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Centrifugal, mixed flow and axial pumps — Code for hydraulic performance tests — Precision class

*Pompes centrifuges, hélico-centrifuges et hélices — Code d'essais de fonctionnement
hydraulique — Classe de précision*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 5198 was prepared by Technical Committee ISO/TC 115, *Pumps*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Contents

	Page
0 Introduction	1
1 Scope	1
2 Field of application	1
3 References	2
 Section one: General recommendations	
4 Definitions and symbols	3
5 Specified duty	10
6 General requirements for tests	10
 Section two: Measurement methods	
7 Measurement of rate of flow	17
8 Measurement of head	21
9 Measurement of speed of rotation	38
10 Measurement of power input	38
11 Measurement of pump efficiency by the thermodynamic method	41
12 Cavitation tests	51
 Annexes	
A Estimation and analysis of uncertainties	57
B Comparison of test results with specified duty	61
C Thermodynamic properties of water and assessment of the accuracy of efficiency measurements by the thermodynamic method	65
D Other cavitation tests	78
E Friction losses	80

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Centrifugal, mixed flow and axial pumps — Code for hydraulic performance tests — Precision class

0 Introduction

This International Standard is the first of a set of International Standards dealing with performance tests of centrifugal, mixed flow and axial pumps (in the rest of the text referred to as “pumps”).

It specifies precision class tests (former class A). Engineering class I and class II tests (former classes B and C) will be the subject of a further International Standard.¹⁾

The aims of these classes are quite different.

The precision class is mainly used for research, development and scientific purposes in laboratories, where an extremely high accuracy of measurement is important.

The engineering classes are generally applied for acceptance tests.

In most cases, engineering class II is adequate for acceptance tests. The use of engineering class I is restricted to special cases when there is a need to have the pump performance more precisely defined. However, there may be cases of high importance, in which even an engineering class I acceptance test will be judged inadequate for the precision required for defining pump performance. In these cases the use of the precision class may exceptionally be necessary for an acceptance test.

Attention must be paid to the fact that the accuracy required for a precision class test significantly increases the test costs by comparison with the costs for an engineering class test.

Precision class tests may not always be practicable, even when great effort and expense are devoted to measurements. Performance tests to precision class specifications will be required, and are possible, only in suitable circumstances. Therefore both the purchaser and the manufacturer shall carefully examine whether the accuracy required for a precision class test might be achieved either on site, on the manufacturer's test bed or in a mutually agreed laboratory. It should be noted that it may not be possible to guarantee precision class accuracy in advance of the tests.

The purpose of this International Standard is to specify how to carry out a test with extremely high precision.

This International Standard does not recommend any constructional tolerance nor any global tolerance for acceptance purposes; it is devoted to specifying and describing procedure and methods for accurately ascertaining the performance of a pump under the conditions in which it is tested. Contractual interpretation of the test results must be the subject of a special agreement between the parties concerned (see annex B).

Pump performance may be greatly affected by the installation conditions, and this must be especially considered when drawing up the contract if a precision class test is to be carried out.

1 Scope

This International Standard specifies precision class performance tests for centrifugal, mixed flow and axial pumps.

It defines the terms and quantities that are used and specifies general requirements for tests. It specifies ways of measuring the characteristic quantities of the precision class so as to ascertain the performance of the pump and thus provide a basis for comparison with the performance specified in the contract.

The structural details of pumps and the mechanical properties of their components lie outside the scope of this International Standard.

This International Standard does not specify constructional tolerances, which are purely contractual.

2 Field of application

This International Standard gives recommendations for hydraulic performance testing of centrifugal, mixed-flow and axial pumps when these tests have to meet very special requirements for research, development or acceptance of industrial high-tech. pumps, or when very accurate knowledge of performance characteristics is of prime importance.

This International Standard also applies to models and prototypes whether the pumps are tested on a test bench or on site if installation conditions so permit.

1) At present, they are dealt with in ISO 2548 and ISO 3555.

It applies

- either to the pump itself without fittings, which requires that the pump ends are accessible; or
- to the whole assembly of pump and of all or part of its upstream and downstream fittings, which is the case for pumps with inaccessible ends (submerged pumps, etc.).

NOTES

- 1 Attention is drawn to the fact that nearly all industrial needs are covered by the codes of acceptance testing of industrial classes I and II.
- 2 Acceptance tests for site and model storage pumps are dealt with in IEC Publications 198 and 497.

3 References

ISO 31, *Quantities, units and symbols*.

ISO 555, *Liquid flow measurement in open channels — Dilution methods for measurement of steady flow —*

Part 1: Constant-rate injection method.

Part 2: Integration (sudden injection) method.

Part 3: Constant-rate injection method and integration method using radioactive tracers.

ISO 1438, *Liquid flow measurement in open channels using thin-plate weirs and venturi flumes.*

ISO 1438/1, *Water flow measurement in open channels using weirs and venturi flumes — Part 1: Thin-plate weirs.*

ISO 2186, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements.*

ISO 2548, *Centrifugal, mixed flow and axial pumps — Code for acceptance tests — Class C.*

ISO 2975, *Measurement of water flow in closed conduits — Tracer methods —*

Part 1: General.

Part 2: Constant rate injection method using non-radioactive tracers.

Part 3: Constant rate injection method using radioactive tracers.

Part 6: Transit time method using non-radioactive tracers.

Part 7: Transit time method using radioactive tracers.

ISO 3354, *Measurement of clean water flow in closed conduits — Velocity-area method using current-meters.*

ISO 3534, *Statistics — Vocabulary and symbols.*

ISO 3555, *Centrifugal, mixed flow and axial pumps — Code for acceptance tests — Class B.*

ISO 3846, *Liquid flow measurement in open channels by weirs and flumes — Free overfall weirs of finite crest width (rectangular broad-crested weirs).*

ISO 3966, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes.*

ISO 4185, *Measurement of liquid flow in closed conduits — Weighing method.*

ISO 4359, *Liquid flow measurement in open channels — Rectangular, trapezoidal and U-shaped flumes.*

ISO 4360, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs.*

ISO 4373, *Measurement of liquid flow in open channels — Water level measuring devices.*

ISO 5167, *Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO 7194, *Measurement of fluid flow in closed conduits — Velocity-area methods of flow measurement in swirling or asymmetric flow conditions in circular ducts by means of current-meters or Pitot static tubes.*

ISO 8316, *Measurement of liquid flow in closed conduits — Method by collection of the liquid in a volumetric tank.¹⁾*

IEC Publication 34-2, *Rotating electrical machines — Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles).*

IEC Publication 41, *International code for the field acceptance tests of hydraulic turbines.*

IEC Publication 193, *International code for model acceptance tests of hydraulic turbines.*

IEC Publication 198, *International code for the field acceptance tests of storage pumps.*

IEC Publication 497, *International code for model acceptance tests of storage pumps.*

¹⁾ At present at the stage of draft.

Section one: General recommendations

4 Definitions and symbols

4.1 Definitions

For the purposes of this International Standard, the following definitions apply.

4.1.1 measuring system: System composed of a measuring instrument, including a transducer which picks up physical information, and one or several elements in series transmitting or transforming the resulting signal.

Such a system has a response function which can be illustrated by a gain response or a phase response curve over a frequency range. In particular, a filtering effect appears between the picked up physical quantity and the observed signal. This filtering effect is essentially characterized by a cut frequency. In most measuring systems which are used, the continuous component of the signal can pass and the cut frequency is then strongly related to the response time of the system.

4.1.2 measuring instrument: Instrument, forming part of a measuring system, which transforms any physical quantity (pressure, speed, current, etc.) into a signal which can be directly observed (a mercury level, a point on a dial scale, a digital reading, etc.).

4.1.3 first order statistical moment: mean value of a signal: Characterization of a random process $x(t)$ by a first order statistical moment which generally is the mean μ_x calculated over a period of time T given by the equation

$$\mu_x = \frac{1}{T} \int_t^{t+T} x(t) dt$$

NOTE — To calculate the mean value of a signal or physical quantity, an integration period T much longer than the response time of the corresponding measuring system is usually chosen.

To determine simultaneously the mean value of several signals of several physical quantities corresponding to the same operating point, the integration period T is chosen by considering the longest response time among all the measuring systems which are used.

According to the value of the integration period T chosen to calculate the mean value of the signals, the operating conditions will be determined to be either steady or unsteady.

4.1.4 second order statistical moment: variance or autocorrelation function: Characterization of a random process $x(t)$ by a second order statistical moment calculated over a time period T and for which can be chosen either the variance σ_x^2 expressed as :

$$\sigma_x^2 = \frac{1}{T} \int_t^{t+T} [x(t) - \mu_x]^2 dt$$

or the autocorrelation function, R_{xx} , given by the equation

$$R_{xx}(t, T) = \frac{1}{T} \int_t^{t+T} x(t) [x(t+T)] dt$$

4.1.5 steady and unsteady process: Random process $x(t)$ is said to be **slightly steady** or **steady in a general sense** when its first order statistical moment (mean μ_x) and its second order statistical moment [variance σ_x^2 , or autocorrelation function $R_{xx}(t, T)$] are not dependent on time t , at which the observation begins nor on the period of time T during which the observation is made.

Inversely, when the statistical moments are dependent on t or T , the physical phenomenon is said to be **unsteady**.

When all statistical moments of the process $x(t)$ (beyond the second order), which completely describe the statistical property of $x(t)$, are not dependent on t and T , the process is then said to be **strongly or strictly steady**.

NOTE — From a practical point of view and in this International Standard, only slightly steady processes are considered (first and second order statistical moments). It should be noted that when the considered process follows a normal or Gaussian distribution law, the first and second order statistical moments are sufficient to describe the statistical properties of the process completely and both concepts of strong or slight steadiness are then equivalent.

