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Rotodynamic pumps — Hydraulic performance acceptance tests — Grades 1, 2 and 3

Pompes rotodynamiques — Essais de fonctionnement hydraulique pour la réception — Niveaux 1, 2 et 3

Reference number
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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. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9906 was prepared by Technical Committee ISO/TC 115, *Pumps*, Subcommittee SC 2, *Methods of measurement and testing*.

This second edition cancels and replaces the first edition (ISO 9906:1999), which has been technically revised.

Introduction

The tests in this International Standard are intended to ascertain the performance of the pump and to compare this with the manufacturer's guarantee.

The nominated guarantee for any quantity is deemed to have been met if, where tested according to this International Standard, the measured performance falls within the tolerance specified for the particular quantity (see 4.4).

Rotodynamic pumps — Hydraulic performance acceptance tests — Grades 1, 2 and 3

1 Scope

This International Standard specifies hydraulic performance tests for customers' acceptance of rotodynamic pumps (centrifugal, mixed flow and axial pumps, hereinafter "pumps").

This International Standard is intended to be used for pump acceptance testing at pump test facilities, such as manufacturers' pump test facilities or laboratories.

It can be applied to pumps of any size and to any pumped liquids which behave as clean, cold water.

This International Standard specifies three levels of acceptance:

— grades 1B, 1E and 1U with tighter tolerance;

— grades 2B and 2U with broader tolerance;

— grade 3B with even broader tolerance.

This International Standard applies either to a pump itself without any fittings or to a combination of a pump associated with all or part of its upstream and/or downstream fittings.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 17769-1, *Liquid pumps and installation — General terms, definitions, quantities, letter symbols and units — Part 1: Liquid pumps*

ISO 17769-2, *Liquid pumps and installation — General terms, definitions, quantities, letter symbols and units — Part 2: Pumping system*

3 Terms, definitions, symbols and subscripts

3.1 Terms and definitions

For the purposes of this document, the terms, definitions, quantities and symbols given in ISO 17769-1 and 17769-2 and the following apply.

NOTE 1 Table 1 gives an alphabetical list of the symbols used and Table 2 gives a list of subscripts; see 3.3.

NOTE 2 All formulae are given in coherent SI units. For conversion of other units to SI units, see Annex I.

3.1.1 General terms

NOTE All of the types of test in 3.1.1 apply to guarantee point to fulfil the customer's specification(s).

3.1.1.1
guarantee point
flow/head (Q/H) point, which a tested pump shall meet, within the tolerances of the agreed acceptance class

3.1.1.2
factory performance test
pump test performed to verify the initial performance of new pumps as well as checking for repeatability of production units, accuracy of impeller trim calculations, performance with special materials, etc.

NOTE A typical performance test consists of the measurement of flow, head and power input to the pump or pump test motor. Additional measurements, such as NPSH, may be included as agreed upon. A factory test is understood to mean testing at a dedicated test facility, often at a pump manufacturer's plant or at an independent pump test facility.

3.1.1.3
non-witnessed pump test

3.1.1.3.1
factory test
test performed without the presence of a purchaser's representative, in which the pump manufacturer is responsible for the data collection and judgement of pump acceptance

NOTE The advantage of this test is cost savings and accelerated pump delivery to the pump user. In many cases, if the purchaser is familiar with the performance of the pump (e.g. identical pump model order), a factory non-witnessed test may be acceptable.

3.1.1.3.2
signed factory test
test performed without the presence of a purchaser's representative, in which the pump manufacturer is responsible for compliance with the parameters of the agreed acceptance class

NOTE The pump manufacturer conducts the test, passes judgement of pump acceptance and produces a signed pump test document. The advantage of this test is the same as seen on the non-witnessed test. Compared to a witnessed test, this test is substantially less expensive and often leads to accelerated pump delivery to the end user.

3.1.1.4
witnessed pump test

NOTE The witnessing of a pump test by a representative of the pump purchaser can serve many useful functions. There are various ways of witnessing a test.

3.1.1.4.1
witnessing by the purchaser's representative
testing physically attended by a representative of the purchaser, who signs off on the raw test data to certify that the test is performed satisfactorily

NOTE It is possible for final acceptance of the pump performance to be determined by the witness. The benefit of witness testing depends largely on the effectiveness and expertise of the witness. A witness cannot only ensure the test is conducted properly, but also observes operation of the pump during testing prior to pump shipment to the job site. A disadvantage of witness testing can be extended delivery times and excessive cost. With just-in-time manufacturing methods, the scheduling of witness testing requires flexibility on the part of the witness and can lead to additional costs if the schedule of the witness causes delays in manufacturing.

3.1.1.4.2
remote witnessing by the purchaser's representative
pump performance testing witnessed from a distance by the purchaser or his/her representative

NOTE With a remote camera system, the purchaser can monitor the entire testing remotely in real-time. The raw data, as recorded by the data acquisition system, can be viewed and analysed during the test, and the results can be discussed and submitted for approval. The advantages of this type of testing are savings in travel costs and accelerated pump delivery.

3.2 Terms relating to quantities

3.2.1
angular velocity
ω
number of radians of shaft rotation

NOTE 1 It is given by:

$$\omega = 2\pi n \tag{1}$$

NOTE 2 It is expressed in time, e.g. s^{-1}, where n is given in $60 \times min^{-1}$.

3.2.2
speed of rotation
number of rotations per second

3.2.3
mass flow rate
rate of flow discharged into the pipe from the outlet connection of the pump

NOTE 1 The mass flow rate is given in kilograms per second.

NOTE 2 The following losses or limiting effects are inherent to the pump:

a) discharge necessary for hydraulic balancing of axial thrust;

b) cooling of the pump bearings.

