference level of the machine (see figure 45)</p> $NPSE = \frac{p_{abs2} - p_{va}}{\rho_2} + \frac{v_2^2}{2} - g(z_r - z_2)$ $= -E_s + \frac{p_{abs2} - p_{va}}{\rho_2} + \frac{v_2^2}{2}$                                                                                                                                                                                                                                                                                                                                                                                  | NPSE           | J kg <sup>-1</sup> |
| <p><sup>1)</sup> Subclause 3.5 illustrates some common cases of application of the basic formula for the specific hydraulic energy.</p> <p><sup>2)</sup> For derivation of E, see annex C.</p> <p><sup>3)</sup> See 1.3.3.3.4.</p> |                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                    |

| Subclause                                                                       | Term                                 | Definition                                                                                                                                                                                                                                                                                                      | Symbol        | Unit               |
|---------------------------------------------------------------------------------|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|--------------------|
| 1.3.3.6.6                                                                       | Thoma number                         | Dimensionless term indicating the conditions of cavitation under which the machine operates. It is expressed as the ratio of net positive suction specific energy NPSE to a specific hydraulic energy $E$ (see 1.3.3.12.9)                                                                                      | $\sigma$      | -                  |
| 1.3.3.6.7                                                                       | Cavitation coefficient               | Dimensionless term indicating the conditions of cavitation under which the machine operates. It is expressed as the ratio of net positive suction specific energy NPSE to $n^2 D^2$ (see 1.3.3.12.10)                                                                                                           | $\sigma_{nD}$ | -                  |
| 1.3.3.6.8                                                                       | Thoma number zero <sup>1)</sup>      | 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. In some cases, the shape of the cavitation curve $\eta_h(\sigma)$ is such that the Thoma number zero is difficult to define (see figure 4) | $\sigma_o$    | -                  |
| 1.3.3.6.9                                                                       | Thoma number one <sup>1)</sup>       | 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. In some cases, the shape of the cavitation curve is such that the Thoma number one is difficult to define (see figure 4)                                    | $\sigma_1$    | -                  |
| 1.3.3.6.10                                                                      | Defined Thoma number <sup>1)</sup>   | The value of the Thoma number associated with a defined onset of cavitation, e.g. a specified performance loss                                                                                                                                                                                                  | $\sigma_d$    | -                  |
| 1.3.3.6.11                                                                      | Incipient Thoma number <sup>1)</sup> | The value of the Thoma number associated with the beginning of visible runner/impeller cavitation usually detected by observation                                                                                                                                                                               | $\sigma_i$    | -                  |
| 1.3.3.6.12                                                                      | Plant Thoma number                   | The value of the Thoma number at the operating conditions of the prototype (see annex M)                                                                                                                                                                                                                        | $\sigma_{pl}$ | -                  |
| 1.3.3.6.13                                                                      | Specific hydraulic energy loss       | The specific hydraulic energy dissipated between any two sections                                                                                                                                                                                                                                               | $E_L$         | J kg <sup>-1</sup> |
| 1) A similar definition can be given for cavitation coefficient (see figure 4). |                                      |                                                                                                                                                                                                                                                                                                                 |               |                    |

Figure 4 – Definition of  $\sigma_0$  and  $\sigma_1$

### 1.3.3.7 Height and head terms

| Subclause | Term                                                 | Definition                                                                                                          | Symbol | Unit |
|-----------|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------|------|
| 1.3.3.7.1 | Head                                                 | Energy per local unit weight of water at any section $h = e/g$<br>For the definition of $e$ , see 1.3.3.6.1         | $h$    | m    |
| 1.3.3.7.2 | Turbine or pump head                                 | $H = E/g$<br>For the definition of $E$ , see 1.3.3.6.2                                                              | $H$    | m    |
| 1.3.3.7.3 | Zero discharge (shut-off) head of pump               | $H_0 = E_0 / g$<br>For the definition of $E_0$ , see 1.3.3.6.3                                                      | $H_0$  | m    |
| 1.3.3.7.4 | Suction height                                       | $Z_s = E_s / g$<br>For the definition of $E_s$ , see 1.3.3.6.4                                                      | $Z_s$  | m    |
| 1.3.3.7.5 | Net positive suction head                            | $NPSH = NPSE/g$<br>For the definition of $NPSE$ , see 1.3.3.6.5                                                     | NPSH   | m    |
| 1.3.3.7.6 | 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    |
| 1.3.3.7.7 | Cavitation reference level                           | Elevation of a point of the machine taken as reference for cavitation evaluation during model tests (see 2.3.1.5.1) | $z_c$  | m    |
| 1.3.3.7.8 | Reference level of the pressure measuring instrument | Elevation of a pressure measuring device (see figure 38)                                                            | $z_M$  | m    |



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) machines with fixed runner/impeller blades and with runner/impeller band.

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

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

e) Axial machines, such as propeller turbines, tubular turbines<sup>1)</sup>, axial pumps and pump-turbines with fixed runner/impeller blades.

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

g) Pelton turbines.

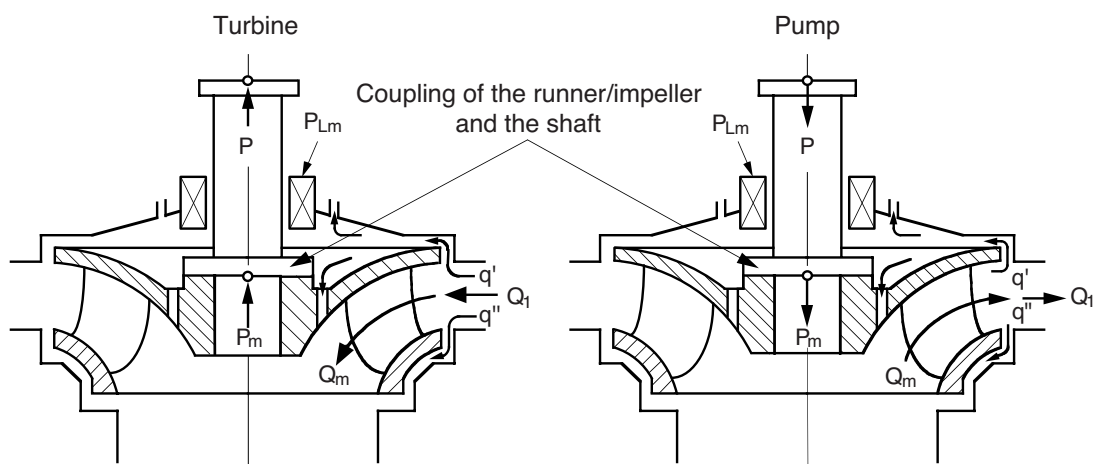
**Figure 5 – Reference level of machine**

<sup>1)</sup> The term "tubular turbines" includes bulb, pit, rim generator and S-type units.

<sup>2)</sup> See 1.3.3.2.10.

### 1.3.3.8 Power and torque terms

| Subclause | Term                                        | Definition                                                                                                                                                                                 | Symbol   | Unit |
|-----------|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|------|
| 1.3.3.8.1 | Hydraulic power                             | The hydraulic power available for producing power (turbine) or imparted to the water (pump)<br>$P_h = E(\rho Q)_1$                                                                         | $P_h$    | W    |
| 1.3.3.8.2 | 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    |
| 1.3.3.8.3 | 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    |
| 1.3.3.8.4 | Mechanical power losses                     | Mechanical power dissipated in guide bearings, thrust bearings and shaft seals of the hydraulic machine (see figure 6)                                                                     | $P_{Lm}$ | W    |
| 1.3.3.8.5 | 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                                                                           | $P_o$    | W    |
| 1.3.3.8.6 | Shaft torque                                | Torque applied to the shaft of the hydraulic machine and corresponding to the mechanical power of the machine (see 1.3.3.8.2)                                                              | $T$      | N·m  |
| 1.3.3.8.7 | 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 1.3.3.8.3)                                  | $T_m$    | N·m  |
| 1.3.3.8.8 | Friction torque                             | Friction torque in guide bearings, thrust bearings and shaft seals of the hydraulic machine (see 1.3.3.8.4)                                                                                | $T_{Lm}$ | N·m  |



|                               | <b>Turbine</b>                   | <b>Pump</b>                      |
|-------------------------------|----------------------------------|----------------------------------|
|                               | $q = q' + q''$                   | $q = q' + q''$                   |
|                               | $Q_1 = Q_m + q$                  | $Q_1 = Q_m - q$                  |
|                               | $P_h = E \cdot (\rho \cdot Q)_1$ | $P_h = E \cdot (\rho \cdot Q)_1$ |
|                               | $P = P_m - P_{Lm}$               | $P = P_m + P_{Lm}$               |
| Volumetric efficiency         | $\eta_v = \frac{Q_m}{Q_1}$       | $\eta_v = \frac{Q_1}{Q_m}$       |
| Hydraulic efficiency (note 3) | $\eta_h = \frac{P_m}{P_h}$       | $\eta_h = \frac{P_h}{P_m}$       |
| Efficiency                    | $\eta = \frac{P}{P_h}$           | $\eta = \frac{P_h}{P}$           |

## NOTES

- 1) The formulae ignore the compressibility of the water.
- 2) For detailed analysis of internal losses, refer to annex N.
- 3) The disk friction losses and leakage losses (volumetric losses) are considered as hydraulic losses in this formula. These "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