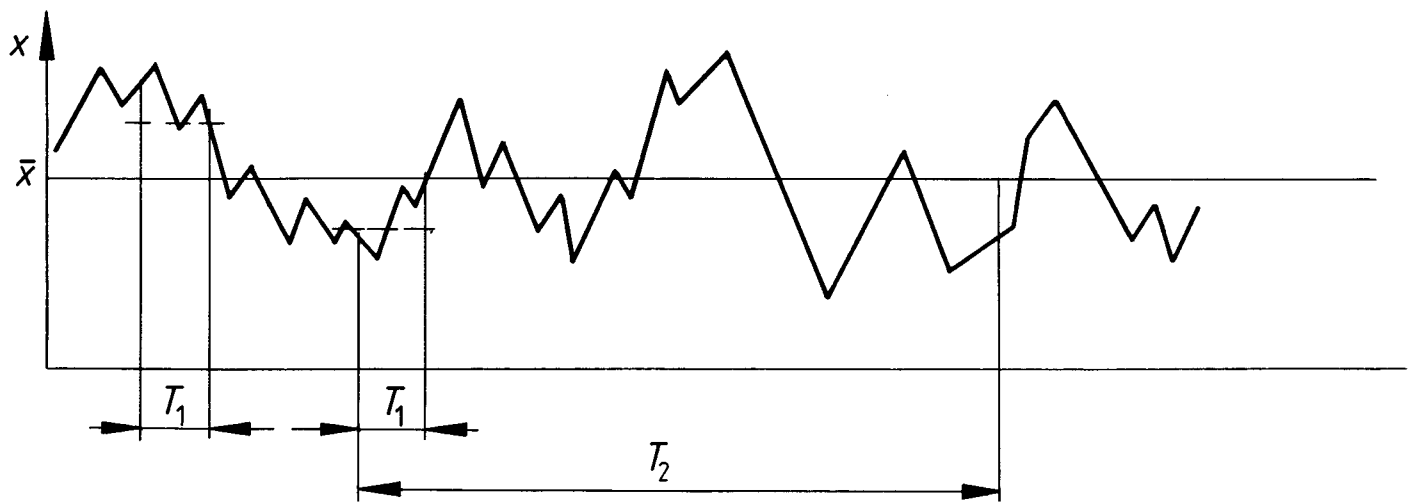
4.1.6 steady operating conditions: The operating conditions are said to be steady when the different signals delivered by the measuring systems and the physical quantities calculated from these signals have first order (mean μ_x) and second order [variance σ_x^2 , or autocorrelation function $R_{xx}(t, T)$] statistical moments which do not depend on the time t at which the observation begins nor on the duration T during which the observation is made.

NOTE — The random signal delivered by a measuring system can be found to be steady only if the integration period T is sufficiently long. This point is difficult to check for one is never calculated for a sufficient duration; this is why, from a practical point of view, only a steadiness with a certain confidence level is defined.

4.1.7 unsteady operating conditions: The operating conditions are said to be unsteady when the different signals delivered by the measuring systems and the physical quantities calculated from these signals have a first order (mean μ_x) or second order [variance σ_x^2 , or autocorrelation function $R_{xx}(t, T)$] statistical moment which depends on the time t at which the observation begins or on the period T during which the observation is made.

NOTE — The dynamic component (see figure 1) of the picked up physical quantities has different origins:

- a random origin: turbulence, white noise of the electronic system, etc.,
- a determinist origin: blade passing frequency, speed of rotation in connection with the electric network frequency, flow singularities, vibration modes, etc.



T_1 is an insufficiently long integration period. The mean value, $\bar{x}$, of x as estimated from T_1 will vary.

T_2 is a sufficiently long period.

Figure 1 — Graph of the evolution of a phenomenon (supposed to be known)

It is supposed that the possible unsteadiness of the operating conditions has a frequency lower than that corresponding to these phenomena (less than half the lowest encountered frequency); as a consequence, the integration period T will not be less than twice the period T corresponding to the lowest frequency mentioned above.

4.1.8 fluctuations: Periodic or random evolutions of a phenomenon $x(t)$ as a function of time, varying around a mean value and describing a physical quantity or a signal delivered by a measuring system.

All evolutions having a period or a pseudo-period less than twice the integration period chosen to calculate the mean values are considered as fluctuations. Then the fluctuations can be considered as being "rapid" compared to the variations of the mean value (see 4.1.9).

NOTE — Only fluctuations having a period or a pseudo-period higher than twice the response time of the corresponding measuring system can be detected.

4.1.9 variations of the mean value (in unsteady operating conditions): Evolution of the mean value of a physical quantity or of signal delivered by a measuring system, between one reading and the next, in unsteady operating conditions.

The variations of the mean values should show a period or a pseudo-period higher than twice the integration period T chosen to calculate the mean value.

Then the variations of the mean value can be considered as being "slow" compared to fluctuations (see 4.1.8).

4.1.10 readings: Visual observations allowing the recording of the value of the signal delivered by a measuring system.

Two types of readings should be considered:

a) the "quasi-instantaneous" reading of the signal, which is made during as short a time as possible (but not shorter than the response time of the measuring system considered);

NOTE — The group of "quasi-instantaneous" readings made during the integration period T allows the calculation of statistical moments (see 4.1.3 and 4.1.4).

b) the "averaging reading" of the signal which is made over or at the end of the integration period T depending on the measuring system, this "averaging reading" leads directly to the mean value of the signal.

4.1.11 set of readings: Group of "quasi-instantaneous" readings leading to the determination of the values of the different signal or physical quantities characterizing an operating point.

4.1.12 response time of a measuring instrument: Time interval between the instant when a stimulus is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits of its final steady value.

4.1.13 Prandtl number, Pr :

$$Pr = \frac{\mu c_p}{\lambda}$$

where

μ is the dynamic viscosity of the fluid;

λ is its thermal conductivity.

(Definition taken from ISO 31/12.)

4.2 Quantities, symbols and units

Table 1 gives concepts and some of their uses in this International Standard, together with any associated symbols which have been allocated; it is based on ISO 31.

The definitions, particularly those given for kinetic energy coefficient, specific energy and NPSH may not be appropriate for completely general use in hydrodynamics, and are for the purposes of this International Standard only.

Table 2 gives an alphabetical list of symbols used, and table 3 gives a list of subscripts.

Table 1 — List of quantities (based on ISO 31)¹⁾

Quantity	Definition ²⁾	Symbol	Dimension ³⁾	Unit
Mass		m	M	kg
Length		l	L	m
Time		t	T	s
Temperature		θ	Θ	°C
Area		A	L ²	m ²
Volume		V	L ³	m ³
Angular velocity		ω	T ⁻¹	rad/s
Velocity		v	LT ⁻¹	m/s
Acceleration due to gravity ⁴⁾		g	LT ⁻²	m/s ²
Speed of rotation	Number or rotations per unit time	n	T ⁻¹	s ⁻¹
Density	Mass per unit volume	ρ	ML ⁻³	kg/m ³
Pressure	Force per unit area. Unless otherwise specified all pressures are gauge pressures, i.e. measured with respect to atmospheric pressure.	p	ML ⁻¹ T ⁻²	Pa (1 bar = 10 ⁵ Pa)
Kinematic viscosity		ν	L ² T ⁻¹	m ² /s
Specific energy	Energy per unit mass	E	L ² T ⁻²	J/kg
Power (general term)		P	ML ² T ⁻³	W
Reynolds number		Re	dimensionless	
Diameter		D	L	m
Flow rates				
Mass rate of flow	The mass rate of flow designates the external mass rate of flow of the pump, i.e. the rate of flow discharged into the pipe from the outlet branch of the pump. NOTE — Losses or abstractions inherent to the pump, i.e. : a) discharge necessary for hydraulic balancing of axial thrust; b) cooling of bearings of the pump itself; c) water seal to the packing; d) leakage from the fittings, internal leakage, etc., are not to be reckoned in the quantity delivered. On the contrary, if they are taken at a point before the flow measuring section, all derived quantities used for other purposes, such as : e) cooling of the motor bearings; f) cooling of a gear box (bearings, oil cooler), etc., should be added to the measured rate of flow.	$q_m(q)$	MT ⁻¹	kg/s

Table 1 — List of quantities (based on ISO 31)¹⁾ (continued)

Quantity	Definition ²⁾	Symbol	Dimension ³⁾	Unit
Volume rate of flow	The outlet volume rate of flow is given by the equation $q_V = \frac{q_m}{\rho}$ For the purposes of this International Standard, this symbol may also designate the volume rate of flow in a given section⁵⁾ of the pump outlet; it is the quotient of the mass rate of flow in this section by the density. (The section may be designated by subscripts.)	$q_V (Q)$	$L^3 T^{-1}$	m ³ /s
Mean velocity	The mean velocity of flow equal to the volume rate of flow divided by the pipe cross-section ⁵⁾ $U = \frac{q_V}{A}$	U	LT^{-1}	m/s
Local velocity	Velocity of flow at any point	v	LT^{-1}	m/s
Gauge pressure	Any pressure used in this International Standard except atmospheric and vapour pressure; the effective pressure, relative to the atmospheric pressure. Its value is — positive if this pressure is greater than the atmospheric pressure; — negative if this pressure is less than the atmospheric pressure.	p_e	$ML^{-1} T^{-2}$	Pa
Atmospheric pressure (absolute)		p_b	$ML^{-1} T^{-2}$	Pa
Vapour pressure (absolute)		p_v	$ML^{-1} T^{-2}$	Pa
Head	The energy per unit mass of fluid divided by gravitational acceleration.		L	m
Height	Elevation of a point above a reference plane. If the point is below the reference plane, z is negative.	z	L	m
Reference plane	Any horizontal plane to be used as a datum for height measurement. A materialized reference plane may be more practical than an imaginary one for measurement purposes.	—	—	—
Inlet impeller height (or eye height)	The height of the centre of the circle described by the external point of the entrance edges of the first impeller blades. In case of double inlet pumps, z_s is the higher impeller height. The manufacturer should indicate the position of this point with respect to precise reference points on the pump.	z_s	L	m
Velocity head	Height of fluid corresponding to the kinetic energy per unit mass of fluid divided by gravitational acceleration. Its value is given by the formula $\alpha U^2 / 2g$		L	m
Velocity head coefficient	A coefficient relating velocity head in the section with the mean velocity in that section. It is defined by the equation $\alpha = \frac{\int_A v^3 dA}{U^3 A}$ If v is constant, $\alpha = 1$	α	dimensionless	
Available velocity head	The part of the velocity head contributing to the total head. Its value is given by the formula $\alpha_a U^2 / 2g \quad \text{where} \quad 1 < \alpha_a < \alpha$ See 8.1.1.3		L	m
Available velocity head coefficient	A coefficient relating available velocity head in a section to the mean velocity in that section. See 8.1.1.3	α_a	dimensionless	