NOTE 3 Leakage from the fittings, internal leakage, etc., are not to be reckoned in the rate of flow. On the contrary, all derived flows for other purposes, such as

a) cooling of the motor bearings, and

b) cooling of a gear box (bearings, oil cooler)

are to be reckoned in the rate of flow.

NOTE 4 Whether and how these flows should be taken into account depends on the location of their derivation and of the section of flow-measurement respectively.

3.2.4
volume rate of flow
rate of flow at the outlet of the pump, given by:

$$Q = \frac{q}{\rho} \tag{2}$$

NOTE In this International Standard, this symbol may also designate the volume rate of flow in any given section. It is the quotient of the mass rate of flow in this section by the density. (The section may be designated by subscripts.)

3.2.5
mean velocity
mean value of the axial speed of flow, given by:

$$U = \frac{Q}{A} \tag{3}$$

NOTE Attention is drawn to the fact that in this case, Q may vary for different reasons across the circuit.

3.2.6
local velocity
speed of flow at any given point

3.2.7
head
energy of mass of liquid, divided by acceleration due to gravity, g, given by:

$$H = \frac{y}{g} \tag{4}$$

See 3.2.16.

3.2.8
reference plane
any horizontal plane used as a datum for height measurement

NOTE For practical reasons, it is preferable not to specify an imaginary reference plane.

3.2.9
height above reference plane
height of the considered point above the reference plane

See Figure A.1.

NOTE Its value is:

— positive, if the considered point is above the reference plane;

— negative, if the considered point is below the reference plane.

3.2.10
gauge pressure
pressure relative to atmospheric pressure

NOTE 1 Its value is:

— positive, if this pressure is greater than the atmospheric pressure;

— negative, if this pressure is less than the atmospheric pressure.

NOTE 2 All pressures in this International Standard are gauge pressures read from a manometer or similar pressure sensing instrument, except atmospheric pressure and the vapour pressure of the liquid, which are expressed as absolute pressures.

3.2.11
velocity head
kinetic energy of the liquid in movement, divided by g, given by:

$$\frac{U^2}{2g} \tag{5}$$

3.2.12
total head
overall energy in any section

NOTE 1 The total head is given by:

$$H_x = z_x + \frac{p_x}{\rho \times g} + \frac{U_x^2}{2 \times g} \tag{6}$$

where

z is the height of the centre of the cross-section above the reference plane;

p is the gauge pressure related to the centre of the cross-section.

NOTE 2 The absolute total head in any section is given by:

$$H_{x(\mathrm{abs})} = z_x + \frac{p_x}{\rho \times g} + \frac{p_{\mathrm{amb}}}{\rho \times g} + \frac{U_x^2}{2g} \quad (7)$$

3.2.13
inlet total head
overall energy at the inlet section of the pump

NOTE Inlet total head is given by:

$$H_1 = z_1 + \frac{p_1}{\rho \times g} + \frac{U_1^2}{2g} \quad (8)$$

3.2.14
outlet total head
overall energy at the outlet section of the pump

NOTE Outlet total head is given by:

$$H_2 = z_2 + \frac{p_2}{\rho \times g} + \frac{U_2^2}{2g} \quad (9)$$

3.2.15
pump total head
algebraic difference between the outlet total head, H_2, and the inlet total head, H_1

NOTE 1 If compressibility is negligible, $H = H_2 - H_1$. If the compressibility of the pumped liquid is significant, the density, ρ, should be replaced by the mean value:

$$\rho_{\mathrm{m}} = \frac{\rho_1 + \rho_2}{2} \quad (10)$$

and the pump total head should be calculated by Formula (12):

$$H = z_2 - z_1 + \frac{p_2 - p_1}{\rho_{\mathrm{m}} \cdot g} + \frac{U_2^2 - U_1^2}{2g} \quad (11)$$

NOTE 2 The correct mathematical symbol is $H_{1\text{–}2}$.

3.2.16
specific energy
energy of liquid, given by:

$$y = gH \quad (12)$$

3.2.17
loss of head at inlet
difference between the total head of the liquid at the measuring point and the total head of the liquid in the inlet section of the pump

3.2.18
loss of head at outlet
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

3.2.19
pipe friction loss coefficient
coefficient for the head loss by friction in the pipe

3.2.20
net positive suction head
NPSH
absolute inlet total head above the head equivalent to the vapour pressure relative to the NPSH datum plane

NOTE 1 NPSH is given by:

$$\mathrm{NPSH} = H_1 - z_D + \frac{p_{amb} - p_v}{\rho_1 \cdot g} \tag{13}$$

NOTE 2 This NPSH relates to the NPSH datum plane, whereas inlet total head relates to the reference plane.

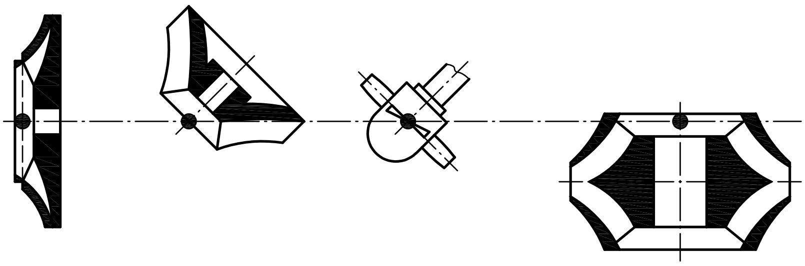
NOTE 3 A derogation has been given to allow the use of the abbreviated term NPSH (upright and not bold) as a symbol in mathematical formulae as a consequence of its well-established, historical use in this manner.

3.2.20.1
NPSH datum plane
<multistage pumps> horizontal plane through the centre of the circle described by the external points of the entrance edges of the impeller blades

3.2.20.2
NPSH datum plane
<double inlet pumps with vertical or inclined axis> plane through the higher centre

See Figure 1.