### 1.3.3.9 Efficiency terms

| Subclause                                                                                                                                                                                                                                                                              | Term                               | Definition                                                                                                                                                                                                                                                                                                                              | Symbol   | Unit |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|------|
| 1.3.3.9.1                                                                                                                                                                                                                                                                              | Hydraulic efficiency <sup>1)</sup> | <p>a) Turbine: ratio of mechanical power of runner to the hydraulic power</p> $\eta_h = \frac{P_m}{P_h}$ <p>b) Pump: ratio of hydraulic power to the mechanical power of the impeller</p> $\eta_h = \frac{P_h}{P_m}$ <p>See figure 6</p>                                                                                                | $\eta_h$ | -    |
| 1.3.3.9.2                                                                                                                                                                                                                                                                              | Mechanical efficiency              | <p>a) Turbine</p> $\eta_m = \frac{P}{P_m}$ <p>b) Pump</p> $\eta_m = \frac{P_m}{P}$                                                                                                                                                                                                                                                      | $\eta_m$ | -    |
| 1.3.3.9.3                                                                                                                                                                                                                                                                              | Efficiency                         | <p>a) Turbine</p> $\eta = \frac{P}{P_h} = \eta_h \eta_m$ <p>b) Pump</p> $\eta = \frac{P_h}{P} = \eta_h \eta_m$                                                                                                                                                                                                                          | $\eta$   | -    |
| 1.3.3.9.4                                                                                                                                                                                                                                                                              | Weighted average efficiency        | <p>Calculated from the formula</p> $\eta_w = \frac{w_1 \eta_1 + w_2 \eta_2 + w_3 \eta_3 + \dots}{w_1 + w_2 + w_3 + \dots}$ <p>where <math>\eta_1, \eta_2, \eta_3, \dots</math> are the values of efficiency at specified operating conditions and <math>w_1, w_2, w_3, \dots</math> are their agreed weighting factors respectively</p> | $\eta_w$ | -    |
| 1.3.3.9.5                                                                                                                                                                                                                                                                              | Arithmetic average efficiency      | <p>The weighted average efficiency (1.3.3.9.4) with</p> $w_1 = w_2 = w_3 \dots$                                                                                                                                                                                                                                                         | $\eta_a$ | -    |
| <sup>1)</sup> The disk friction losses and leakage losses (volumetric losses) are included and are considered here as hydraulic losses. The disk friction losses are the friction losses of the outer surfaces of the runner/impeller not in contact with the flow passing the blades. |                                    |                                                                                                                                                                                                                                                                                                                                         |          |      |

### 1.3.3.10 General terms relating to fluctuating quantities

IEC 60994 provides a reference for terms relating to these quantities. The following table lists the terms relevant to this standard, some of which are illustrated in figure 7:

| Subclause  | Term                                                      | Definition                                                                                                               | Symbol                   | IEC 60994 Reference |
|------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------|---------------------|
| 1.3.3.10.1 | Discrete quantity                                         | Quantity represented by a sequence of its momentary values                                                               | $X$                      |                     |
| 1.3.3.10.2 | Fluctuation of quantity (pulsation of quantity)           | Oscillatory variation of a quantity $X$ referred to its mean value during a time interval $\Delta t$ previously selected | $\tilde{X}(t)$           | 2.3.1.5, etc.       |
| 1.3.3.10.3 | Mean value                                                | $\bar{X} = \frac{\sum_{n=1}^N X_n}{N}$                                                                                   | $\bar{X}$                | 2.3.3.1             |
| 1.3.3.10.4 | Maximum value                                             |                                                                                                                          | $X_{\max}$               |                     |
| 1.3.3.10.5 | Minimum value                                             |                                                                                                                          | $X_{\min}$               |                     |
| 1.3.3.10.6 | Standard deviation (effective value referred to the mean) | $\tilde{X}_{\text{eff}} = \sqrt{\frac{\sum_{n=1}^N (X_n - \bar{X})^2}{N}}$                                               | $\tilde{X}_{\text{eff}}$ | 2.3.3.2             |
| 1.3.3.10.7 | Root-mean-square value                                    | $X_{\text{rms}} = \sqrt{\frac{\sum_{n=1}^N X_n^2}{N}}$                                                                   | $X_{\text{rms}}$         | 2.3.3.3             |
| 1.3.3.10.8 | Peak-to-peak value                                        | $\Delta X_{\text{pp}} = X_{\max} - X_{\min}$                                                                             | $\Delta X_{\text{pp}}$   | 2.3.2.11            |
| 1.3.3.10.9 | Amplitude                                                 | Maximum value of a sinusoidal quantity $X(t)$ :<br>$A = \frac{1}{2} \Delta X_{\text{pp}}$                                | $A$                      | 2.3.2.10            |

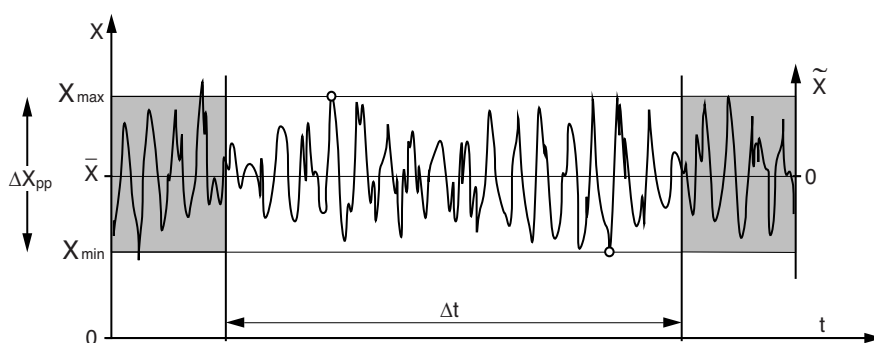


Figure 7 – Illustration of some definitions related to oscillating quantities

### 1.3.3.11 Fluid dynamic and scaling terms <sup>1)</sup>

| Subclause                                                                                                                                                 | Term                               | Definition                                                                                                                                                                                                                          | Symbol         | Unit |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------|
| 1.3.3.11.1                                                                                                                                                | Reynolds number                    | Ratio of inertia forces to viscous forces<br>$Re = \frac{Du}{\nu}$ or $\frac{Bu}{\nu}$ (see 2.3.1.1)                                                                                                                                | Re             | -    |
| 1.3.3.11.2                                                                                                                                                | Froude number <sup>2)</sup>        | Square root of the ratio of inertia forces to gravity forces<br>$Fr = \left[ \frac{E}{gD} \right]^{1/2}$ or $\left[ \frac{E}{gB} \right]^{1/2}$ (see 2.3.1.1)                                                                       | Fr             | -    |
| 1.3.3.11.3                                                                                                                                                | Weber number <sup>2)</sup>         | Ratio of inertia forces to surface tension forces<br>$We = \left[ \frac{\rho L v^2}{\sigma^*} \right]^{1/2}$<br>where<br>v is the velocity<br>$\sigma^*$ is the surface tension<br>$\rho$ is the density<br>L is a linear dimension | We             | -    |
| 1.3.3.11.4                                                                                                                                                | Euler number                       | Ratio of pressure forces to inertia forces<br>$Eu = \frac{\Delta p}{\rho v^2}$<br>where $\Delta p$ is the differential pressure                                                                                                     | Eu             | -    |
| 1.3.3.11.5                                                                                                                                                | Loss distribution coefficient      | Ratio of relative scalable losses to relative total losses                                                                                                                                                                          | V              | -    |
| 1.3.3.11.6                                                                                                                                                | Relative scalable loss             | $\delta = (1 - \eta_h) V$                                                                                                                                                                                                           | $\delta$       | -    |
| 1.3.3.11.7                                                                                                                                                | Relative non-scalable loss         | $\delta_{ns} = (1 - \eta_h) - \delta = (1 - \eta_h) \cdot (1 - V)$                                                                                                                                                                  | $\delta_{ns}$  | -    |
| 1.3.3.11.8                                                                                                                                                | Relative total loss                | $1 - \eta_h = \delta + \delta_{ns}$                                                                                                                                                                                                 |                | -    |
| 1.3.3.11.9                                                                                                                                                | Difference of hydraulic efficiency | Difference between the values of hydraulic efficiency at two hydraulically similar <sup>3)</sup> operating points measured at different Reynolds numbers.                                                                           | $\Delta\eta_h$ | -    |
| <sup>1)</sup> See ISO 31-12.<br><sup>2)</sup> Other definitions of these numbers can be found in relevant scientific works.<br><sup>3)</sup> See 2.3.1.2. |                                    |                                                                                                                                                                                                                                     |                |      |