Table 1 — List of quantities (based on ISO 31)¹⁾ (continued)

Quantity	Definition ²⁾	Symbol	Dimension ³⁾	Unit
Total head (in section <i>i</i>)	Total head in a given section, <i>i</i> , is usually calculated as: $H_i = z_i + \frac{p_{ei}}{\rho_i g} + \alpha_{ai} \frac{U_i^2}{2g}$ This equation assumes that pressure varies hydrostatically in the section and that compressibility of the liquid pumped may be neglected. See 8.1.1.2 concerning the correctness of this last assumption.	H_i	L	m
Inlet total head	Total head at inlet section 1	H_1	L	m
Outlet total head	Total head at outlet section 2	H_2	L	m
Pump total head	Algebraic difference between outlet total head H_2 and inlet total head H_1 : $H = H_2 - H_1$ Separate evaluation of H_1 and H_2 is not always necessary. Other methods may even be recommended if compressibility is to be accounted for. See 8.1.1.2.	H	L	m
Loss of head at inlet	The difference between the total head of the liquid at the measuring point, or possibly of the liquid without velocity in the suction chamber, and the total head of the liquid in the inlet section of the pump.	H_{J1}	L	m
Loss of head at outlet	The difference between the total head of the liquid in the outlet section of the pump, and the total head of the liquid at the measuring point.	H_{J2}	L	m
Net positive suction head; NPSH	Inlet total head increased by the head (in flowing liquid) corresponding to the atmospheric pressure at the test location and decreased by the sum of the head corresponding to the vapour pressure of the pump liquid at the inlet temperature and of the inlet impeller height. $(\text{NPSH}) = H_1 + \frac{p_b}{\rho_1 g} - \frac{p_v}{\rho_1 g} - z_1$ NOTES 1 To maintain consistency between precision class and engineering classes I and II, the arbitrary definition of (NPSH) is the same. Therefore, in calculating (NPSH) values, the value of α_{a1} is taken to be equal to unity (see velocity head coefficient). 2 Local velocity distribution may influence (NPSH) performance of the pump. Limitation of local velocity variation is given in clause 12. 3 It is necessary to make a distinction between — the (NPSH) required at given flow and speed of rotation for a given pump — this is specified by the manufacturer; — the (NPSH) available for the same flow, which is inferred from the installation; — the cavitation test (NPSH). Subscripts may be used to differentiate these quantities [for example (NPSH)_r when the value required by the pump is concerned, (NPSH)_a when the available value is concerned and (NPSH)_c when cavitation test (NPSH) is concerned].	(NPSH)	L	m
Critical net positive suction head	Net positive suction head associated with $[2 + (K/2)]$ % either of head drop in the first stage or of the efficiency drop.	(NPSH) _c	L	m

Table 1 — List of quantities (based on ISO 31)¹⁾ (concluded)

Quantity	Definition ²⁾	Symbol	Dimension ³⁾	Unit
Type number	A number defined by the equation $K = \frac{2\pi n (q'_V)^{1/2}}{(gH')^{3/4}} = \frac{\omega q'_V{}^{1/2}}{E'^{3/4}}$ where q'_V is the volume rate of flow per eye and H' is the head of the first stage. This quantity shall be calculated at the best efficiency point.	K	dimensionless	
Pump power input	Mechanical power transmitted to the pump shaft.	P	ML^2T^{-3}	W
Driver power input	Power input to driving unit.	P_{gr}	ML^2T^{-3}	W
Pump power output	The power transferred to the liquid at its passage through the pump $P_u = \rho q_V g H = \rho q_V E$	P_u	ML^2T^{-3}	W
Pump efficiency	$\eta = \frac{P_u}{P}$	η	dimensionless	
Overall efficiency	$\eta_{gr} = \frac{P_u}{P_{gr}}$	η_{gr}	dimensionless	

1) Further symbols used in the thermodynamic method are given in table 9.

2) In order to avoid any error of interpretation, it is deemed desirable to reproduce the definitions of quantities and units as given in ISO 31 and to supplement these definitions by some specific information on their use in this International Standard.

3) M = mass, L = length, T = time, Θ = temperature.

4) For precision class tests, the local values of g should be used. Nevertheless, in most cases, a value of $9,81 \text{ m/s}^2$ would not involve significant error. The local value should be calculated by the equation

$$g = 9,780 \ 3 (1 + 0,005 \ 3 \sin^2 \varphi) - 3 \times 10^{-6} z$$

where φ and z are respectively the latitude, in degrees, and the altitude, in metres.

5) Attention is drawn to the fact that in this case q_V may vary for different reasons across the circuit.

Table 2 — Alphabetical list of symbols

Symbol	Quantity	Units
A	Area	m^2
D	Diameter	m
e	Relative value of uncertainty	—
E	Specific energy	J/kg
f	Frequency	Hz
g	Acceleration due to gravity	m/s^2
H	Pump total head	m
H_J	Losses in terms of head of liquid	m
k	Equivalent uniform roughness	m
K	Type number	dimensionless
l	Length	m
m	Mass	kg
n	Speed of rotation	s^{-1}
(NPSH)	Net positive suction head	m
p	Pressure	Pa
P	Power	W
q_m	Mass rate of flow	kg/s
q_V	Volume rate of flow	m^3/s
Re	Reynolds number	dimensionless
t	Time	s
U	Mean velocity	m/s
v	Local velocity	m/s
V	Volume	m^3
z	Height above reference plane	m
α	Velocity head coefficient	dimensionless
η	Efficiency	dimensionless
θ	Temperature	$^{\circ}\text{C}$
λ	Universal coefficient for head loss	dimensionless
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
ω	Angular velocity	rad/s

NOTE — See also clause 11.

Table 3 — List of letters and figures used as subscripts

Subscript	Designation
1	inlet
2	outlet
a	available
ac	acoustic
b	atmospheric
c	critical
d	drop
e	effective (gauge)
f	fully developed
gr	unit (overall)
<i>H</i>	pump total head
int	intermediate
<i>M</i>	manometric
m	mass
mot	motor
<i>P</i>	pump power input
p	pump
r	required
s	eye
sp	specified
t	total
<i>T</i>	translated
u	useful
<i>V</i>	volume
v	vapour (pressure)
vis	visible
η	efficiency

5 Specified duty

5.1 Main specification

One or more of the following quantities may be specified under the conditions and speed or rotation stated in the contract:

- pump total head, H_{sp} , at the agreed flow rate, q_{Vsp} , or flow rate of the pump, q_{Vsp} , at the agreed total head, H_{sp} .
- power input or efficiency of the pump or combined pump-motor unit at the specified q_{Vsp} , H_{sp} point.
- net positive suction head, (NPSH), required by the pump at the agreed flow rate q_{Vsp} for a specified cavitation effect as defined, for example, in 12.1.3.2 at the agreed flow rate.
- other points of the $H(q_V)$ curve may be indicated by specifying either the total head at a reduced or increased flow rate, or the flow rate at a reduced or increased total head.

5.2 Other specifications

Unless specifically agreed otherwise in the contract, the specified values are valid in the following conditions :

- unless the chemical and physical properties of the liquid are stated, it shall be taken that the points specified apply to clean cold water (see table 4);

Table 4 — Specification of "clean cold water"

Characteristic	Unit	max.
Temperature	°C	40
Kinematic viscosity	m ² /s	$1,5 \times 10^{-6}$
Density	kg/m ³	1050
Non-absorbent free solid content	kg/m ³	2,5
Dissolved solid content	kg/m ³	50

- the relation between the specified values under clean cold water conditions and the likely performance under other liquid conditions shall be agreed in the contract;

- specified values shall apply only to the pump as tested by the methods and in the test arrangements specified in this International Standard.

6 General requirements for tests

6.1 Organization of tests

6.1.1 Place of testing

Performance tests shall be carried out at the manufacturer's works, or alternatively at a place to be mutually agreed between the manufacturer and the purchaser.

Both purchaser and manufacturer shall be entitled to have representatives present at all tests and calibrations in order to verify that they are performed in accordance with this International Standard and any prior written agreements.

6.1.2 Time of testing

The time of testing shall be mutually agreed by the manufacturer and the purchaser.

6.1.3 Staff

Accurate measurements depend not only on the quality of the measuring instruments used, but also on the ability and skill of the persons operating and reading the measuring devices during the tests. The staff entrusted with effecting the measurements shall be selected just as carefully as the instruments to be used in the test.

A chief of tests possessing adequate experience in measuring operations shall be appointed. Normally, when the test is carried out at the manufacturer's works, the chief of tests is a staff member of the manufacturing firm.

All persons charged with effecting the measurements are subordinated during the tests to the chief of tests, who conducts and supervises the measurements, reports on test conditions and the results of the tests and then drafts the test report. All questions arising in connection with the measurements and their execution are subject to his decision.

The parties concerned shall provide all assistance that the chief of tests considers necessary.

6.1.4 State of pump

When tests are not carried out at the manufacturer's works, opportunity shall be allowed for preliminary adjustments by both the manufacturer and the installer.

6.1.5 Test programme

Only the specified operational data shall form the basis of the test; other data determined by measurement during the tests shall have merely an indicative (informative) function and this shall be stated if they are included in the programme.

6.1.6 Test equipment

When deciding on the measuring procedure, the measuring and recording apparatus required shall be specified at the same time.

The chief of tests shall be responsible for checking the correct installation of the apparatus and its perfect functioning.

All measuring apparatus shall be covered by reports showing, by calibration or by comparison with other International Standards, that it complies with the requirements of 6.4. These reports shall be presented if required.