NOTE It is the responsibility of the manufacturer to indicate the position of this plane with respect to precise reference points on the pump.



Key
1 NPSH datum plane

Figure 1 — NPSH datum plane

3.2.21
available NPSH
NPSHA
NPSH available as determined by the conditions of the installation for a specified rate of flow

NOTE A derogation has been given to allow the use of the abbreviated term NPSHA (upright and not bold) as a symbol in mathematical formulae as a consequence of its well-established, historical use in this manner.

3.2.22
required NPSH
NPSHR
minimum NPSH given by the manufacturer for a pump achieving a specified performance at the specified rate of flow, speed and pumped liquid (occurrence of visible cavitation, increase of noise and vibration due to cavitation, beginning of head or efficiency drop, head or efficiency drop of a given amount, limitation of cavitation erosion)

NOTE A derogation has been given to allow the use of the abbreviated term NPSHR (upright and not bold) as a symbol in mathematical formulae as a consequence of its well-established, historical use in this manner.

3.2.23
NPSH3
NPSH required for a drop of 3 % of the total head of the first stage of the pump as standard basis for use in performance curves

NOTE A derogation has been given to allow the use of the abbreviated term NPSH (upright and not bold) as a symbol in mathematical formulae as a consequence of its well-established, historical use in this manner.

3.2.24
type number
dimensionless quantity calculated at the point of best efficiency

NOTE 1 It is given by:

$$K = \frac{2\,\pi n\, Q'^{1/2}}{(gH')^{3/4}} = \frac{\omega\, Q'^{1/2}}{y'^{3/4}} \qquad (14)$$

where

Q' is the volume rate of flow per eye;

H' is the head of the first stage;

n is given in s^{-1}.

NOTE 2 The type number is to be taken at maximum diameter of the first stage impeller.

3.2.25
pump power input
P_2
power transmitted to the pump by its driver

3.2.26
pump power output
hydraulic power at the pump discharge

NOTE Pump power output is given by:

$$P_h = \rho Q g H = \rho Q y \qquad (15)$$

3.2.27
driver power input
P_{gr}
power absorbed by the pump driver

3.2.28
maximum shaft power
$P_{2,max}$
maximum pump shaft power, as set by the manufacturer, which is adequate to drive the pump over the specified operating conditions

3.2.29
pump efficiency
pump power output divided by the pump power input

NOTE Pump efficiency is given by:

$$\eta = \frac{P_h}{P_2} \qquad (16)$$

3.2.30
overall efficiency
pump power output divided by the driver power input

NOTE Overall efficiency is given by:

$$\eta_{\mathrm{gr}} = \frac{P_{\mathrm{h}}}{P_{gr}} \tag{17}$$

3.3 Symbols and subscripts

Table 1 — Alphabetical list of basic letters used as symbols

Symbol	Quantity	Unit
A	Area	m^2
D	Diameter	m
e	Overall uncertainty, relative value	%
f	Frequency	s^{-1}, Hz
g	Acceleration due to gravity[a]	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	Pure number
l	Length	m
M	Torque	Nm
n	Speed of rotation	s^{-1}, min^{-1}
NPSH	Net positive suction head	m
p	Pressure	Pa
P	Power	W
q	Mass flow rate[b]	kg/s
Q	(Volume) rate of flow[c]	m^3/s
Re	Reynolds number	Pure number
τ	Tolerance factor, relative value	%
t	Students distribution	Pure number
U	Mean velocity	m/s
v	Local velocity	m/s
V	Volume	m^3
y	Specific energy	J/kg
z	Height above reference plane	m
z_D	Difference between NPSH datum plane and reference plane (see 3.2.20)	m
η	Efficiency	Pure number
θ	Temperature	°C
λ	Pipe friction loss coefficient	Pure number
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
ω	Angular velocity	rad/s

a In principle, the local value of g should be used. Nevertheless, for grades 2 and 3, it is sufficient to use a value of 9,81 m/s^2. For the calculation of the local value $g = 9{,}780\,3\,(1 + 0{,}005\,3 \sin^2 \varphi) - 3 \times 10^{-6} \cdot Z$, where φ is the latitude and Z is the height above sea level.

b An optional symbol for mass flow rate is q_m.

c An optional symbol for volume rate of flow is q_v.

Table 2 — List of letters and figures used as subscripts

Subscript	Meaning
1	inlet
1′	inlet measuring section
2	outlet (except for P_2)
2′	outlet measuring section
abs	absolute
amb	ambient
D	difference, datum
f	liquid in measuring pipes
G	guaranteed
H	pump total head
h	hydraulic
gr	combined motor/pump unit (overall)
J	losses
M	manometer
n	speed of rotation
P	power
Q	(volume) rate of flow
ref	reference plane
sp	specified
T	translated, torque
v	vapour (pressure)
η	efficiency
x	at any section

4 Pump measurements and acceptance criteria

4.1 General

The specified and contractually agreed upon rated point (duty point), hereinafter "the guarantee point", shall be evaluated against one acceptance grade and its corresponding tolerance. For a pump performance test, this guarantee point shall always specify the guaranteed flow, Q_G, and guaranteed head, H_G, and may, optionally, specify guaranteed efficiency, guaranteed shaft power or guaranteed net positive suction head required (NPSHR). Where applicable, these optional guarantee parameters need to be specified for those tests, see respective tests in 4.4.3 and 5.8.

The acceptance grade tolerance applies to the guarantee point only. Other specified duty points, including their tolerances, shall be by separate agreement between the manufacturer and purchaser. If other specified duty points are agreed upon, but no tolerance is given for these points, the default acceptance level for these points shall be grade 3.

A guarantee point may be detailed in a written contract, a customer-specific pump performance curve or similar written and project specific documentation.