### 1.3.3.12 Dimensionless terms

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

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

| Subclause   | Term                   | Definition                                  | Symbol        | Relations                                                                                                                                              |
|-------------|------------------------|---------------------------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.3.3.12.1  | Speed factor           | $\frac{nD}{E^{0,5}}$                        | $\eta_{ED}$   | $= \frac{1}{E_{nD}^{0,5}}$                                                                                                                             |
| 1.3.3.12.2  | Discharge factor       | $\frac{Q_1}{D^2 E^{0,5}}$                   | $Q_{ED}$      | $= \frac{Q_{nD}}{E_{nD}^{0,5}}$                                                                                                                        |
| 1.3.3.12.3  | Torque factor          | $\frac{T_m}{\rho_1 D^3 E}$                  | $T_{ED}$      | $= \frac{T_{nD}}{E_{nD}} = \frac{P_{ED}}{2\pi n_{ED}}$                                                                                                 |
| 1.3.3.12.4  | Power factor           | $\frac{P_m}{\rho_1 D^2 E^{1,5}}$ (see note) | $P_{ED}$      | $= Q_{ED} \eta_{hT}$ (turbine)<br>$= \frac{Q_{ED}}{\eta_{hP}}$ (pump)<br>$= \frac{P_{nD}}{E_{nD}^{1,5}} = P_{nD} n_{ED}^3$<br>$= 2\pi n_{ED} T_{ED}$   |
| 1.3.3.12.5  | Energy coefficient     | $\frac{E}{n^2 D^2}$                         | $E_{nD}$      | $= \frac{1}{n_{ED}^2}$                                                                                                                                 |
| 1.3.3.12.6  | Discharge coefficient  | $\frac{Q_1}{n D^3}$                         | $Q_{nD}$      | $= \frac{Q_{ED}}{n_{ED}} = Q_{ED} E_{nD}^{0,5}$                                                                                                        |
| 1.3.3.12.7  | Torque coefficient     | $\frac{T_m}{\rho_1 n^2 D^5}$                | $T_{nD}$      | $= \frac{T_{ED}}{n_{ED}^2} = T_{ED} E_{nD} = \frac{P_{nD}}{2\pi}$                                                                                      |
| 1.3.3.12.8  | Power coefficient      | $\frac{P_m}{\rho_1 n^3 D^5}$ (see note)     | $P_{nD}$      | $= E_{nD} Q_{nD} \eta_{hT}$ (turbine)<br>$= \frac{E_{nD} Q_{nD}}{\eta_{hP}}$ (pump)<br>$= \frac{P_{ED}}{n_{ED}^3} = P_{ED} E_{nD}^{1,5} = 2\pi T_{nD}$ |
| 1.3.3.12.9  | Thoma number           | $\frac{NPSE}{E}$                            | $\sigma$      | $= \frac{\sigma_{nD}}{E_{nD}} = \sigma_{nD} n_{ED}^2$                                                                                                  |
| 1.3.3.12.10 | Cavitation coefficient | $\frac{NPSE}{n^2 D^2}$                      | $\sigma_{nD}$ | $= \sigma E_{nD} = \frac{\sigma}{n_{ED}^2}$                                                                                                            |
| 1.3.3.12.11 | Specific speed         | $\frac{nQ^{0,5}}{E^{0,75}}$                 | $N_{QE}$      | $= n_{ED} Q_{ED}^{0,5} = \frac{Q_{nD}^{0,5}}{E_{nD}^{0,75}}$                                                                                           |

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

1) Units: H (m); D (m); E (J kg<sup>-1</sup>); n (s<sup>-1</sup>);  $\rho$  (kg m<sup>-3</sup>); T (N m); P (W); Q (m<sup>3</sup> s<sup>-1</sup>).

### 1.3.3.13 Dimensionless terms relating to oscillating quantities

For presentation and analysis of the measured oscillating quantities, it is recommended to use dimensionless terms as defined hereafter and in 4.3 to 4.6. 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.

- Measured quantities are:
  - F force;
  - M moment;
  - p pressure;
  - T torque.
- Subscripts for machine components are:
  - B runner blade;
  - D Pelton deflector;
  - G guide vane;
  - N Pelton needle.
- Subscripts for force and torque components are:
  - a axial;
  - r radial;
  - x,y,z cartesian coordinates related to the machine.

The following table lists the dimensionless terms relating to oscillating quantities.

| Subclause  | Term                           | Definition                               | Symbol        |
|------------|--------------------------------|------------------------------------------|---------------|
| 1.3.3.13.1 | Torque factor                  | $T_{ED} = \frac{T}{\rho D^3 E}$          | $T_{ED}$      |
| 1.3.3.13.2 | Force factor                   | $F_{ED} = \frac{F}{\rho D^2 E}$          | $F_{ED}$      |
| 1.3.3.13.3 | Torque coefficient             | $T_{nD} = \frac{T}{\rho n^2 D^5}$        | $T_{nD}$      |
| 1.3.3.13.4 | Force coefficient              | $F_{nD} = \frac{F}{\rho n^2 D^4}$        | $F_{nD}$      |
| 1.3.3.13.5 | Factor of pressure fluctuation | $\tilde{p}_E = \frac{\tilde{p}}{\rho E}$ | $\tilde{p}_E$ |

## 1.4 Nature and extent of guarantees related to hydraulic performance

### 1.4.1 General

#### 1.4.1.1 Design data and co-ordination

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 1.3.3.6.2), and specific hydraulic energy losses. The purchaser is also responsible for co-ordinating of 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).

Attention shall be paid to flow conditions at the model inlet and outlet (see 2.1.2.4 and 2.1.3.3). 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 standard. 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.

#### 1.4.1.2 Definition of the hydraulic performance guarantees

A contract for both regulated<sup>1)</sup> 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 1.4.2.2). 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.

The current state of the art permits the verification of some of these prototype guarantees by model test (see 1.4.2), while others cannot be verified by model tests (see 1.4.3). Moreover, additional data may be obtained from the model as an indication of the expected prototype operation (see 1.4.4).

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<sup>1)</sup> "Regulated" as used in this standard refers to the control of the discharge through variations of guide vane opening, needle stroke and/or runner/impeller blade angle.

### 1.4.1.3 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.

### 1.4.1.4 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 3.8. For impulse turbines, when it is agreed in the contract, the scale effect should be taken into account in accordance with annex K.
- 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 2.3.1 shall be met.

## 1.4.2 Main hydraulic performance guarantees verifiable by model test

### 1.4.2.1 Guaranteed quantities for any machine

The main hydraulic performance guarantees of the prototype or model that can be verified by model tests are described in detail in 1.4.2.1.1 to 1.4.2.1.5 below.

#### 1.4.2.1.1 Power

The term "power" usually refers to the mechanical power of the runner/impeller (see 1.3.3.8.3). When the mechanical power of the machine (see 1.3.3.8.2) is guaranteed for the prototype, the mechanical power losses (see 1.3.3.8.4) are to be taken into account.

#### 1.4.2.1.2 Discharge and/or specific hydraulic energy

This refers either to the discharge at the reference section (see 1.3.3.4.4), obtained when operating under specified specific hydraulic energies, or to the specific hydraulic energy obtained when operating with specified discharges.

#### 1.4.2.1.3 Efficiency

The term "efficiency" refers to the hydraulic efficiency (see 1.3.3.9.1) unless otherwise specified. When the prototype efficiency (see 1.3.3.9.3) is guaranteed, the mechanical power losses (see 1.3.3.8.4) or the mechanical efficiency (see 1.3.3.9.2) is to be taken into account.

In reaction machines, the relationship between model and prototype hydraulic efficiencies due to the Reynolds number scale effect is well documented at and around the point of best efficiency, as explained in 3.8. The currently accepted convention is to apply this relationship to the entire range of guaranteed efficiencies (see annex F), however recognizing the decreased reliability the further away the point to be checked is from the point of best efficiency.

#### 1.4.2.1.4 Steady-state runaway speed and/or discharge

A guarantee for maximum steady-state runaway speed (see 1.3.3.4.12) or for the reverse runaway speed in case of pumps is required. An additional guarantee for maximum discharge under runaway conditions may be required.

The no-load discharge for turbine operation shall be determined as part of the characteristic runaway-curve (see figure 55).

#### 1.4.2.1.5 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 2.3.1.5.1, 2.3.3.3.6, 3.8.2.3.7 and 3.8.3.2.

The application of efficiency scale-up due to Reynolds number is limited to the range of  $\sigma$ -values specified in 3.8.2.4.2. The contract shall specify the procedure to be used if  $\sigma_{pl}$  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 ( $\sigma_d$ ) shall be lower than the plant Thoma number  $\sigma_{pl}$  by a safety margin (see 3.10.5). The criterion and the safety margin shall be specified in the contract.

#### 1.4.2.2 Specific application

##### 1.4.2.2.1 Regulated turbine (see 3.10.3.1)

- Power: to be reached at one or more specified specific hydraulic energies.
- Discharge: to be reached at one or more specified specific hydraulic energies.
- Efficiency: guarantees may be required for one or more specified specific hydraulic energy as follows:
- at one or more specified power or discharge,
  - or
  - as weighted average efficiencies over a specified range of power or discharge,
  - or
  - as arithmetic average efficiencies<sup>1)</sup> over a specified range of power or discharge.
- 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.

<sup>1)</sup> Weighted or arithmetic average efficiencies and a series of individual efficiencies shall not be guaranteed simultaneously.

Cavitation: guarantees as outlined in 1.4.2.1.5 may be required for one or more specified specific hydraulic energy, discharge or power, usually for the corresponding minimum  $\sigma_{pl}$  value.

#### 1.4.2.2.2 Non-regulated turbine (see 3.10.3.2)

Power: power to be reached and power not to be exceeded over a specified range of specific hydraulic energies<sup>1)</sup>.

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 as follows  
 – at one or more specified specific hydraulic energy,  
 or  
 – as a weighted average efficiency over a specified range of specific hydraulic energy,  
 or  
 – as an arithmetic average efficiency<sup>2)</sup> over a specified range of specific hydraulic energy.

Runaway speed: guaranteed steady-state runaway speed not to be exceeded when operating under maximum specific hydraulic energy.

Cavitation: guarantees as outlined in 1.4.2.1.5 may be required for one or more specified specific hydraulic energy, usually for the corresponding minimum  $\sigma_{pl}$  value.

#### 1.4.2.2.3 Non-regulated/regulated pump (see 3.10.3.3)

Power: power not to be exceeded over a specified range of specific hydraulic energy or discharge.

Discharge and/or specific hydraulic energy: discharge over a specified range of specific hydraulic energy or specific energy over a specified range of discharge, including values to be reached and/or not to be exceeded.

Efficiency: guarantees may be required for one or more specified specific hydraulic energy or discharge as follows:  
 – at one or more specified specific hydraulic energy or discharge,  
 or  
 – as a weighted average efficiency over a specified range of specific hydraulic energy or discharge,  
 or  
 – as an arithmetic average efficiency<sup>2)</sup> over a specified range of specific hydraulic energy or discharge.