The measuring devices used shall have valid calibration. Periodic calibration shall be performed by an entitled body. During the pump tests, the indications of the various instruments shall be cross-compared to check that their calibration is maintained. Generally after site testing or in case of dispute, new calibration shall be performed as soon as possible.

6.1.7 Test report

After actual scrutiny, the test results shall be summarized in a report signed either by the chief of tests alone, or by him and representatives of the manufacturer and of the purchaser.

All parties to the contract shall receive a copy of the report as an essential condition for the completion of the contract.

The test report shall contain the following information :

- a) place and date of the performance test;
- b) manufacturer's name, type of pump, serial number, and if possible year of construction;
- c) specified characteristics, operational conditions during the performance test;

- d) specification of the pump's drive;
- e) description of the test procedure and the measuring apparatus used including calibration data;
- f) observed readings;
- g) evaluation and analysis of test results with calculation of measuring uncertainties according to 6.4, 6.5 and annex A;
- h) conclusion : comparison of the test results with the specified duties (see annex B).

All test records and record charts shall be initialled by the chief of tests and by the representatives of both the purchaser and the manufacturer, each of whom shall be provided with a copy of all records and charts.

The evaluation of the test results shall be made as far as possible while the tests are in progress and, in any case, before the installation and instrumentation are dismantled, in order that measurements regarded as suspect can be repeated without delay.

6.2 Test arrangements

The performance of a pump in a given test arrangement, however accurately measured, cannot be assumed to be a correspondingly accurate indication of its performance in another arrangement.

Moreover, the conditions which permit the most accurate measurements to be taken are not necessarily those under which the pump may perform most satisfactorily nor those under which the user may ultimately require it to perform.

This International Standard therefore defines the conditions necessary to measure performance most accurately and discusses the errors which may be caused by failing to meet those conditions, in order that the interested parties may define the test arrangement most suited to the circumstances.

Recommendations and general guidance about suitable pipe arrangements upstream of a measuring device are given in clauses 7 and 8; if necessary, they can be used in conjunction with International Standards on flow measurement in closed conduits concerning the different flow measurement methods.

6.2.1 Standard test arrangements

The most accurate measurement of head is possible when the flow at the measuring section has:

- a) an axially symmetrical velocity distribution;
- b) a uniform static pressure distribution;
- c) freedom from swirl induced by the installation.

The complete flow patterns at both inlet and outlet measuring sections may be influenced by both the pump and by the geometry of the installations.

It is recommended that for standard test circuits leading from reservoirs with a free surface, or from large stilling vessels in a closed circuit, the inlet straight length, L , be determined by the equation:

$$L > (1,5 K + 5,5) D$$

where

L is the inlet straight length;

D is the pipe inside diameter;

K is the type number.

In a standard works or laboratory test rig, satisfactory conditions established by previous tests should be considered as sufficient proof for subsequent tests.

If the inlet conditions are not satisfactory, this may be remedied in one or more of the following ways:

- a) increasing the straight length following the source of disturbance causing the flow maldistribution;
- b) fitting an appropriate straightener or swirl remover (ISO 7194 gives a detailed description of the functional and geometrical characteristics of these devices.)
- c) changing the nature of, or removing, the source of disturbance.

If none of these devices is practicable on site, precision class measurements cannot be made.

NOTE — Attention is drawn to the fact that in some particular cases where this International Standard applies to partial flow rate operation, for which pre-swirl occurs, the arrangements agreed upon for that part of the test installation at the suction side may modify the pump performance.

6.2.2 Simulated test arrangements

When pumps are tested under simulated site conditions, flow straighteners shall not be installed immediately before the pump. It is important that the characteristics of flow to the simulated circuit should be controlled, and that the flow should, as far as possible, be free from significant swirl induced by the installation and have a symmetrical velocity distribution. If necessary, the velocity distribution of the flow into the simulated circuit shall be determined by careful Pitot tube traverses, in order to establish that the required flow characteristics exist. If not, the required characteristics can be obtained by the installation of an adequate straightener (see ISO 7194); however, care shall be taken to ensure that the test conditions will not be affected by the high, irrecoverable pressure losses associated with efficient straightening devices.

6.2.3 Pumps tested with fittings

If specified in the contract, standard tests can be carried out on a combination of a pump and

- a) associated fittings at the final site installation; or
- b) an exact reproduction thereof; or

- c) fittings introduced for testing purposes and taken as forming part of the pump itself.

Connection on the inlet and outlet sides of the whole combination shall be made in accordance with 6.2.

6.3 Test conditions

6.3.1 Performance of tests

In order to obtain consistent results having regard to the degree of accuracy to be achieved, the duration of the test shall be sufficient to take more particularly into account the response time (see 4.1.12) of measuring instruments and the relative steadiness of each operating point, within the limits defined in table 5.

The measurements shall be made under either steady operating conditions (see 4.1.6) or unsteady conditions (see 4.1.7) within the limits defined in table 5.

The decision to make measurements when such conditions cannot be obtained shall be a matter of agreement between the parties concerned.

When only one duty point is indicated for checking, at least five measurement points closely and evenly grouped around the duty point shall be recorded, for instance between $0,9 q_{V, G}$ and $1,1 q_{V, G}$.

When performance over a range of operating conditions is to be determined, a sufficient number of measurement points duly distributed shall be recorded, in order to establish the performance within the uncertainty stated in 6.4.

If the test has to be carried out at a speed of rotation different from that specified, the limits stated in 6.3.3 shall be respected and the characteristics obtained at the actual speed of rotation can be translated to the specified speed of rotation; see 6.5.2.1.

6.3.2 Steadiness of operating conditions

6.3.2.1 Definitions

For the purposes of this International Standard the following concepts (see 4.1) are used:

- measuring system and instrument;
- first order statistical moment, mean value of a signal;
- second order statistical moment, variance and autocorrelation;
- steady and unsteady phenomena;
- steady operating conditions;
- unsteady operating conditions;
- fluctuations;
- variations of the mean value (in unsteady operating conditions);
- readings;
- set of readings.

6.3.2.2 Fluctuations of the signals delivered by the measuring systems and of the physical quantities determined from the signals

The physical quantities considered in a test and especially those relating to the turbulent flow in the pipes or in the pump are naturally fluctuating ones. Nevertheless, the fluctuations which appear on the signals delivered by the measuring systems are only seen through the response function of these systems which leads to a partial or total filtering effect, and more particularly to a damping effect over a given frequency range.

Therefore measuring instruments with low inertia and a very short response time may give a fluctuating signal with large fluctuations at every operating point. Conversely, measuring instruments with high inertia and a long response time may give only small fluctuations and sometimes only in the abnormal operating range of the pump.

6.3.2.2.1 Direct visual observation of the signals delivered by measuring systems

To make a satisfactory direct visual observation, the maximum permissible amplitudes of fluctuations given in table 5 shall be respected for each measured quantity.

Where the operating conditions of a pump are such that fluctuations of great amplitude occur, measurement may be carried out by providing, in the elements of the measuring system, a filtering or damping device capable of reducing the fluctuation amplitude to within the values given in table 5.

As the damping may significantly affect the accuracy of the readings, a symmetrical and linear damping device, for example a capillary tube, shall be used.

Where pressure measurements particularly are concerned the damping device shall comply with the specifications of 8.4.1.3.

Table 5 — Maximum permissible amplitude of fluctuations as a percentage of mean value of quantity to be measured, for direct visual observation

Measured quantity	Maximum permissible amplitude of fluctuations %
Rate of flow Head Torque Power	± 3
Speed of rotation	± 1

When using a differential pressure device to measure flow, the maximum permissible amplitude of the fluctuation of the observed differential head can be ± 6 %.

In the case of separate measurement of inlet total pressure head and outlet total pressure head, the maximum permissible amplitude of fluctuation should be calculated on the basis of the pump total head.

6.3.2.2.2 Automatic recording or integration of signals delivered by measuring systems

When the signals delivered by the measuring systems are automatically recorded or integrated by the measuring device, the maximum permissible fluctuation amplitude of these signals may be higher than the value given in table 5, if

- the measuring system used includes an integrating device carrying out automatically, with the required accuracy, the integration necessary to calculate the mean value as defined in 4.1.3; or
- the integration necessary to calculate the mean value may be carried out later on, from the continuous or sampled record of the analogue signal $x(t)$. (The sampling conditions should be specified in the test report.)

6.3.2.3 Number of sets of readings or number of averaging readings

The number of sets of readings or the number of averaging readings necessary to obtain consistent results having regard to the degree of accuracy required and within the limits of error stated in 6.4 is dependent on the steadiness of the operating conditions of the pump in the test installation.

When several sets of readings have to be made, for the same operating point, only speed and temperature may be controlled. Throttle valve, water level, gland, and balance water settings shall be left completely unaltered.

In order to determine whether the operating conditions are steady, it is necessary to check whether the different signals delivered by the measuring systems employed are steady, slightly steady or unsteady (see 4.1.6 and 4.1.7).

6.3.2.3.1 Steady operating conditions

When operating conditions are steady, the signals delivered by the measuring systems may be constant or present steady fluctuations.

When the signal is constant only one set of readings or only one averaging reading may be taken at the considered operating point.

When the signal fluctuates, the observer shall check that the operating conditions are steady before determining the quantity to be measured, which requires several sets of readings or several averaging readings.

6.3.2.3.2 Unsteady operating conditions

In cases where the unsteadiness of test conditions gives rise to doubts concerning the accuracy of the tests, several sets of readings shall be taken for each operating point considered (see 6.3.2.3). The difference between the mean values deduced from the repeated readings of the same quantities will be a measure of the unsteadiness of the test conditions, which are at least partly influenced by the pump under test as well as the installation.

A minimum of three sets of readings shall be taken at unequal intervals at the chosen point and the mean value of each quantity and of the efficiency derived from each set of readings shall be recorded. The percentage difference between the largest and smallest mean values of each quantity shall not be greater than that given in table 6. It will be noted that a wider tolerance is permitted if the number of readings is increased up to the maximum requirement of nine readings.