If not otherwise agreed upon between the manufacturer and the purchaser, the following shall apply.

a) The acceptance grade shall be in accordance with the grades given in Table 8.

b) Tests shall be carried out on the test stand of the manufacturer's works with clean, cold water using the methods and test arrangements specified in this International Standard.

c) The pump performance shall be guaranteed between the pump's inlet connection and outlet connection.

d) Pipe and fittings (bends, reducers and valves) outside of the pump are not a part of the guarantee.

The combination of manufacturing and measurement tolerances in practice necessitates the usage of tolerances on tested values. The tolerances given in Table 8 take into account both manufacturing and measurement tolerances.

The performance of a pump varies substantially with the nature of the liquid being pumped. Although it is not possible to give general rules whereby performance with clean, cold water can be used to predict performance with other liquids, it is desirable for the parties to agree on empirical rules to suit the particular circumstances. For further information, see ISO/TR 17766.

If a number of identical pumps are being purchased, the number of pumps to be tested shall be agreed between the purchaser and manufacturer.

Both the purchaser and manufacturer shall be entitled to witness the testing. If tests are not carried out at the manufacturer's test stand, opportunity shall be allowed for verification of the pump installation and instrumentation adjustments by both parties.

4.2 Guarantees

The manufacturer guarantees that, for the guarantee point and at the rated speed (or in some cases frequency and voltage), the measured pump curve touches, or passes through a tolerance surrounding the guarantee point, as defined by the applicable acceptance grade (see Table 8 and Figures 2 and 3).

A guarantee point shall be defined by a guaranteed flow, Q_{G}, and a guaranteed head, H_{G}.

In addition, one or more of the following quantities may be guaranteed at the specified conditions and at the rated speed:

a) as defined in 4.4.3 and Figures 4, 5 and 6,

   1) the minimum pump efficiency, η_{G}, or the maximum pump input power, P_{G}, or

   2) in the case of a combined pump and motor unit, the minimum combined efficiency, η_{grG}, or the maximum pump motor unit input power, P_{grG}.

b) the maximum NPSHR at the guarantee flow.

The maximum power input may be guaranteed for the guarantee point or for a range of points along the pump curve. This, however, can require larger tolerances to be agreed upon between the purchaser and manufacturer.

4.3 Measurement uncertainty

4.3.1 General

Every measurement is inevitably subject to some uncertainty, even if the measuring procedures and the instruments used, as well as the methods of analysis, fully comply with good practice and with the requirements of this International Standard.

The guidance and procedures described in 4.3.2 and 4.3.3 are intended to provide general information to the user, as well as practical procedures allowing the user to estimate measurement uncertainty with reasonable confidence in applying the testing in conformity with this International Standard.

NOTE For comprehensive information on measurement uncertainty, see ISO/IEC Guide 99 and associated documents.

4.3.2 Fluctuations

Where the design or operation of a pump is such that fluctuations of great amplitude are present, measurements may be carried out by providing a damping device in the measuring instruments or their connecting lines, which is capable of reducing the amplitude of the fluctuations to within the values given in Table 3. A symmetrical and linear damping device shall be used, for example a capillary tube, which shall provide integration over at least one complete cycle of fluctuations.

Table 3 — Permissible amplitude of fluctuation as a percentage of mean value of quantity being measured

Measured quantity	Permissible amplitude of fluctuations		
	Grade 1 %	Grade 2 %	Grade 3 %
Rate of flow	±2	±3	±6
Differential head	±3	±4	±10
Outlet head	±2	±3	±6
Inlet head	±2	±3	±6
Input power	±2	±3	±6
Speed of rotation	±0,5	±1	±2
Torque	±2	±3	±6
Temperature	0,3 °C	0,3 °C	0,3 °C

4.3.3 Statistical evaluation of overall measurement uncertainty

4.3.3.1 The estimate of the random component (random uncertainty)

The random component due either to the characteristics of the measuring system or to variations of the measured quantity or both appears directly as a scatter of the measurements. Unlike the systematic uncertainty, the random component can be reduced by increasing the number of measurements of the same quantity under the same conditions.

A set of readings not less than three (3) shall be taken at each test point. The random component, e_R, shall be calculated as follows:

The estimate of the random component of measurement uncertainty is calculated from the mean and the standard deviation of the observations. For the uncertainty of the readings, replace x with the actual measurement readings of flow, Q, head, H, and power, P.

If n is the number of readings, the arithmetic mean, $\bar{x}$, of a set of repeated observations x_i $(i = 1...n)$ is

$$\bar{x} = \frac{1}{n}\sum x_i \tag{18}$$

The standard deviation, s, of these observations is given by:

$$s = \sqrt{\frac{1}{n-1}\sum (x_i - \bar{x})^2} \tag{19}$$

The relative value of the uncertainty, e_R, of the mean due to random effects is given by:

$$e_R = \frac{100\,ts}{\bar{x}\sqrt{n}}\,\% \tag{20}$$

where t is a function of n as given in Table 4.

NOTE 1 If the value of the overall uncertainty, e, does not meet the criteria given in Table 7, the value of the random component, e_R, of the measurement can be reduced by increasing the number of measurements of the same quantity under the same conditions.

NOTE 2 The random component, as defined in this International Standard, is classified as Type A uncertainty (see ISO/IEC Guide 99).

Table 4 — Values of Student's t-distribution
(based on 95 % confidence level)

n	t	n	t
3	4,30	12	2,20
4	3,18	13	2,18
5	2,78	14	2,16
6	2,57	15	2,14
7	2,45	16	2,13
8	2,36	17	2,12
9	2,31	18	2,11
10	2,26	19	2,10
11	2,23	20	2,09

4.3.3.2 The estimate of the instrumental measurement uncertainty (systematic uncertainties)

After all known errors have been removed by zero adjustment, calibration, careful measurement of dimensions, proper installation, etc., there remains an uncertainty which never disappears. This uncertainty cannot be reduced by repeating the measurements if the same instrument and the same method of measurement are used.