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 runner blade angle is maintained (on-cam condition) or/and to the maximum runaway speed occurring in the worst possible off-cam condition.

<sup>1)</sup> For the contractual limits of the power corresponding to the specified specific hydraulic energies, see 3.10.3.2.

<sup>2)</sup> Weighted or arithmetic average efficiencies and a series of individual efficiencies shall not be guaranteed simultaneously.

Cavitation: guarantees as outlined in 1.4.2.1.5 may be required for one or more specified specific hydraulic energy, discharge or power, usually for the corresponding minimum  $\sigma_{pl}$  value.

#### 1.4.3 Guarantees not verifiable by model test

There are certain guarantees that cannot be checked by model tests. Amongst them are:

##### 1.4.3.1 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 IEC 60609.

The model test may reveal some of the potential areas of cavitation erosion by visual inspection during the tests (see 2.3.3.3.6).

##### 1.4.3.2 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.

##### 1.4.3.3 Guarantees covering noise and vibration

Determination of prototype noise and vibration by model tests lies outside the scope of this standard. This standard 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).

#### 1.4.4 Additional performance data

Additional data may be obtained from the model as an indication of expected prototype operation:

- a) pressure fluctuations (see 4.3);
- b) shaft torque fluctuations (see 4.4);
- c) hydraulic thrust, both radial and axial (see 4.5);
- d) hydraulic torque on guide vanes and adjustable runner/impeller blades or hydraulic forces on needles and deflectors over the full operating range (see 4.6);
- e) 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 4.7);
- f) differential pressure measurements in view of prototype index tests (see 4.8);
- g) cam relationship for optimum performance in the case of double regulated machines (relation between guide vane and runner/impeller blade openings) (see 3.8).

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

## 2 Execution of tests

### 2.1 Requirements of test installation and model

#### 2.1.1 Choice of laboratory

Any laboratory satisfying the criteria set out in this standard 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.

#### 2.1.2 Test installation

##### 2.1.2.1 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 air bubbles produced by cavitation 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. This criteria should be easily verifiable.

##### 2.1.2.2 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 2.3.2.2 can be met.

The operation shall be stable and steady without surging or fluctuating effects (see 2.3.2.3).

##### 2.1.2.3 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.

The gas content (see 2.3.1.6.2), 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. It shall be measured at the inlet, close to the model (see 2.5.3.2).

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<sup>1)</sup>. It may strongly influence the cavitation pattern and the resulting cavitation characteristics (see 2.3.1.5, 2.3.1.6.2 and figures 71 and 72).

Cavitation similitude should be respected by performing the test using an appropriate specific hydraulic energy or/and nuclei injection.

<sup>1)</sup> Nuclei are small air or gas bubbles with diameter less than 50 µm. Travelling cavitation has the aspect of bubbles moving with the flow. Travelling cavitation is typical at the outlet of Francis turbines (see [1], annex P, Bibliography).

The water temperature should in principle not exceed 35 °C and should not vary significantly during the tests (e.g. 5 °C per day). Large differences between the water temperature and the ambient temperature of instruments should be avoided, as they could influence the accuracy of the measurements.

#### 2.1.2.4 Flow conditions given by the installation

At the model inlet, the test installation shall ensure favourable hydraulic conditions free from vortices, undue turbulence and unsteadiness.

At the model outlet, the flow pattern shall not be influenced by the layout or construction of the test facility.

#### 2.1.2.5 Measuring instruments

The measuring equipment used to determine the main parameters shall satisfy the specified conditions of this standard.

The traceability of each instrument to a recognized national or international standard shall be ensured. All instruments should be calibrated *in situ*, especially discharge and torque measuring instruments.

The measuring instruments should be such that a direct reading, independent of the data acquisition system, is possible in order to permit an easy verification.

### 2.1.3 Model requirements

The model shall meet the following conditions:

#### 2.1.3.1 Model size

The minimum values for model size are prescribed in 2.3.2.2.

Normally, models shall be as large as practical but never less than the values stated. The same model should be used for all tests related to main hydraulic performance guarantees and influence of cavitation (see 1.4.2). Comparative model tests shall be performed with models of the same size.

#### 2.1.3.2 Layout and mechanical design of the model

The layout and mechanical design of the model shall comply with the specified items of testing. The following points shall be carefully considered:

- deformations due to loading under the chosen test head shall be minimized by appropriate design and choice of material;
- elements used to vary machine geometry (runner/impeller blades, guide vanes, nozzles) shall be capable of repeating and maintaining a set position;
- bearing system, shaft and stationary parts shall have sufficient rigidity to avoid contact in the labyrinth during normal operation. Blade tip and seal labyrinth clearances of less than 0,15 mm are not recommended for mechanical reasons;
- hydraulically smooth surfaces of the water passages are recommended;
- in addition to general requirements for surface conditions, great care should be given to the proper matching of joints in order to avoid any local flow separation;
- materials should be chosen to avoid oxidation and electrochemical corrosion. The water passage surfaces should remain in good condition for the test duration;

- provision shall be made for easy cleaning or repairing of water passages;
- a transparent cone or windows should be provided for observation of the flow in the runner/impeller and in the adjacent portion of the draft tube (at the low pressure stage in case of a multistage machine);
- wherever shaft seals and shaft bearings are required to be a part of the model (e.g. multistage machines) when comparative model tests are performed, these parts are to be of identical design;
- for comparative tests of the same model, but with different impeller/runner, provisions shall be made that all runners/impellers can be tested with the same clearances;
- where additional data have to be measured (such as pressure fluctuations, guide vane torque, velocity distribution) the model shall permit easy installation and checks of the corresponding measuring equipment;
- if any non-homology exists (e.g. differences in runner band/crown thickness, seal design, etc.), any analytical procedures adopted to account for these differences shall be mutually agreed.

### **2.1.3.3 Extent of model**

The position of reference sections and the extent of the water passages from inlet to outlet to be included in the model (at least the part between the high pressure and low pressure reference sections) shall be clearly defined in the contract (see figure 1 and as an example figure 44).

All the water passages influencing the performance of the prototype, i.e. inflow and outflow conditions, should as far as possible be included in the model.

Especially for low specific hydraulic energy turbines, it is recommended that the model extends from the prototype inlet to the outlet section of the draft tube.

Upstream or downstream gate slots are not required, unless they are located between the measuring or reference sections of the machine. Information on the influence of these parts on the hydraulic behaviour of the machine may be obtained from tests in addition to the model acceptance tests.

### **2.1.3.4 Geometric similarity of model and prototype**

#### **2.1.3.4.1 General requirements**

A basic requirement for determining prototype performance from model tests is to have geometrical similarity (homology) between model and prototype. Therefore it is necessary to compare on both machines the geometrical dimensions and the surface finish of all components in contact with the flow.

The geometric similarity between model and prototype is to be checked in accordance with 2.2.

Unless otherwise specified, the model shall be geometrically similar (homologous) to the prototype in all wetted parts within the limits defined in 2.1.3.3. This also includes details that may have a measurable influence on the performance. However, in particular cases where some minor deviations from the similarity cannot be avoided, an agreement shall be reached whether the results are to be corrected or not.

In the case of acceptance tests on both model and prototype, the same measuring sections should be used if possible.

For comparative model tests, all models shall rotate in the same direction.

#### 2.1.3.4.2 Multistage machines

Normally the model test should be performed with the same number of stages as the prototype.

For a prototype with four or more stages, in exceptional cases, the model may be tested with a reduced number of stages, for instance a three-stage model for a four-stage prototype.

#### 2.1.3.4.3 Labyrinth seals and thrust balancing provisions

For mechanical reasons, it may not be possible or desirable (especially for large scale ratios) for the shaft and runner/impeller seal clearances and the thrust balancing provision to be either geometrically similar or hydraulically equivalent between the model and the prototype. In such cases, seal leakage losses and thrust coefficient will differ between model and prototype. The differences shall either be negligible or be accurately estimated so that the hydraulic efficiency and the thrust of the prototype can be computed.

An agreement should be reached before the tests concerning the monitoring and measuring of leakage flow rate  $q'$  (see figure 6) and whether or not it should be taken into account in determining machine performance.

### 2.2 Dimensional check of model and prototype

#### 2.2.1 General

As stated in 2.1.3.4, the geometrical similarity between model and prototype shall be checked. The checking procedure and admissible tolerances are described below.

This applies even in the case where the model is manufactured according to an existing machine and hence the prototype is the starting point of the process.

##### 2.2.1.1 Explanation of terms used for model and prototype

###### a) individual value

The value resulting from:

- the measurement of the **same** dimension of the **same** component taken at **different** locations (e.g. reference diameter of a runner/impeller);

or:

- the measurement of the **same** dimension of **different recurrent** components taken at the **same** location (e.g. maximum thickness of guide vanes).

###### b) average value

The value is the arithmetical mean value calculated from several individual values.