These tolerances are designed to ensure that the errors due to scatter, taken together with the systematic error limits given in clauses 7 to 12 will result in overall measurement errors not greater than those given in table 7.

Table 6 — Limits of variation between repeated mean values of the same quantity (based on 95 % confidence limits as defined in annex A)

Number of sets of readings	Maximum permissible difference between largest and smallest mean values of each quantity	
	Rate of flow Head Torque Power	Speed of rotation
	%	%
3	0,8	0,25
5	1,6	0,5
7	2,2	0,7
9	2,8	0,9

The arithmetic mean of the mean values from all sets of readings for each quantity shall be taken as the actual value given by the test for the operating conditions considered.

If the values given in table 6 cannot be reached, the cause shall be ascertained, the conditions rectified and a new complete set of readings made, i.e. all the readings in the original set shall be rejected. No reading or selection of readings in the set of readings may be rejected because it lies outside the limits given in table 6.

Where the excessive variation is not due to procedure or instrumentation errors, and cannot therefore be eliminated, the number of sets of readings shall be increased and the limits of error shall be calculated by statistical analysis (see annex A).

It is unlikely that variations outside the requirements of table 6 will occur for the majority of pump tests carried out under well-controlled conditions, particularly in a laboratory or at the manufacturer's works.

6.3.3 Deviation from specified speed

A difference of ± 20 % between the specified speed of rotation and the test speed of rotation measurement may be allowed for the determination of flow rate, head and pump efficiency. For $(NPSH)_c$ measurements, the difference allowed between the test speed and the specified rotational speed shall be within the limits of ± 20 % provided that the flow rate is between 70 % and 120 % of the value corresponding to the maximum efficiency at the same speed. For cavitation appearance tests, see annex D.

Scale effects are not sufficiently established to permit precise performance forecasts outside these limits and therefore should be a matter of agreement.

For a combined motor pump unit, the motor efficiency change between specified and test speeds shall be established at the time of agreeing the contract.

6.3.4 Control of operating conditions

The test conditions may be obtained, among other methods, by throttling at the outlet or possibly at the inlet or both at inlet and outlet. Nevertheless, control of the operating conditions by throttling at the inlet is not considered a normal test method. When throttling at the inlet, due consideration shall be given to the possibility of flow distortion, increase in turbulence, or of air coming out of the water, all phenomena which may affect the operation of the pump (see 12.2) or of the flow measuring device (see 7.1) or both.

6.3.5 Tests carried out with a different liquid

If the liquid used during the tests differs from the liquid pumped in normal operation, its kinematic viscosity and the speed of rotation of the pump shall be such that the mean friction coefficient λ estimated for the whole pump does not differ by more than 5 % from its value in the conditions of use of the pump. In the case of larger variations of the friction coefficient λ , a conversion formula may be used by agreement between the parties. The variations of the Reynolds number :

$$Re = \frac{D_1 \sqrt{2gH'}}{\nu}$$

where

D_1 is the inlet diameter of the pump;

H' is the head generated by stage;

shall be estimated from figure 29 and the admissible variations of the ratio n/ν shall be deduced.

The tests for total head, flow rate and efficiency carried out under these conditions are valid as long as no cavitation appears and compressibility is negligible.

6.4 Measuring uncertainty

6.4.1 General

When the methods, instruments, and calibrations employed comply with this International Standard, the measurements obtained represent, at the time, the best estimates of the true value of the quantities being measured. Better, or more accurate, estimates can be obtained only by gathering new data.

It is essential that the parties concerned should establish, before the test, the range of uncertainty that can be tolerated. Strictly speaking, the measuring uncertainties can only be calculated when the results of the measurements are complete.

6.4.2 Level of confidence

The uncertainty on a set of measurements of a single quantity depends on the confidence level attached to this uncertainty. The higher the confidence level, the higher the absolute value of the uncertainty and the higher the probability that any measurement falls within the uncertainty bandwidth. It is then necessary to specify the confidence level with which this uncertainty is evaluated, together with the permissible uncertainty. In this International Standard, the uncertainty is associated to a 95 % confidence level, i.e. there is one possibility out of twenty that a reading lies outside the measurement uncertainty bandwidth (see ISO 3534).

6.4.3 Uncertainties of individual quantities

In any one test, enough evidence is seldom available to make exhaustive analyses of all possible sources of error and deduce percentage confidence levels as described in textbooks on statistics. Where there is such evidence, it should be used, but in its absence estimates should nevertheless be made based on the available data together with past experience of the method of measurement.

Strictly speaking, the uncertainty on each individual measured quantity (q_v , H , P , η , etc.) can only be evaluated when the results of measurements are complete.

The fact that the uncertainties used may be, at best, estimates in no way detracts from the value of defining agreed explicit terms in a contract using numerical quantities which can be processed in an unbiased way.

For guidance, some values of the uncertainties which may be expected in satisfactory measuring conditions are given in clauses 7 to 11 dealing with the measurement methods of each quantity, and maximum values which should not be exceeded for precision class tests are given in table 7.

6.4.4 Errors

The error of a measurement depends partly on the residual error in the instrument or measuring system at the start of the tests. At this time, all known errors will have been removed by calibration, careful measurement of dimensions, proper installation, etc. The uncertainty still remaining is called systematic error, and always exists, however small.

Another source of error arises from the non-repeatability of measurements, which must always exist provided the readout equipment has adequate discrimination. Such errors may arise either from the characteristics of the measuring system, or from changes in the quantity being measured, or both. They are observed directly in the form of scatter readings, unlike systematic errors, which do not affect repeatability during the test. This second type of error is called random error.

Repetition of a set of measurements using the same equipment can reduce the uncertainty introduced by random experimental errors, but has no effect on the systematic error. The latter can be reduced only if equipment of a higher standard of accuracy is used, or if the same equipment can be calibrated to a higher standard. The systematic error does not contribute in any way to the scatter of repeated observations.

6.4.5 Mean values

The mean value of a large number of repeated measurements is a better estimate of the true value than the average of a smaller one, provided there is no systematic change with time of the measuring system or the measured quantity which cannot be corrected. When analysing test results, the chief of tests shall satisfy himself that no such tendency is present.

6.4.6 Treatment of errors

It is advisable to treat systematic and random errors separately as described in annex A.

Table 7 — Maximum permissible limits of uncertainty¹⁾

Quantity	Maximum permissible limit %
Rate of flow	$\pm 1,5$
Pump total head Pump power input (direct method) Electrical power input by the motor-pump group	± 1
Pump power input (determined from the efficiency of the motor)	$\pm 1,3$
Speed of rotation	$\pm 0,2$
Overall efficiency of motor-pump unit	± 2
Pump efficiency	$\pm 2,25$

1) This table gives, as guidance, maximum values of the uncertainties which may be obtained with the apparatus existing at the present time. These values are for normal site conditions : laboratory and works tests may be more accurate.

6.5 Analysis of test results

6.5.1 Test data required for the analysis

The characteristics which may be specified by the manufacturer are given in clause 5.

The measurement methods of the quantities necessary for the calculation of these characteristics are given in clauses 7 to 12.

6.5.2 Conversion of the test results to the specified conditions

Such conversion serves to determine whether the performance specification would have been fulfilled if the tests had been conducted under the same conditions as those on which the performance specification is based.

6.5.2.1 Conversion of the test results into data based on the specified speed of rotation or frequency

All test data obtained at speeds of rotation other than the one specified shall be converted to the basis of the specified speed of rotation n_{sp} .

If the deviation from this speed of rotation to the specified speed of rotation n_{sp} does not exceed the permissible variations stated in 6.3.3, and if the deviation from test liquid to specified liquid is within the limits stated in 6.3.5, the measured data on the flow rate q_V , the total head H , the power input P , and the efficiency η , can be converted by means of the equations:

$$q_{V,T} = q_V \frac{n_{sp}}{n}$$

$$H_T = H \left(\frac{n_{sp}}{n} \right)^2$$

$$P_T = P \left(\frac{n_{sp}}{n} \right)^3 \times \frac{\rho_{sp}}{\rho}$$

$$\eta_T = \eta$$

and the results obtained for the (NPSH) can be converted by means of the equation:

$$(\text{NPSH})_T = (\text{NPSH}) \left(\frac{n_{sp}}{n} \right)^x$$

The value $x = 2$ may be used as a first approximation for the (NPSH) if the specified conditions given in 6.3.3 for the speed of rotation and the flow rate have been fulfilled and if the physical state of the liquid at the entrance of the impeller is such that no awkward gas separation can affect correct operation of the pump. If the pump operates near the cavitation limits, or if the deviation of the test speed from the specified speed exceeds the specifications given in 6.3.3, the phenomena may be influenced by factors such as thermodynamic effects, the variation of the surface tension or the differences in dissolved or occluded air content. Values of exponent x between 1,3 and 2¹⁾ have been observed and an agreement between the parties to establish the conversion formula to be used is mandatory.

In the case of combined motor-pump units, or where the performance specifications are with respect to an agreed frequency and voltage instead of an agreed speed, the flow rate, pump total head, power input, and efficiency data are subject to these conversion laws, provided that n_{sp} is replaced by the frequency f_{sp} and n by the frequency f .

Such conversion, however, shall be restricted to the cases where the frequency during the test varies by no more than 1 % from the frequency prescribed for the characteristics specified. If the voltage used in the test is no more than 5 % above or below the voltage on which the specified characteristics are based, the other operational data require no change.

If these tolerances, i.e. 1 % for frequency and 5 % for voltage, are exceeded, it will be necessary for the purchaser and the manufacturer to reach agreement.

6.5.2.2 Tests made with (NPSH) different from that specified

After correction for speed of rotation within the permitted limits (see 6.3.3), measured pump performance at a higher (NPSH) cannot be accepted to indicate performance at a lower (NPSH).

After correction for speed of rotation within the permitted limits (see 6.3.3), measured pump performance at a low (NPSH) can be accepted to indicate performance at a higher (NPSH) provided that the absence of cavitation has been checked in accordance with clause 12.