The estimate of the systematic uncertainty of the uncertainty, e_S, is in practice based on calibration traceable to international measurement standards. Permissible relative values for the systematic uncertainty in this International Standard are given in Table 5.

Table 5 — Permissible relative values of the instrumental uncertainty, e_S

Measured quantity	Maximum permissible systematic uncertainty (at guarantee point)	
	Grade 1 %	Grades 2 and 3 %
Rate of flow	±1,5	±2,5
Differential head	±1,0	±2,5
Outlet head	±1,0	±2,5
Inlet head	±1,0	±2,5
Suction head for NPSH testing	±0,5[a]	±1,0
Driver power input	±1,0	±2,0
Speed of rotation	±0,35	±1,4
Torque	±0,9	±2,0

[a] See Annex J for explanation.

4.3.3.3 The overall uncertainty

The value for overall uncertainty, e, is given by:

$$e = \sqrt{e_R^2 + e_S^2} \tag{21}$$

Permissible values of overall measurement uncertainties, e, are given in Table 6.

NOTE The overall uncertainty, as defined in this International Standard, is equated with expanded measurement uncertainty (see ISO/IEC Guide 99).

Table 6 — Permissible values of overall uncertainties

Quantity	Symbol	Grade 1 %	Grades 2, 3 %
Flow rate	e_Q	±2,0	±3,5
Speed of rotation	e_n	±0,5	±2,0
Torque	e_T	±1,4	±3,0
Pump total head	e_H	±1,5	±3,5
Driver power input	e_{Pgr}	±1,5	±3,5
Pump power input (computed from torque and speed of rotation)	e_P	±1,5	±3,5
Pump power input (computed from driver power and motor efficiency)	e_P	±2,0	±4,0

4.3.3.4 Determination of overall uncertainty of efficiency

The overall uncertainty of the overall efficiency and of the pump efficiency is calculated using Formulae (22), (24) and (25):

$$e_{\eta\text{gr}} = \sqrt{e_Q^2 + e_H^2 + e_{P\text{gr}}^2} \tag{22}$$

if efficiency is computed from torque and speed of rotation:

$$e_{\eta} = \sqrt{e_Q^2 + e_H^2 + e_\text{T}^2 + e_n^2} \tag{23}$$

if efficiency is computed from pump power input:

$$e_{\eta} = \sqrt{e_Q^2 + e_H^2 + e_P^2} \tag{24}$$

Using the values given in Table 6, the calculations lead to the results given in Table 7.

Table 7 — Resulting greatest values of the overall uncertainties of efficiency

Quantity	Symbol	Grade 1 %	Grades 2 and 3 %
Overall efficiency (computed from Q, H, P_gr)	$e_{\eta\text{gr}}$	±2,9	±6,1
Pump efficiency (computed from Q, H, M, n)	e_η	±2,9	±6,1
Pump efficiency (computed from Q, H, P_gr, η_mot)	e_η	±3,2	±6,4

4.4 Performance test acceptance grades and tolerances

4.4.1 General

Six pump performance test acceptance grades, 1B, 1E, 1U, 2B, 2U and 3B are defined in this subclause. Grade 1 is the most stringent grade, with 1U and 2U having a unilateral tolerance and grades 1B, 2B and 3B having a bilateral tolerance. Grade 1E is also bilateral in nature and is important to those concerned with energy efficiency.

NOTE The grades 1U, 1E and 1B have the same tolerance for flow and head.

The purchaser and manufacturer may agree to use any grade to judge whether or not a specific pump meets a guarantee point. If a guarantee point is given, but no acceptance grade is specified, this standard reverts to a default test acceptance grade, as described in 4.5.

Guarantee point acceptance grades for pump head, flow, power and efficiency are provided in Table 8. All tolerances are percentages of values guaranteed.

Table 8 — Pump test acceptance grades and corresponding tolerance

Grade	1			2		3	
$\Delta\tau_Q$	10 %			16 %		18 %	Guarantee requirement
$\Delta\tau_H$	6 %			10 %		14 %	
Acceptance grade	**1U**	**1E**	**1B**	**2B**	**2U**	**3B**	
τ_Q	+10 %	±5 %		±8 %	+16 %	±9 %	Mandatory
τ_H	+6 %	±3 %		±5 %	+10 %	±7 %	
τ_P	+10 %	+4 %		+8 %	+16 %	+9 %	Optional
τ_η	≥0 %		−3 %	−5 %		−7 %	
NOTE $\tau_x (x = Q, H, P, \eta)$ stands for the tolerance of the indicated quantity.							

4.4.2 Tolerances for pumps with an input power of 10 kW and below

For pumps with shaft power input of below 10 kW, the tolerance factors given in Table 8 can be too stringent.

If not otherwise agreed upon between the manufacturer and purchaser, the tolerance factors shall be the following:

— rate of flow $\tau_Q = \pm 10$ %;

— pump total head $\tau_H = \pm 8$ %.