###### c) theoretical value

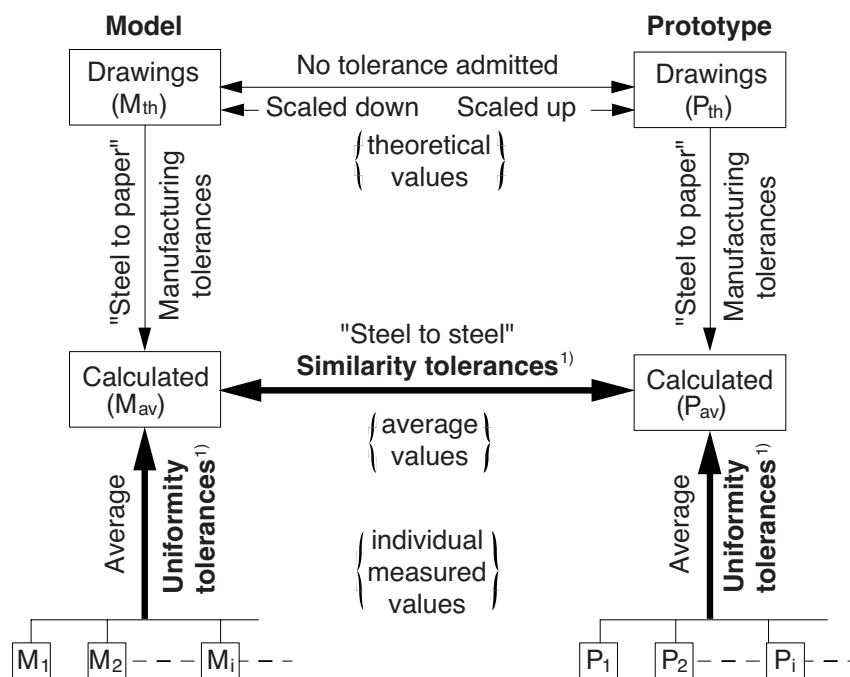
The design value indicated on a drawing. Corresponding model and prototype dimensions  $L_M$  and  $L_P$  are linked by the scale length ratio  $\lambda_L$  (see 1.3.3.2.9).

##### 2.2.1.2 Purpose of dimensional checks

Dimensional checking:

- a) ascertains the main dimensions of model and prototype;

- b) checks the uniformity of model and prototype in their recurrent components, i.e. compares the relative deviation between the individual values and the corresponding average value. The permissible maximum deviations are given in the "uniformity tolerance" columns of 2.2.2.1.7 and 2.2.2.2.5;
- c) checks the geometrical similarity between prototype and model, i.e. compares the relative deviation between the average prototype value and the corresponding average model value scaled up by  $\lambda_L$ . The permissible maximum deviations are given in the "similarity tolerance" columns of 2.2.2.1.7 and 2.2.2.2.5.



1) Numerical values of similarity tolerances and uniformity tolerances are given in 2.2.2.1.7 and 2.2.2.2.5.

**Figure 8 – Procedure for dimensional checks, comparison of results and application of tolerances for model and prototype**

### 2.2.1.3 Procedure

Figure 8 illustrates schematically the application of the geometrical tolerances given by this standard, on individual and average values of model and prototype.

#### a) Checking the uniformity of model and prototype components

By comparing the measurement of individual values with the corresponding average value, it is possible to determine if the uniformity requirement has been met.

If the uniformity requirement is not fulfilled, agreement shall be reached on what components are to be corrected or remanufactured.

In the case where the difference between the average value and the theoretical value is outside the uniformity tolerance, it shall be agreed whether the theoretical value or the geometry of the component shall be corrected.

Where spot-checks are performed, i.e. when not all recurrent components or dimensions are checked, it may be agreed that the individual values are compared directly with the theoretical value.

#### b) Checking the geometric similarity between prototype and model

By comparing the corresponding average values of model and prototype and considering the similarity tolerances as given by this standard, it can be determined whether the geometric similarity requirement has been met. If agreed, the corresponding theoretical values may be substituted for the average values.

If the deviations are greater than the similarity tolerances, further steps shall be agreed which could include a new test with the corrected model.

For some dimensions (e.g. overall dimensions) which are difficult to measure on the model and/or prototype, it may be agreed that, instead of average values of model and/or prototype, theoretical values can be used for comparison, provided that the sum of manufacturing and installation tolerances is less than the similarity tolerance.

#### 2.2.1.4 Application for different types of machines

For turbines, dimensional tolerances are listed for Francis, Kaplan and Pelton turbines.

The tolerances for Francis turbines apply also to diagonal flow machines with fixed blades.

The tolerances for Kaplan turbines apply also to diagonal flow machines with adjustable blades (Deriaz turbines), and to axial flow machines with fixed or adjustable blades (propeller, tubular, etc.).

The tolerances for Pelton turbines can be adapted to inclined jet impulse turbines.

For pumps and pump-turbines, dimensional tolerances are given for centrifugal, mixed flow and axial machines.

#### 2.2.1.5 Methods

To measure the shape of runner/impeller blades, guide vanes and stay vanes, several methods are suitable, including three dimensional co-ordinate measuring machines, optical measuring systems, templates, etc.

The inspection for homology of the hydraulic profiles using three dimensional co-ordinate measuring machines or optical systems can be made either by measuring points along curves or by measuring points on the surface:

- curves are essentially the equivalent of mechanical templates and their use and interpretation are similar to the currently prevailing practice using mechanical templates;
- surfaces are represented by a number of measuring points sufficient to define the complete profile positioned either in geometrically similar locations on the prototype and the model or at random. Computer algorithms must be available to adjust the "surface" so that the resulting measured "error" is minimized for the total surface. Such adjustment is however limited by the permissible tolerances shown in 2.2.2.1.7 and 2.2.2.2.5.

Considering the manufacturing and measuring methods of the runner/impeller, the manufacturer shall propose the most appropriate method in agreement with the customer to demonstrate the geometric similarity between prototype and model.

Figures 9 to 19 give examples showing schematically the location and extent of the geometric checking.

In some cases it is not possible to measure the relevant dimension directly, e.g. if a point of intersection is covered by a fillet. In such cases the measurement shall be made in an agreed location.

In order to protect the confidentiality of the manufacturer's hydraulic design, the manufacturer need only submit the differences between the measured and the theoretical profile and not the actual values of the co-ordinates of the profile. For checking purposes, the measured absolute values of profiles are available from the manufacturer.