6.5.3 Presentation of test results

The presentation of test results shall be made using the overall uncertainties computed from the test or alternatively using contractually pre-agreed values, chosen taking account of the agreed test method and conditions.

Taking into account the total uncertainty on each coordinate, each measured operating point may be represented by an ellipse. The axes of this ellipse represent the total uncertainty for a confidence level of 95 %. They are calculated in annex A.

The absolute values of the uncertainties are:

- for pump discharge $\pm e_Q Q$
- for pump head $\pm e_H H$
- for pump input $\pm e_P P$
- for pump efficiency $\pm e_\eta \eta$

where e represents the fractional total error in the quantities being considered.

After having determined the total uncertainties and drawn the ellipses for each measured point, an upper and lower envelope of the ellipses shall be drawn (see figure 2).

The test result therefore is a band of measurement limited by the two envelopes. All points within this band are equally valid.

Concerning adherence to specification, see annex B.

1) See RÜTSCHI, K., *Messung und Drehzahlumrechnung des NPSH-Wertes bei Kreiselpumpen*, Schweizer Ingenieur und Architekt 39/80.

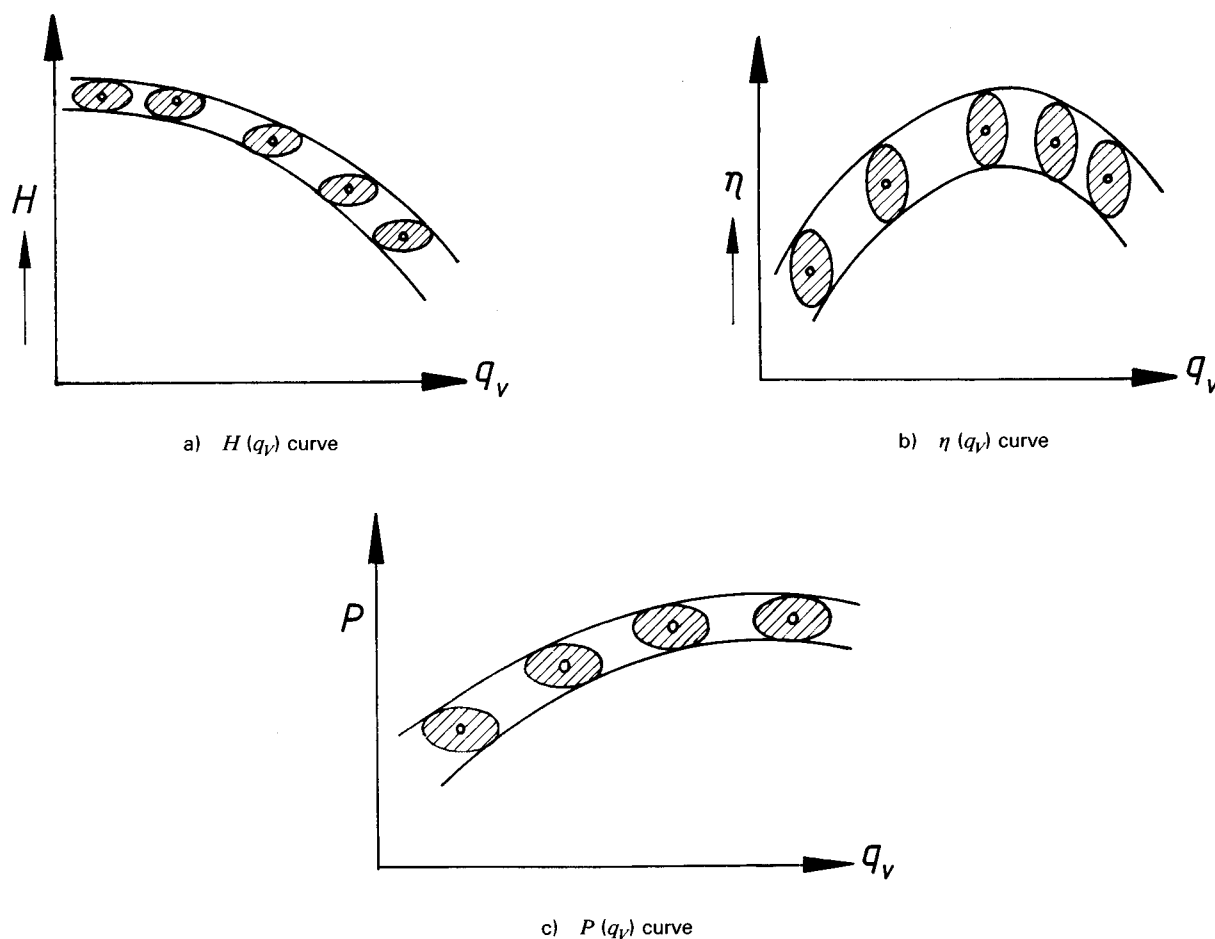


Figure 2 — Envelopes of the ellipses of total uncertainty for each measured point

Section two: Measurement methods

7 Measurement of rate of flow

7.1 General

The choice of the method for measuring the volume rate of flow q_v (see table 1) depends on a number of factors of which the following may be cited:

- the value of the flow rate to be measured;
- the type of test (on a model or on the full-size machine; on a test platform or on site);
- practical conditions of installation and layout of the circuit;
- the accuracy desired;
- the cost of putting the method into operation and possible time out of action.

Table 8 sets out the methods which may be envisaged for each case, and the accuracy or systematic uncertainty that may be expected when they are used in good measurement conditions by experienced personnel and in accordance with existing International Standards. In particular, the values of the uncertainty given in this table imply that the flow is steady and free from disturbance produced by the pump. **It must be emphasized that the overall value of uncertainty for each case can only be determined after the tests.** The methods mentioned vary considerably in accuracy, but they all have an estimated uncertainty of less than 2 % (at a confidence level of 95 %). By virtue of this and depending on test conditions, any one of them may be envisaged for precision class tests.

Other methods which are not indicated in table 8 may also be used subject to the following two conditions:

- their systematic measurement uncertainty shall be determined and checked by periodic calibration using a primary method;
- the resulting uncertainty shall be compatible with table 7.

Table 8 — Methods for flow rate measurement

Values as percentages

Measurement methods and standards	Systematic measuring uncertainty (at a confidence level of 95 %)		
	Laboratory model tests	Tests on full-size pumps	
		on test platform	on site
Primary methods { by weight (ISO 4185) volumetric (ISO 8316) travelling screen (IEC Publication 193)	$\pm 0,1$ to $\pm 0,3$ $\pm 0,1$ to $\pm 0,3$ $\pm 0,1$ to $\pm 0,3$	$\pm 0,1$ to $\pm 0,3$ $\pm 0,1$ to $\pm 0,3$ $\pm 0,1$ to $\pm 0,3$	— $\pm 0,5$ to $\pm 1,5$ —
Differential pressure devices ¹⁾ (ISO 5167 and ISO 2186) Turbine flowmeter ¹⁾	$\pm 0,3$ to $\pm 0,5$	$\pm 0,3$ to $\pm 0,5$	$\pm 0,5$ to ± 1
Electromagnetic flowmeter ¹⁾	$\pm 0,5$ to ± 1	$\pm 0,5$ to ± 1	± 1 to $\pm 1,5$
Calibrated weir (ISO 1438/1, ISO 3846, ISO 4359, ISO 4360) { by a primary method by a secondary method	$\pm 0,5$ to $\pm 1,5$ —	$\pm 0,5$ to $\pm 1,5$ —	— ± 1 to ± 2
Standardized orifice plate (ISO 5167 and ISO 2186)	± 1 to $\pm 1,5$	± 1 to $\pm 1,5$	± 1 to $\pm 1,5$
Standardized venturi tube (ISO 2186)	± 1 to ± 2	± 1 to ± 2	± 1 to ± 2
Velocity area methods { by current meters (ISO 3354) by Pitot tube (ISO 3966)	— ± 1 to ± 2	— ± 1 to ± 2	± 1 to ± 2 ± 1 to ± 2
Tracer methods (ISO 2975 and ISO 555/1 to 3) { dilution transit time	— — —	— — —	± 1 to ± 2 ± 1 to ± 2 ± 1 to ± 2

1) Calibrated by a primary method.

7.2 Measurement by weighing

ISO 4185 specifies two alternative methods:

- the "static weighing method" which consists of diverting the flow alternately inside and outside the weighing tank;
- the "dynamic weighing method", where the weighing is made "in flight", the flow being directed permanently into the tank.

The weighing method, which gives only the value of the average flow rate during the time taken to fill the weighing tank, may be considered the most accurate method of flow rate measurement.

It is affected by errors relating to weighing, to measuring the filling time, and to the determination of the density taking into account the temperature of the fluid. There may also be errors in connection either with diverting the flow (static method) or with dynamic phenomena at the time of weighing (dynamic method). Furthermore, a buoyancy correction has to be made to the readings of the weighing machine to take account of the difference between the up-thrust exerted by the atmosphere on the liquid being weighed and on the reference mass used during the calibration of the weighing machine.

With high quality apparatus, the systematic uncertainty on the measurement of the flow rate (at a confidence level of 95 %) may be in the region of 0,1 to 0,2 %.

It should be noted that the weighing method requires large fixed installations which are only really practicable in a laboratory and for relatively low flow rates (less than 1,5 m³/s for instance).

7.3 Volumetric method

For the description of this method, see ISO 8316.

The volumetric method approaches the accuracy of the weighing method and similarly only supplies the value of the average flow rate during the time it takes to fill the gauged capacity.

The volumetric method is affected by errors relating to the calibration of the reservoir, the measurement of levels, the measurement of filling time, and also by errors in connection either with diverting the flow (static method) or with dynamic phenomena at the time of gauging (dynamic method). Moreover, the watertightness of the reservoir shall be checked and a leakage correction made if necessary.

The calibration of the reservoir may be obtained by measuring the water level after successive volumes of water determined either by weighing or by means of a gauged pipette are poured into the reservoir tank.