The tolerance factor on efficiency, τ_η, if guaranteed, shall be calculated as given by Formula (25):

$$\tau_\eta = -\left[10\left(1 - \frac{P_2}{10}\right) + 7\right] \% \quad (25)$$

where the pump power input, P_2, tallies with the maximum shaft power (input), $P_{2,\mathrm{max}}$, in kilowatts, over the range of operation. A tolerance factor, $\tau_{P,\mathrm{gr}}$,is allowed using Formula (26):

$$\tau_{P,\mathrm{gr}} = \sqrt{(7\ )^2 + \tau_\eta^2} \quad \% \quad (26)$$

4.4.3 Evaluation of flow and head

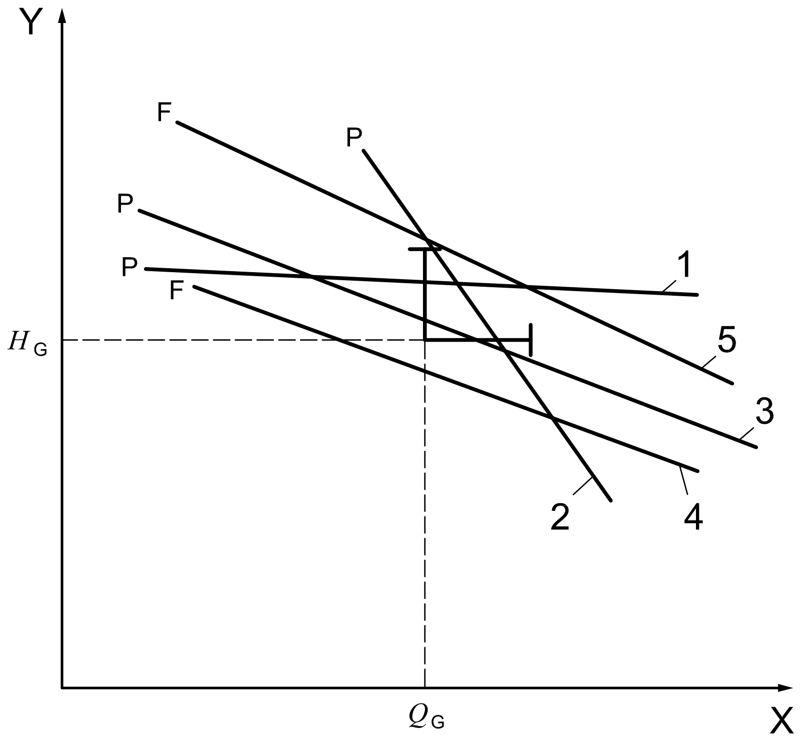
Guarantee point evaluation shall be performed at the rated speed. Test points do not have to be recalculated based on speed in cases where the test speed is identical to the rated speed and for tests with a combined motor and pump (i.e. submersible pumps, close-coupled pumps and all pumps tested with the motor which are installed with the pump). For tests in which the test speed is different from the rated speed, each test point shall be recalculated to the rated speed, using the affinity laws.

The tolerances for flow and head shall be applied in the following manner.

— The pump flow tolerance shall be applied to the guaranteed flow, Q_G, at the guaranteed head, H_G;

— The pump head tolerance shall be applied to the guaranteed head, H_G, at the guaranteed flow, Q_G.

Acceptance is achieved if either flow or head, or both, are found to be within the applicable tolerance (see Figures 2 and 3).



Key

X rate of flow, Q

Y head, H

curve 1: crosses the head tolerance, P = pass

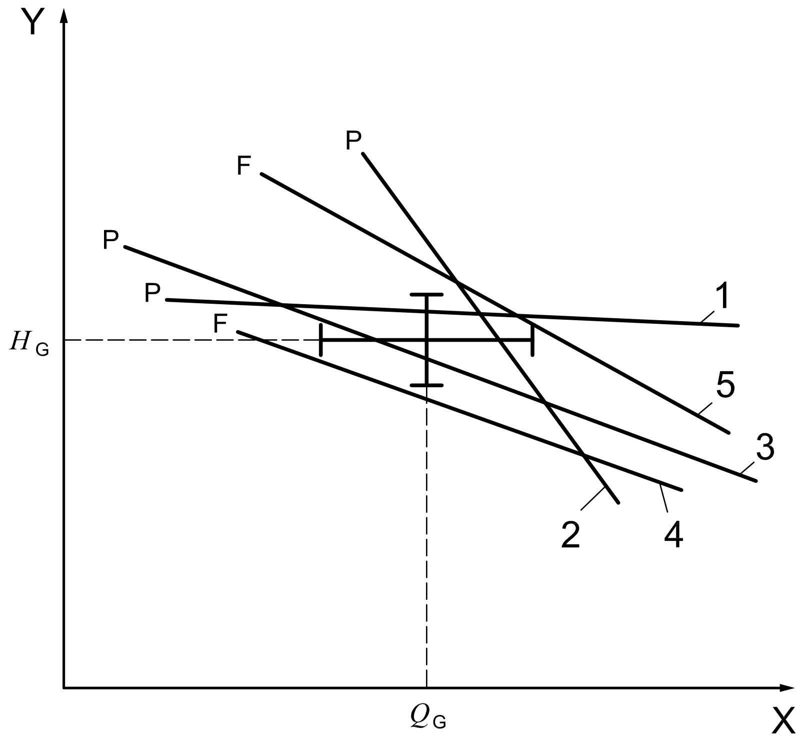
curve 2: crosses the flow tolerance, P = pass