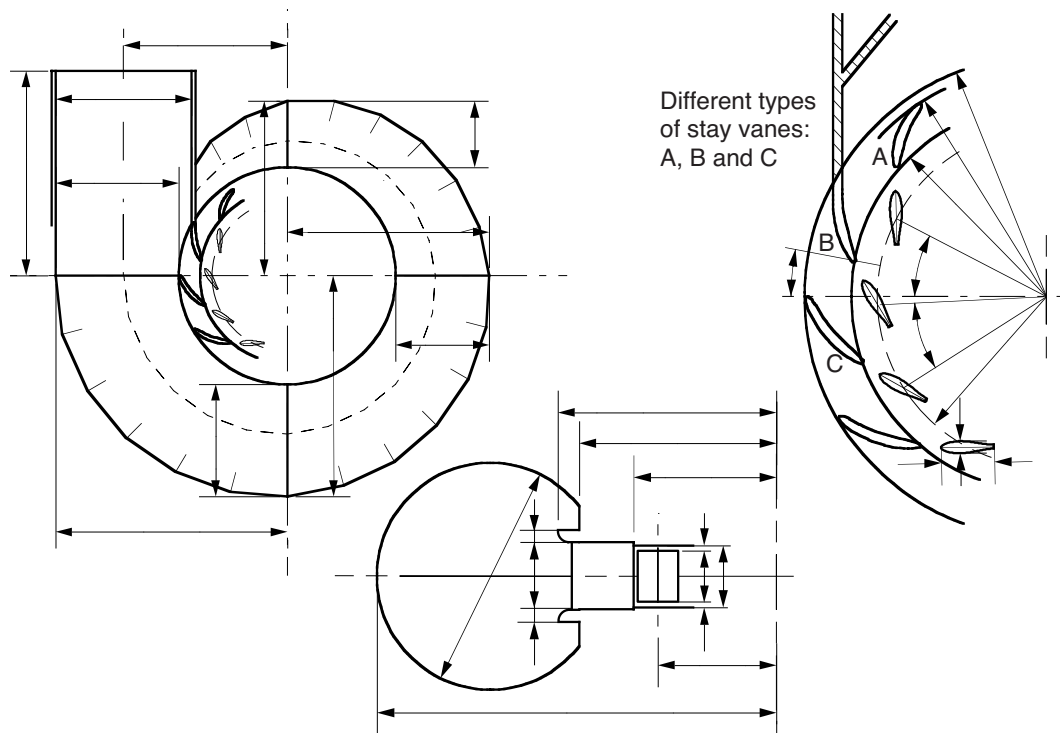


Figure 9 – Example of spiral case and distributor dimensions to be checked

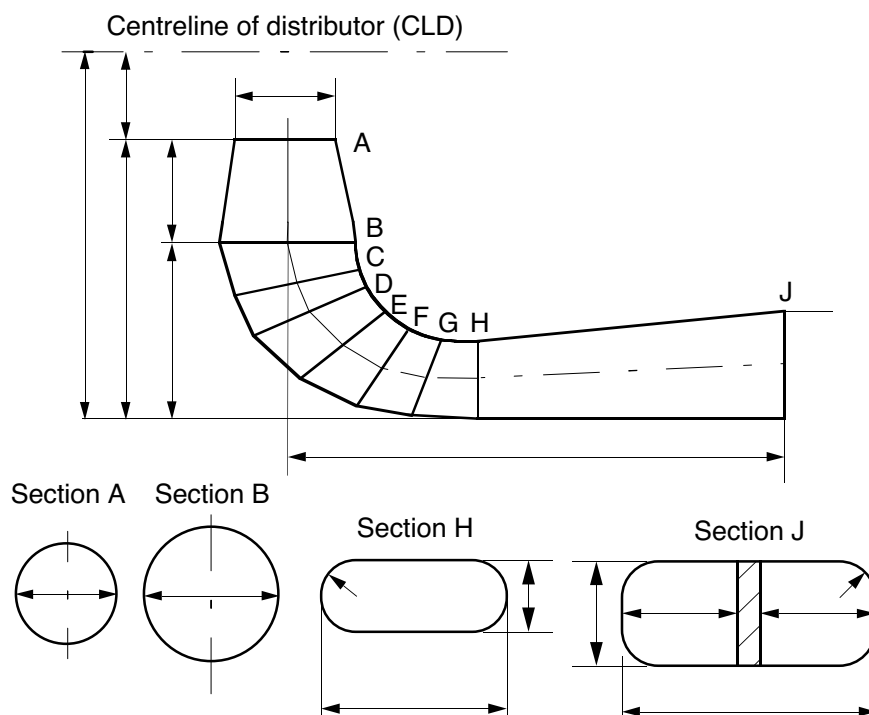


Figure 10 – Example of draft tube dimensions to be checked

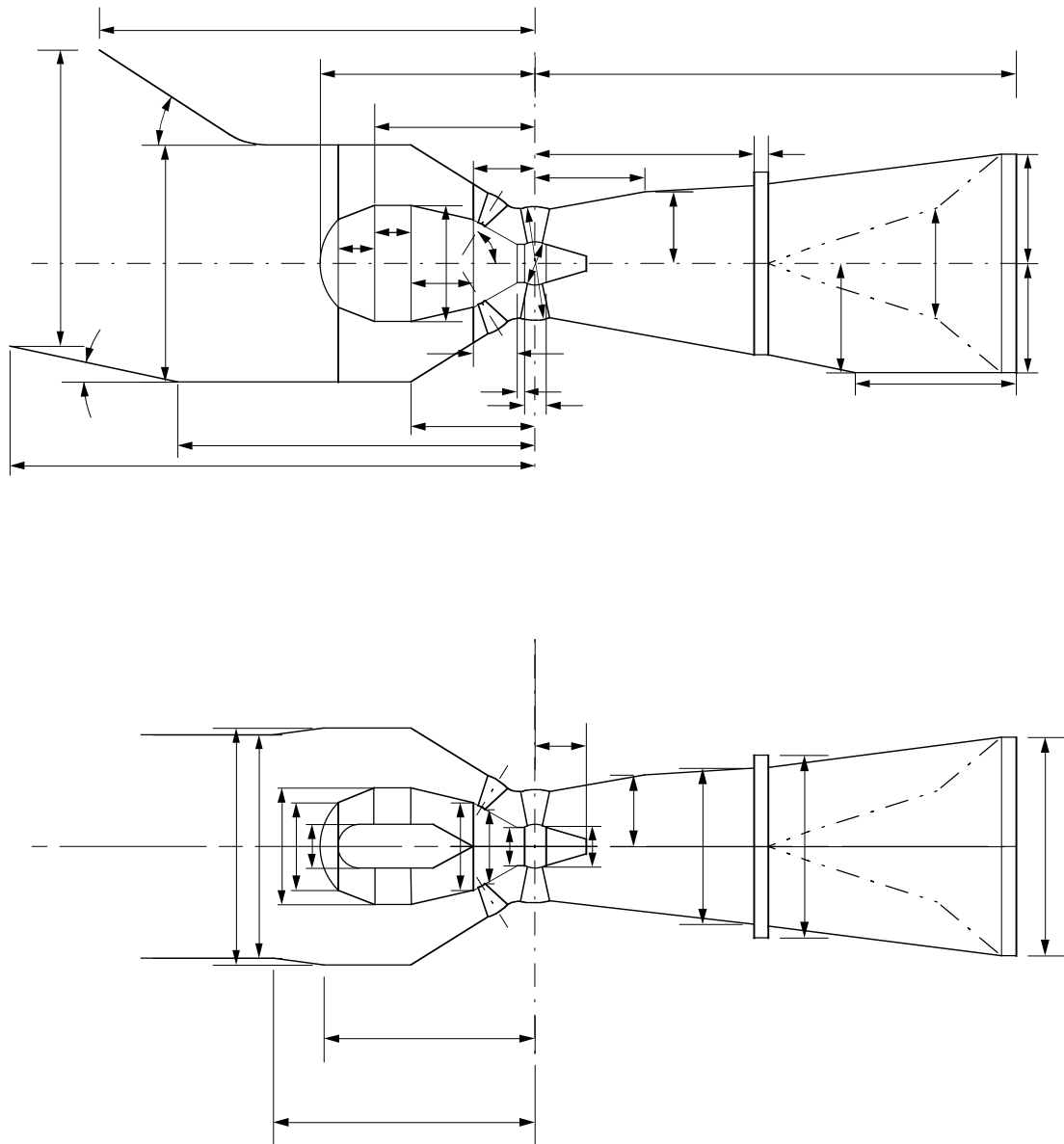


Figure 11 – Example of the dimensions to be checked on a bulb unit

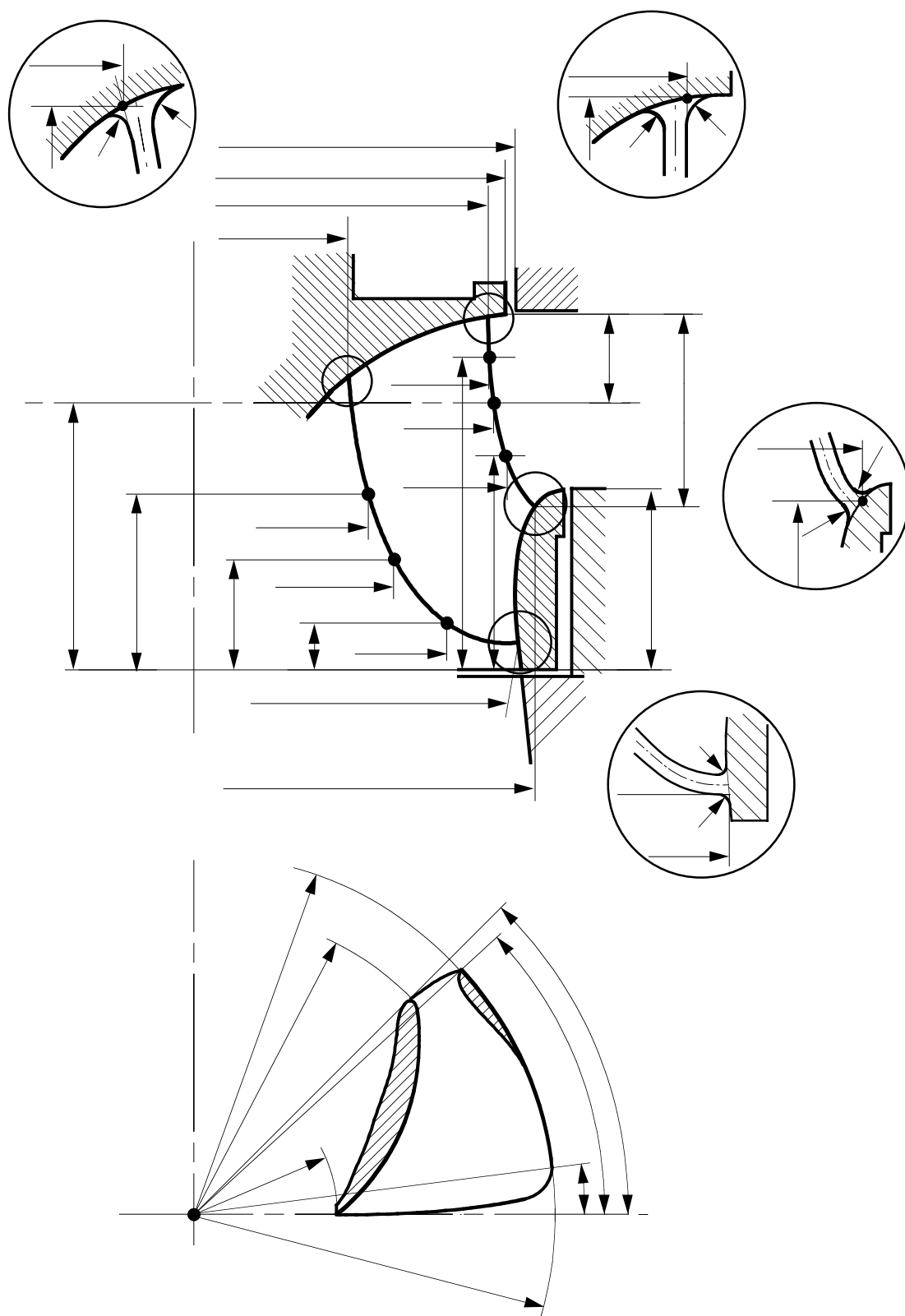
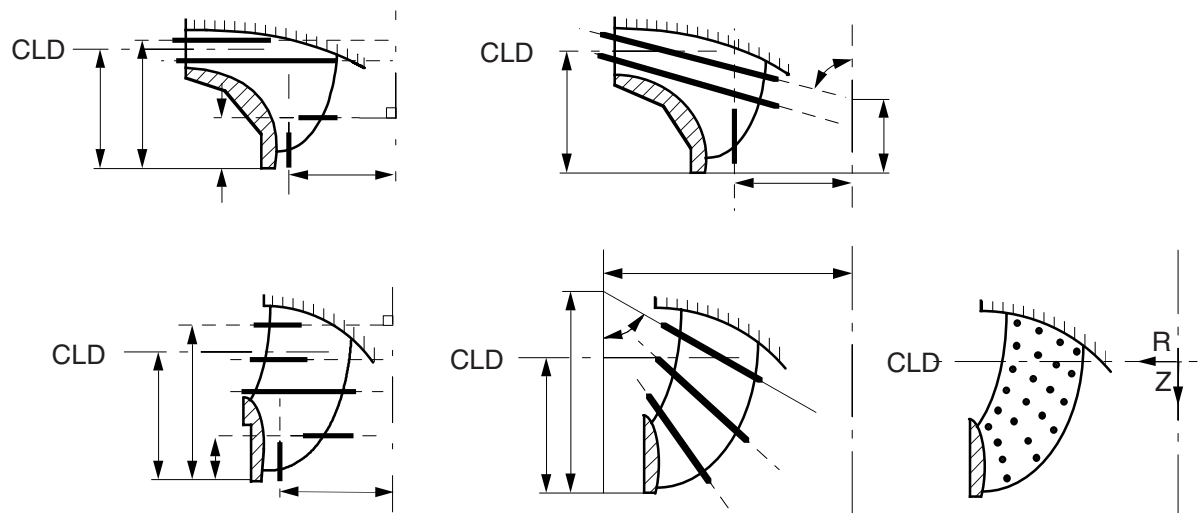