With high quality apparatus, the estimated uncertainty (at a confidence level of 95 %) may be in the region of 0,1 to 0,3 %. However, in its normal form as described above, the volumetric method is subject to the same limitations as the weighing method.

On the other hand, there exists a variant to the volumetric method which can be used on site and for larger flow rates, where a natural reservoir the volume of which has been determined by geometrical or topographical procedures can be used as the gauged capacity (see IEC Publication 41). It must, however, be emphasized that the accuracy of this method is much less than that of the volumetric method used in the

laboratory, notably on account of the inaccuracy in measuring the reservoir, uncertainty about possible leaks or inflows, and the difficulty of determining the levels and disturbances due to atmospheric conditions. Depending on the particular circumstances (whether the reservoir is natural or artificial, the capacity of the reservoir compared to the flow rate to be measured, the stability of conditions over a relatively long period of time, etc.) the systematic uncertainty of a flow rate measured by this method may be estimated at 1 to 2 %.

7.4 Travelling screen

A description of this method and the conditions for its use are given in IEC Publication 193.

Its principle, which is close to that of the volumetric method, makes this a very accurate one, for it only requires the measurement of the dimensions of the channel, the level of the water and the moving time of the screen.

However, as in 7.2 and 7.3, measurement by travelling screen requires large and very carefully maintained apparatus, so that it can only be used for laboratory tests or tests in the works on a full-size pump platform. It is particularly well adapted to the latter type of test, as it enables relatively high flow rates to be obtained (around 3 m³/s, for example) with a systematic uncertainty (at a confidence level of 95 %) of about 0,2 to 0,3 %.

7.5 Differential pressure devices

For the construction, installation and use of orifice plates, nozzles and venturi tubes, see ISO 5167; for specifications on connecting piping for the manometer, see ISO 2186. Different types of standardized differential pressure devices are shown in figure 3.

In particular, attention should be drawn to the minimum straight lengths to be adhered to upstream of the differential pressure device; these are specified in ISO 5167 for various configurations of piping. If it is necessary to place the differential pressure device downstream of the pump (a case not covered in ISO 5167), the pump may be considered to create a disturbance in the flow equivalent to two elbows not in the same plane. However, when working away from the operating conditions corresponding to the best efficiency of the pump, the swirl of the flow produced by the pump can involve more severe conditions. To overcome these it will be necessary to install, downstream of the pump, a swirl remover or flow straightener of one of the types given in ISO 5167, provided the straight lengths specified in this International Standard upstream and downstream of the straightener are complied with.

It should also be noted that the diameter of the pipe and the Reynolds number must fall within the ranges specified in the International Standard for each type of device.

In these conditions, if there is no special calibration, using the discharge coefficient indicated in the relevant International Standards may be considered to give a systematic uncertainty

on the flow rate (at a confidence level of 95 %) of 1 to 1,5 %, for an orifice plate or an ISA 32 nozzle, and from 1 to 2 % for a long-radius nozzle or a venturi tube.

If a departure is made from the standardized conditions, or if greater accuracy is required, the differential pressure device shall be calibrated in its particular conditions of use by means of one of the primary methods described in 7.2 to 7.4. In good measuring conditions, a systematic uncertainty (at a confidence level of 95 %) of approximately 0,3 to 0,5 % can then be obtained.

When choosing between the various types of differential pressure devices, the following factors should be considered:

- a) the greatest accuracy for uncalibrated devices conforming to the relevant International Standards is achieved with orifice plates, the least with venturi tubes;
- b) head loss is much lower for venturi tubes than for orifice plates and nozzles (about five times as low, given an equal differential pressure);
- c) the straight lengths required are much smaller for classical venturi tubes than for orifice plates, nozzles and venturi nozzles;
- d) building and positioning is much simpler for an orifice plate than for a nozzle or a venturi tube — the latter requires a large distance between flanges;
- e) in the case of orifice plates, a significant error can arise if buckling of the plate occurs due to the existence of a large differential pressure across the plate.

7.6 Weirs

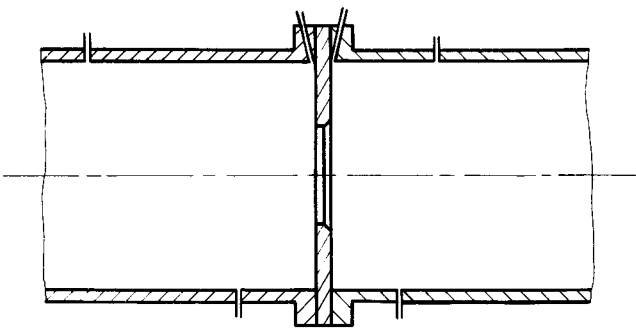
The specifications for thin-plate weirs and measuring flumes are given in ISO 1438/1 and ISO 4359 and those for various types of broad-crested weirs in ISO 3846 and ISO 4360. Figure 4 shows the different types of standardized structures schematically.

However, even for rectangular thin-plate weirs, which are the best known and the most stable, the uncertainty which surrounds the normalized discharge coefficient is not compatible with the accuracy being sought in this International Standard.

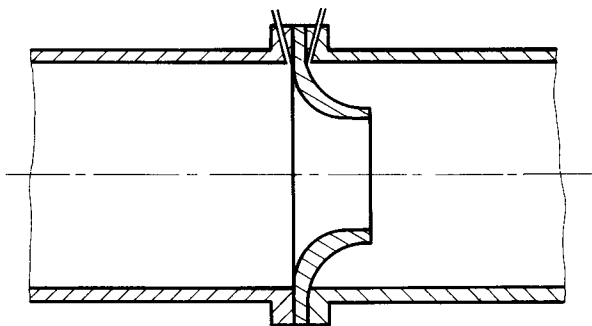
On the other hand, if it is possible to calibrate the weir in its position in the exact conditions of use since great sensitivity to velocity distribution in the approach channel exists and periodically to check this calibration by means of one of the primary methods described in 7.2 to 7.4, for laboratory or platform tests a flow rate measurement with an estimated uncertainty (at confidence level of 95 %) of about 0,5 to 1,5 % may be attained. For on-site tests, calibrating the weir by means of one of the methods described in 7.8 or 7.9 can lead to a systematic uncertainty of 1 to 2 %.

To achieve this, however, great care must be taken to maintain the weir in perfect condition; it may be noted that it is easier to conserve and check the sharpness of the edge of a thin-plate weir than the roughness of the sill and walls of a broad-crested weir or a measuring flume.

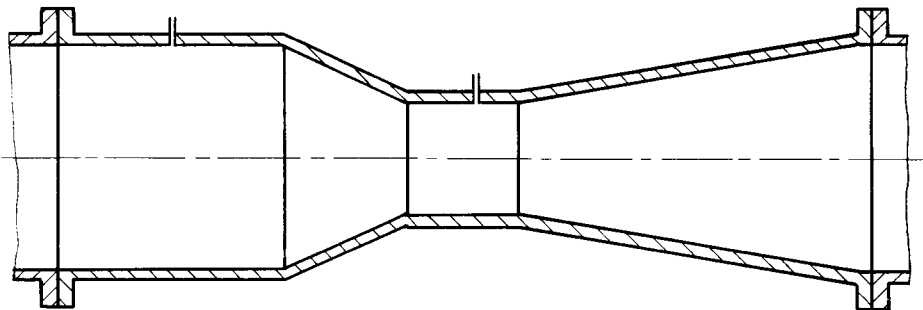
Orifice plate
(with corner taps, D and $D/2$ taps,
or flange taps)



Nozzle
(long radius or "ISA 32")



Classical
Venturi tube



Venturi nozzle

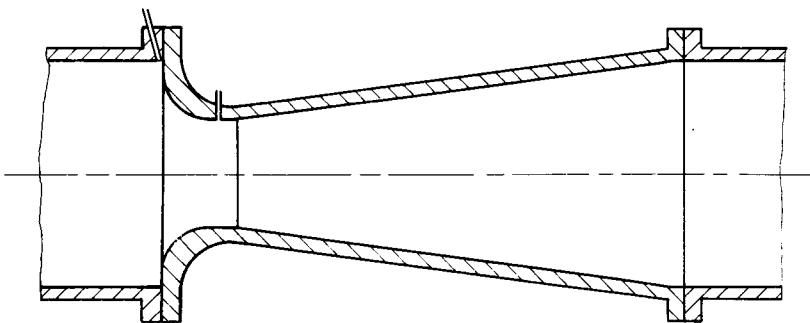


Figure 3 — Different types of standardized differential pressure devices (see ISO 5167)

7.7 Turbine meters and electromagnetic flowmeters¹⁾

Though quite different in conception, these two types of flowmeter have many points in common with regard to practical conditions of use.

In no circumstances should they be used unless calibrated beforehand by means of one of the primary methods described in 7.2 to 7.4. Although these devices do not require very long upstream straight pipe lengths, in general it is desirable that the conditions of calibration should reproduce the circuit configuration in which they will be used. If they are installed permanently on a test platform, the possibility of a periodic check on their calibration must be taken into account. In these conditions, a flow rate may be obtained with a systematic uncertainty (at a confidence level of 95 %) of about 0,3 to 0,5 % for turbine flowmeters and 0,5 to 1 % for electromagnetic flowmeters.

NOTE — The fact that these flowmeters send an electric signal direct makes their integration into an automatic measuring system particularly easy.

7.8 Velocity area methods

ISO 3354 and ISO 3966 specify methods for discharge measurements in closed conduits by means of current meters and Pitot tubes respectively. They give all the specifications considered necessary concerning conditions for application, choice and operation of the apparatus, the measurement of point velocities and the calculation of the flow rate by graphical or numerical integration of the velocity distribution.

In the most favourable measuring conditions, the systematic uncertainty in the measurement of the flow rate (at confidence level of 95 %) is 1 to 2 %.

The main disadvantages of these methods are that

- a) they require fairly long straight lengths to ensure a regular velocity distribution;
- b) with current meters, they can only be used in large diameter pipes;
- c) it is rather difficult to put them into operation; as a result the installation may not be available for several days.

On the other hand, the velocity integration method is often the only one that can be applied when testing pumps with large flow rates.