curve 3: crosses both the head and flow tolerance, P = pass

curve 4: does not cross any tolerance, F = fail

curve 5: does not cross any tolerance, F = fail

Figure 2 — Uni-lateral tolerance acceptance



Key

X rate of flow, Q

Y head, H

curve 1: crosses the head tolerance, P = pass

curve 2: crosses the flow tolerance, P = pass

curve 3: crosses both the head and flow tolerance, P = pass

curve 4: does not cross any tolerance, F = fail

curve 5: does not cross any tolerance, F = fail

Figure 3 — Bi-lateral tolerance acceptance

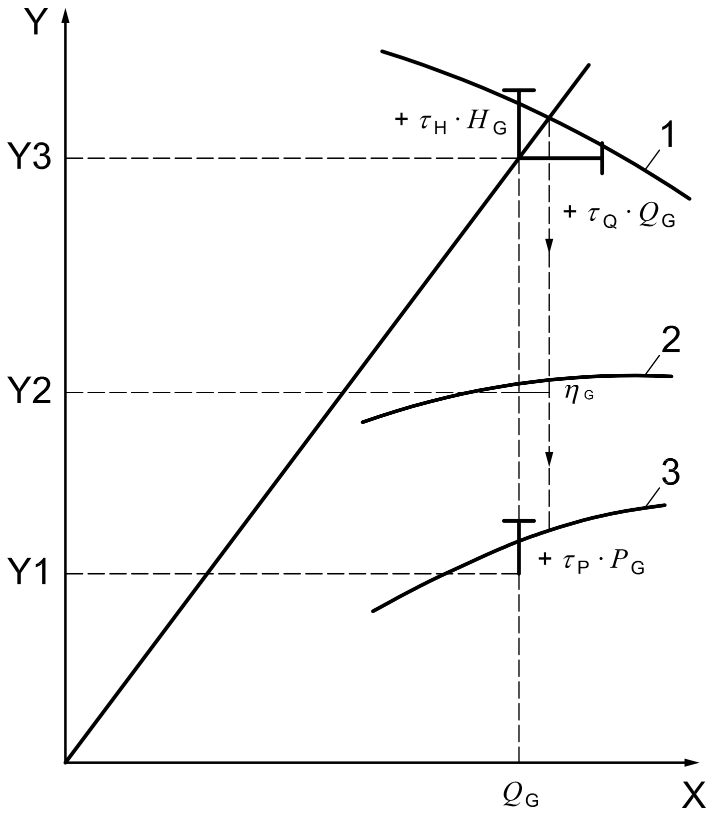
4.4.4 Evaluation of efficiency or power

If efficiency or power has been guaranteed, it shall be evaluated against the applicable acceptance grade tolerance factor, i.e. the same as for Q/H in the following manner:

After a best-fit test curve (Q-H-/Q-η/ or Q-P-curves) is drawn and smoothly fitted through the measured test points, an additional straight line shall be drawn between the origin (0 rate of flow, 0 head) and the guarantee point (rate of flow/head). If necessary, this line shall be extended until it crosses the fitted test curve. The intersection between the smoothly fitted test curve and this straight line shall form the new rate of flow/head point, which is used for evaluation of efficiency or power. The measured input power or calculated efficiency at this point shall be compared against the guaranteed value and the applicable power or efficiency tolerance factors (see Figures 4, 5 and 6).

NOTE 1 The reason for using the “line from origin” method when evaluating the guaranteed efficiency or power is that it best retains the pump characteristics if the impeller diameter is changed. Additionally, this method always gives one single point of reference for evaluation.

NOTE 2 The tolerance limits for flow and head can be reduced as a result of adding a power guarantee.



Key

X rate of flow, Q

Y1 power, P_G

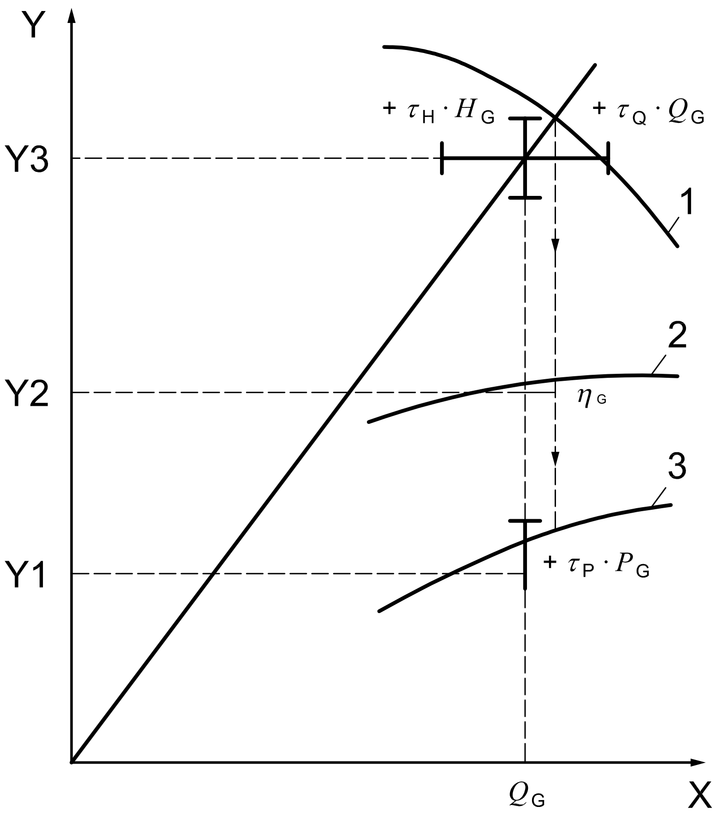
Y2 efficiency, η_G

Y3 head, H_G

1 line of total head (total energy)

NOTE In this case for a horizontal shaft, $z_1 = z_D = z'_1$.