Figure 12 – Example of the dimensions to be checked on the runner/impeller of a radial flow machine



(CLD: Centre line of distributor)

**Figure 13 – Runner/impeller of radial flow machine. Examples of locations for blade profile measuring sections or measuring points**

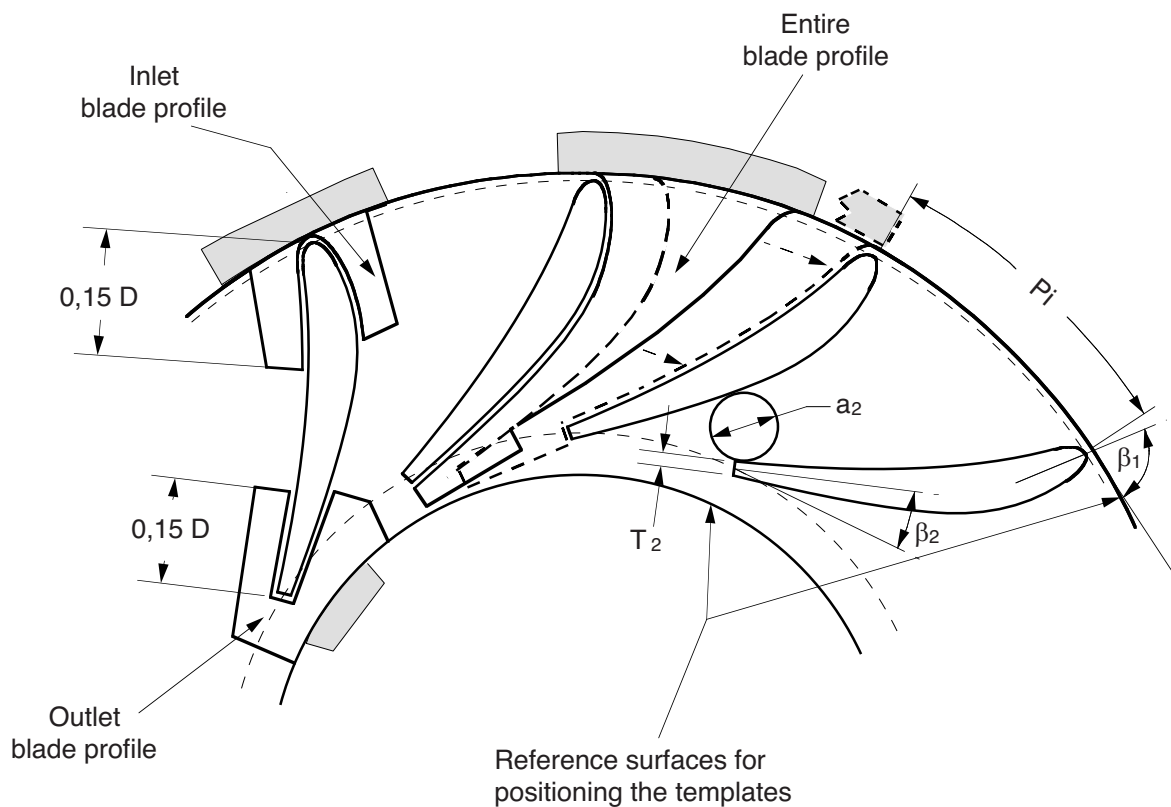


**Figure 14 – Runner/impeller of radial flow machine. Check of outlet width and blade profiles by means of templates or co-ordinate system as illustrated on a Francis runner**

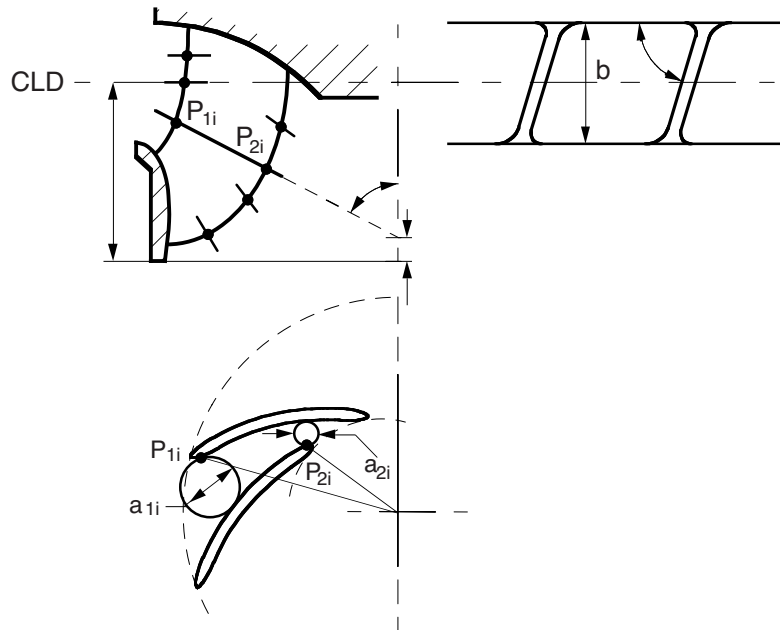


Figure 15 – Runner/impeller of radial flow machine. Check of inlet and outlet widths between blades (example of a pump-turbine runner)

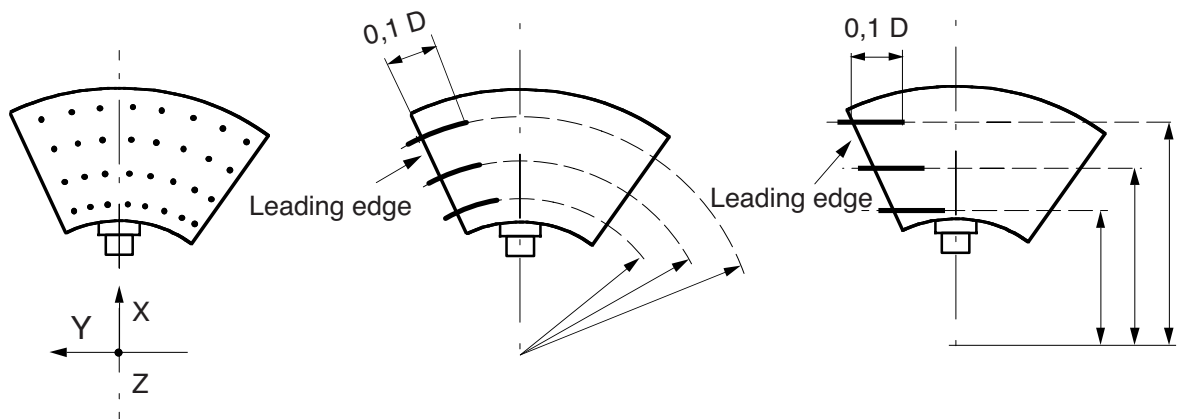


Figure 16 – Runner/impeller of axial flow machine. Example of locations for blade profile measuring sections or measuring points

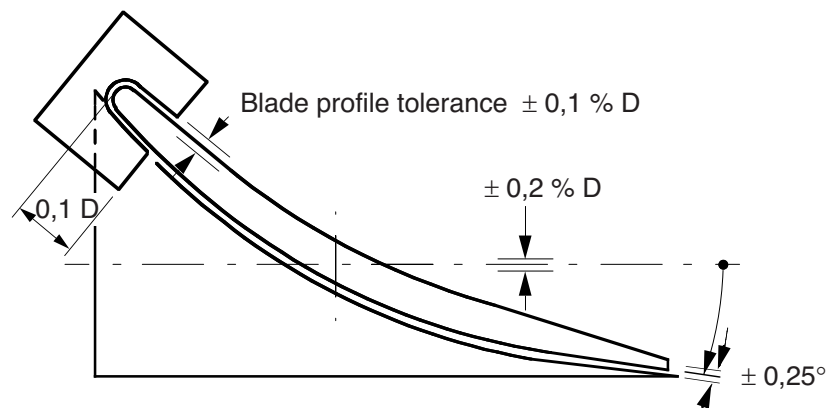


Figure 17 – Runner/impeller of axial flow machine. Definition of blade adjustment and of blade profile tolerances