Among precautions to be taken, it should be particularly ensured that the support of the current meters or Pitot tubes does not create excessive obstruction in the pipe.

Furthermore, except in very long pipe installations, it is preferable that the measuring section should be placed upstream of the pump in order to avoid too much turbulence or swirling flow.

Where the plant comprises a sufficiently long artificial open channel, the discharge may be measured by the velocity area method using current meters in this channel (see IEC Publication 198).

7.9 Tracer methods

The various parts of ISO 2975 apply to the measurement of the flow rate in pipes, by both the dilution method (constant rate injection) and the transit time method (also called the salt velocity method); each method uses either radioactive or non-radioactive tracers. Furthermore, ISO 555/1 to 3 specifies dilution methods for discharge measurements in open channels.

These methods have the advantage of being usable for a very wide range of flow rates, and some of them only require minimal interference with the pipe. The length required in some cases to ensure adequate mixing of the solution injected can in practice be reduced on the one hand by injecting into the suction pipe of the pump which is then used as a mixer or on the other hand by increasing in each section the number of injection positions and sampling or measuring positions.

These methods should only be used by trained staff and it may be noted that the use of radioactive tracers is subject to certain constraints.

It may be considered that the systematic uncertainty in the determination of the flow rate (at a confidence level 95 %) with these methods is from 1 to 2 %.

8 Measurement of head

8.1 General

8.1.1 Principles of measurement

8.1.1.1 Total head and specific hydraulic energy

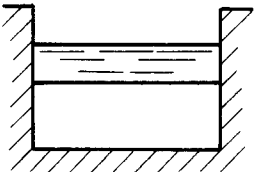
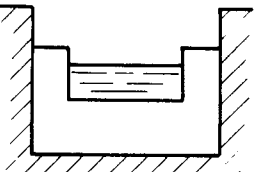
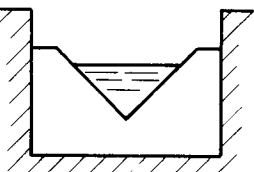
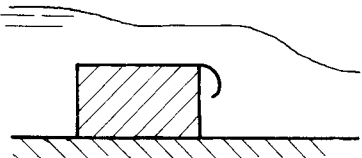
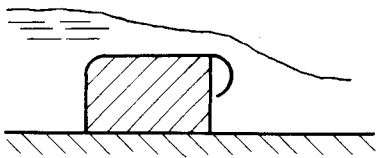
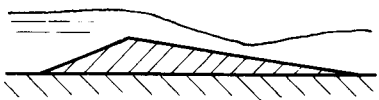
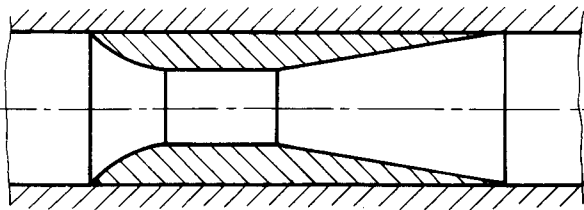
Although expressed as a height of pumped liquid column, the pump total head, H , calculated in accordance with its definition given in table 1, represents in actual fact the energy transmitted by the pump per unit weight of liquid.

This concept of specific energy may replace the one of head and its use is to be recommended, since for instance the column of liquid representing the total head is not exactly the difference in height that may be read at a liquid column (supposing no difference in elevation or available kinetic energy between inlet and outlet). This discrepancy is due to liquid compressibility and atmospheric pressure related to elevation.

8.1.1.2 Effect of liquid compressibility on total head evaluation

Total head is in fact the maximum amount of mechanical energy per unit weight that may be released in bringing the liquid from its actual conditions to reference conditions.

1) These will form the subject of a future International Standard.

Thin-plate weirs (see ISO 1438/1)	Rectangular full-width weir	
	Rectangular notch	
	Triangular notch	
Broad-crested weirs (see ISO 3846)	Rectangular profile weir with sharp upstream edge	
	Rectangular profile weir with rounded upstream edge	
Triangular profile weir (see ISO 4360)		
Standing wave flume (with rectangular, trapezoidal or U-throat) (see ISO 4359)		

NOTE — The accuracy required in this International Standard can only be achieved if the discharge coefficient of such devices is determined by individual on-site calibration; thus it is not permitted to use the values of coefficients as they are given in the relevant International Standards.

Figure 4 — Different types of standardized weirs and flumes

Reference conditions are generally sea level and standard atmospheric pressure, but within the frame of a test where only differences in energy level are of concern, other reference conditions may be chosen, for example floor elevation and atmospheric pressure at the time of test.

For liquid at elevation z_i at the pressure p_{ei} , with velocity U_i and g being constant, the correct evaluation of total head is given by the equation:

$$H_i = z_i + \frac{1}{g} \int_{p_o}^{p_{ei}} \frac{dp}{\varrho} + \alpha_{ai} \frac{U_i^2}{2g}$$

This integration is to be evaluated for an isentropic process. Tables and formulae may be found giving the value of this integral for water.

Generally speaking, ϱ varies with pressure and temperature, therefore evaluation is not straightforward. However, pressure dependence is low and nearly linear and one may write

$$H_i = z_i + \frac{2 p_{ei}}{(\varrho_i + \varrho_o)g} + \alpha_{ai} \frac{U_i^2}{2g}$$

This approximation holds for water up to 40 °C and up to 15 MPa¹⁾. The definition of total head given table 1 is a complementary simplification based on the assumption that

$$\varrho_i = \varrho_o$$

It is the responsibility of the chief of tests to decide whether compressibility may be fully neglected in relation to the acceptable uncertainty allowed by each specific tests.

Direct evaluation of pump total head is recommended where compressibility cannot be disregarded, due to the following

$$\frac{1}{g} \int_{p_o}^{p_{e2}} \frac{dp}{\varrho} - \frac{1}{g} \int_{p_o}^{p_{e1}} \frac{dp}{\varrho} = \frac{1}{g} \int_{p_{e1}}^{p_{e2}} \frac{dp}{\varrho}$$

This calculation requires analytic expression of the state function $v = f(p)$. However, if linearization is possible, the following will be valid :

$$\frac{1}{g} \int_{p_{e1}}^{p_{e2}} \frac{dp}{\varrho} = \frac{2(p_{e2} - p_{e1})}{(\varrho_2 + \varrho_1)g}$$

where

ϱ_1 is unit mass of fluid at p_{e1} and θ_1 ;

ϱ_2 is unit mass of fluid at p_{e2} and θ_1 .

NOTE — The temperature at the end of the reversible process is slightly different from θ_1 . The error due to neglecting this difference does not exceed 0,1 % on efficiency when the pressure is less than 150 bar and the temperature is less than 250 °C (see 11.2).

8.1.1.3 Available velocity head

The velocity head prevailing in a measuring section cannot be fully converted into total head. This is especially the case at the pump outlet [see section (2) of figure 5].

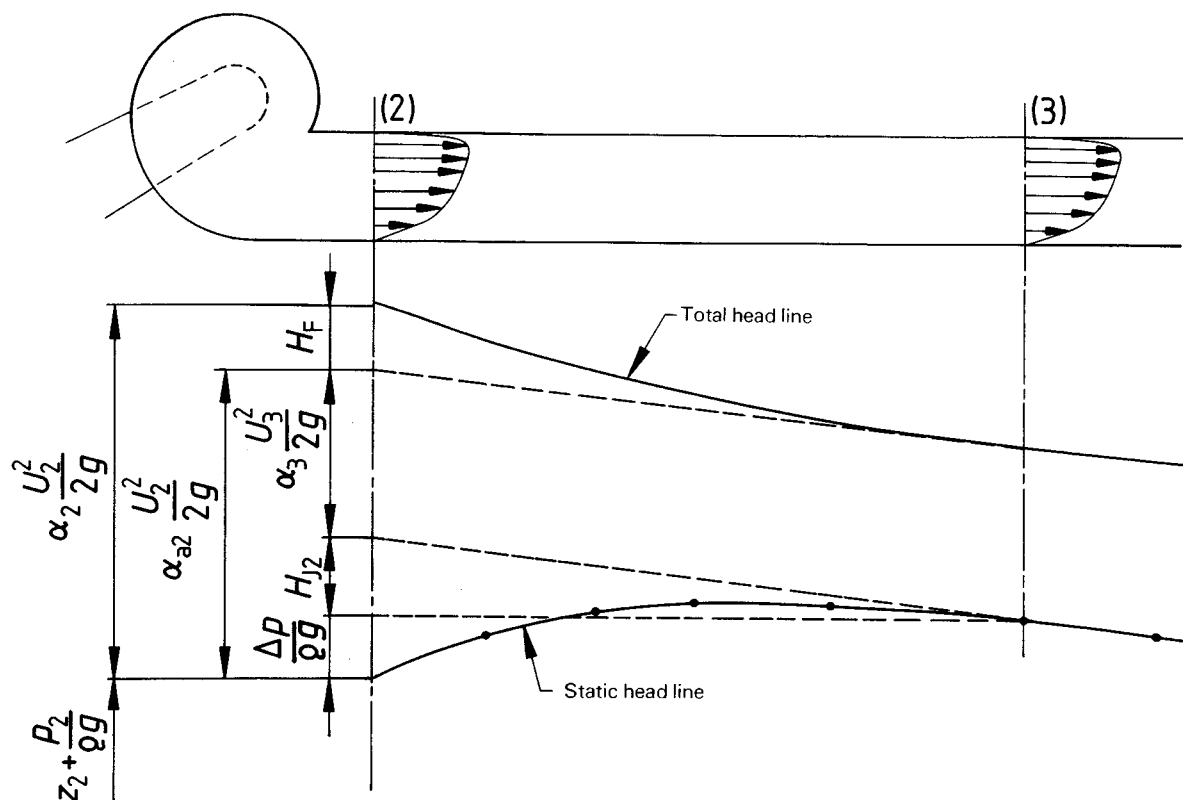


Figure 5 — Determination of available velocity head

1) 1 MPa = 10 bar