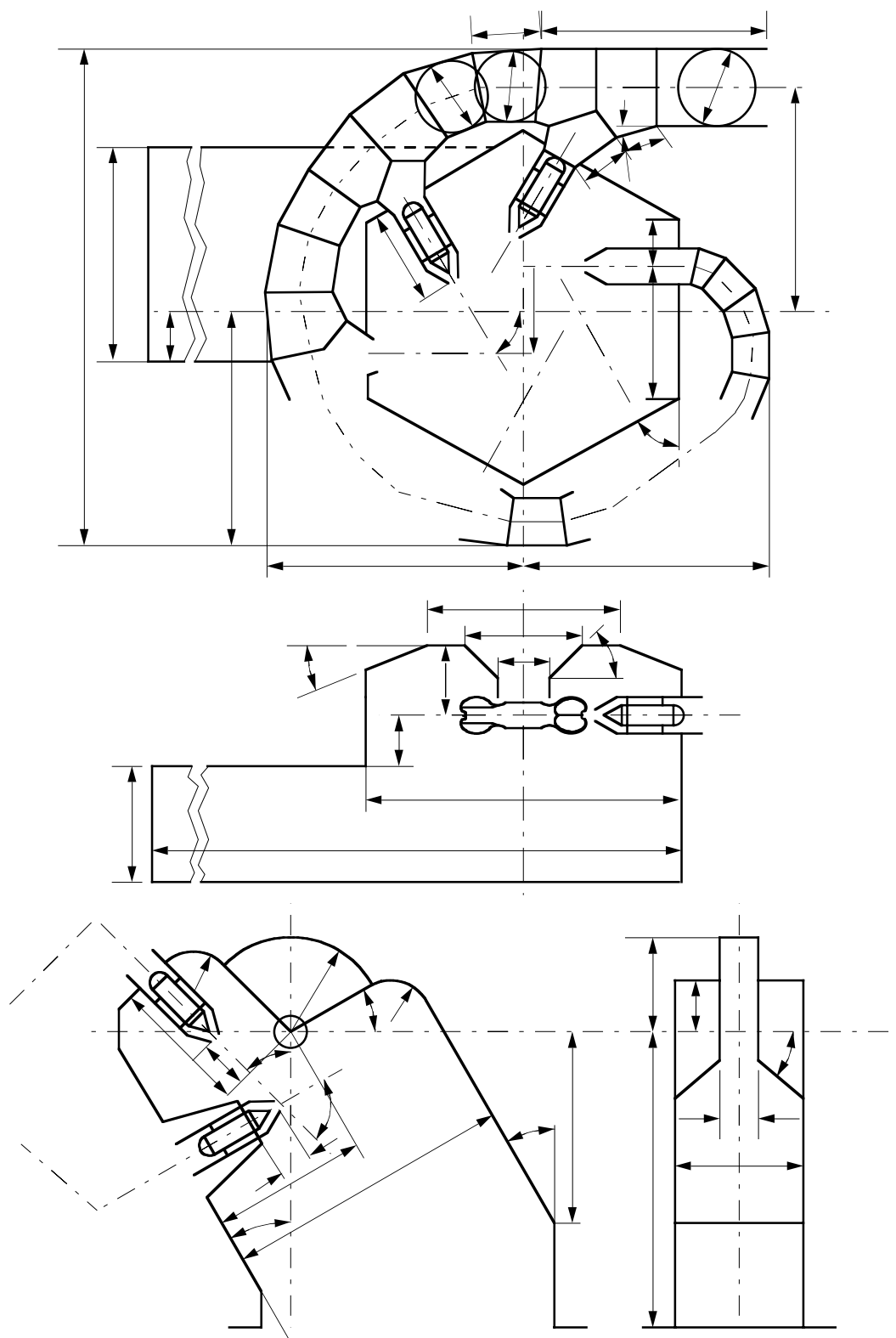


Figure 18 – Pelton turbine: Example of dimensions to be checked on the distributor and the housing of vertical and horizontal shaft machines

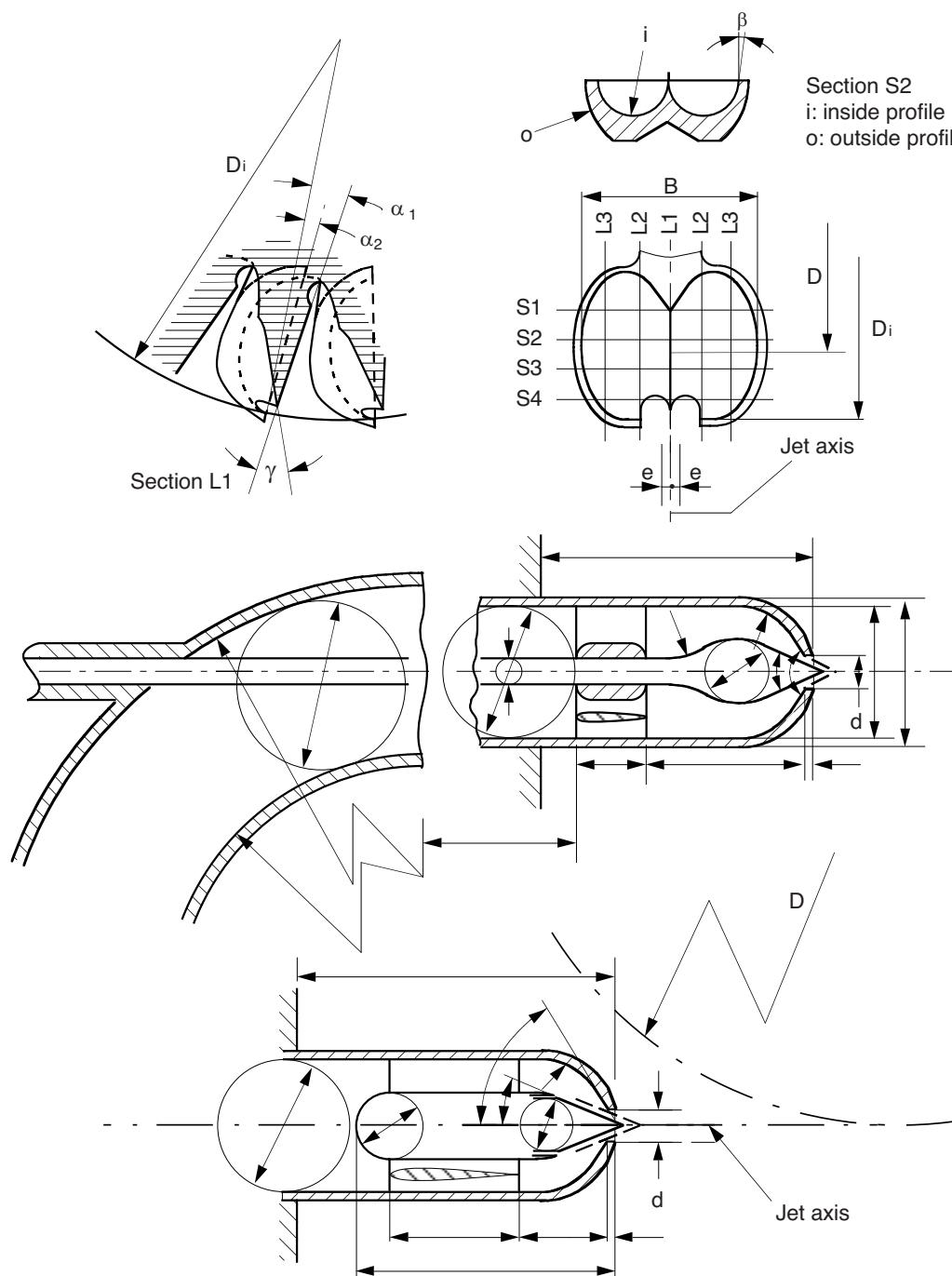


Figure 19 – Pelton turbine: Example of dimensions to be checked on the buckets and nozzles

## 2.2.2 Dimensions of model and prototype to be checked

The dimensions of all significant components defining the water passages shall be checked to an extent agreeable to the parties concerned.

The relevant dimensions and their permitted tolerances for turbines, pumps and pump-turbines are defined in 2.2.2.1 and 2.2.2.2. When a location is defined by more than one dimension, the tolerance applies to only one dimension.

A check of geometric similarity comprises both:

- a) a check on the homology of the individual components before assembly. For practical reasons the dimensions shall be referred to the component itself;
- b) a check on the homology of the whole machine, i.e. with the components assembled. The relevant overall dimensions are usually referred to the runner axis and/or to the centre line of the distributor. Special attention shall be paid to water passages formed by the transition between adjacent components, stationary or rotating, for which no general value of tolerance can be prescribed in this standard.

The meridional contour of the runner/impeller shall be checked with templates or by other appropriate measuring techniques, such as three-dimensional co-ordinate measuring machines or optical measuring systems.

By appropriate checking of the runner/impeller blade profile and its geometric location, the profile angles are properly determined.

In the following subclauses 2.2.2.1 and 2.2.2.2 the permissible maximum deviations are either referred to the corresponding scaled model average value or to the following reference dimensions:

- |            |                                                                                                                                                                                                                                                                                          |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| T          | maximum thickness of guide vanes, stay vanes or runner blades for each measuring section;                                                                                                                                                                                                |
| D          | reference diameter (see figure 3);                                                                                                                                                                                                                                                       |
| $P_i$      | blade inlet pitch for Francis runners (see figure 14);                                                                                                                                                                                                                                   |
| d          | nozzle orifice diameter (see figure 19);                                                                                                                                                                                                                                                 |
| B          | maximum inside width of runner bucket (see figure 19);                                                                                                                                                                                                                                   |
| $a_1, a_2$ | opening between two adjacent blades at high pressure and low pressure side of the runner/impeller (see figures 14 and 15). The opening can be defined either on a blade profile measuring section or as the distance from a given point of the blade edge to the adjacent blade surface. |

The terms used in the following subclauses to indicate the various components of hydraulic machines are defined in IEC 61364.

### 2.2.2.1 Turbines

#### 2.2.2.1.1 Main components

a) Reaction turbines:

- the principal dimensions of the spiral casing (or intake in the case of a tubular turbine), the stay ring, the distributor, the draft tube and if necessary the space between runner and head cover (see for example figures 9 and 10);
- the principal dimensions of the runner including inlet and outlet diameters, inlet height, runner band and crown, and hub in case of Kaplan turbine runners;
- the number of runner blades, guide vanes and stay vanes;