Figure 4 — Tolerance field for acceptance grades 1U and 2U



Key

X rate of flow, Q

Y1 power, P_G

Y2 efficiency, η_G

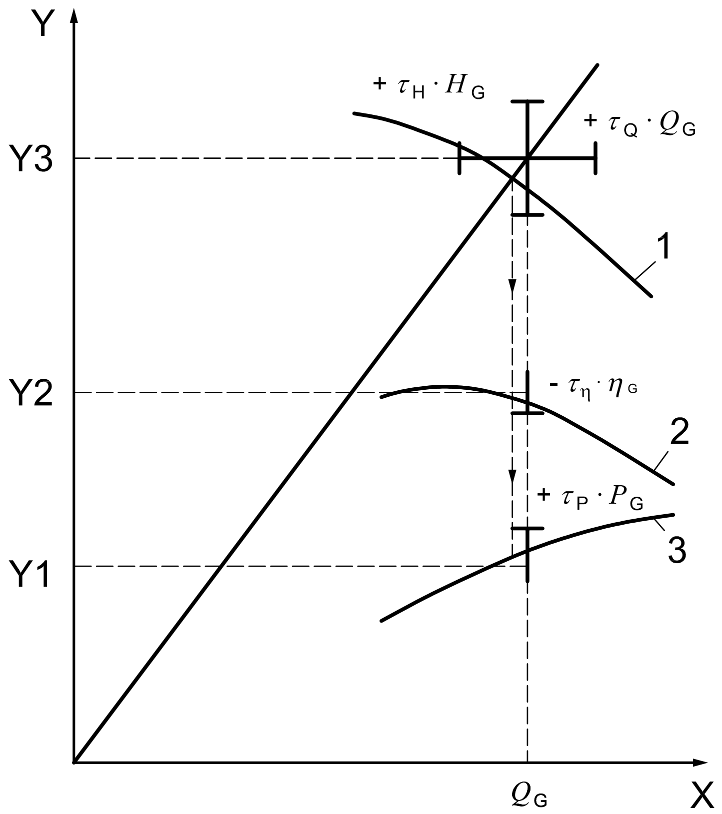
Y3 head, H_G

1 $H(Q)$

2 $\eta(Q)$

3 $P(Q)$

Figure 5 — Tolerance field for acceptance grade 1E



Key

X rate of flow, Q

Y1 power, P_G

Y2 efficiency, η_G

Y3 head, H_G

1 $H(Q)$

2 $\eta(Q)$

3 $P(Q)$

Figure 6 — Tolerance field for acceptance grades 1B, 2B and 3B

4.5 Default test acceptance grades for pump application

If a guarantee point is given, but no acceptance grade is specified, Table 9 shall be applied and this standard reverts to a default test acceptance grade, as given in Table 9, whereby only flow and head are guaranteed. It shall be observed that Table 9 only applies to situations where the purchaser and manufacturer have agreed to a guarantee point, but no test acceptance grade has been specified.

The default test acceptance table specifies the applicable acceptance grade for a pump based on the pump's maximum shaft power and the purchaser's intended service for the pump. The purchaser always has the option to specify his/her own preferred acceptance grade at the time that a guarantee point is agreed upon. If this is done, it takes precedence over any classification provided by this table and this subclause (4.5) shall not be used.

Table 9 — Default acceptance grades

Application		Shaft power of pump, P_2	
		>10 kW and ≤100 kW	>100 kW
Municipal water applications		2B	1B
Municipal wastewater applications		2B	1B
Drainage pumps		3B	2B
Electrical power industry		1B	1B
Oil and gas industry	Pumps in accordance with ISO 13709	1B	1B
	Water Injection	N/A[a]	1B
Marine application		1B	1B
Chemical industry		2B	2B
Cooling tower applications		2B	2B
Pulp and paper applications		2B	2B
Slurry applications		3B	3B
General industry applications		3B	2B
Irrigation applications		3B	2B

[a] N/A = not applicable.

5 Test procedures

5.1 General

This International Standard is intended for tests conducted at pump test facilities, such as manufacturers' pump test facilities or laboratories. Special agreement is necessary for performance tests on site provided all the requirements of this International Standard can be satisfied. It is, however, recognised that the conditions at most sites typically preclude full compliance with this International Standard. In these instances, site performance tests may still be acceptable provided the parties agree on how allowances are made for the added imprecision which inevitably results in a deviation from the specified requirements of this International Standard.

5.2 Date of testing

For witness testing, the date of testing shall be mutually agreed by the manufacturer and the purchaser.

5.3 Test programme

In case of witnessed tests, the programme and procedure to be followed in the test shall be submitted to the purchaser.

NOTE The manufacturer is expected to deliver the information in ample time for consideration and agreement.

Test data other than that guaranteed, determined during the tests, shall have merely an indicative (informative) function.

5.4 Testing equipment

The test instrumentation used shall be documented and this information shall be made available to the customer upon request. Instruments shall be periodically calibrated. Guidance for suitable periods between calibrations of test instruments is given in Annex C.

5.5 Records and report

A complete set of records, written or electronic, shall be kept on file for a minimum of five years.

In the case of witnessed tests, all test records shall be initialled by representatives of the parties witnessing the test, each of whom shall be provided with a copy of all records.

The test results shall be evaluated to the extent possible, while the tests are in progress. In order that questionable measurements can be re-evaluated, it is advisable that the installation and instrumentation remain intact until accurate data are obtained.

If required, the test results shall be summarized in a report. Further guidance regarding the contents of a test report and a suitable pump test sheet is given in Annex F.

5.6 Test arrangements

The conditions necessary to ensure satisfactory measurement of the characteristics of operation are defined here, taking into account the measurement uncertainty required for tests of grade 1, 2 and 3.

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. Recommendations and general guidance about suitable pipe arrangements to ensure satisfactory measurements for flow and head are given in Annex A and, if necessary, they can be used in conjunction with the International Standards on measurement of flow rates in closed conduits concerning the different methods (see D.3).

5.7 Test conditions

5.7.1 Test procedure

The duration of the test shall be sufficient to obtain repeatable results.

All measurements shall be carried out under steady-state conditions (see 4.3.2 and Table 3). If not otherwise specified, the tests shall be conducted under conditions where cavitation does not affect the performance of the pump.

A minimum of five test points shall be taken for all performance tests, regardless of acceptance level, with one of the points being within −5 % and 0 % and one being within 0 % and +5 % of the guarantee point flow rate. The other three points shall be spaced out over the allowable operating range of the pump performance curve, with points taken near the maximum allowable head and flow regions.

NOTE Other test procedures apply to NPSH tests; see 5.8.

5.7.2 Speed of rotation during test

Unless otherwise agreed, tests may be carried out at a speed of rotation within the range 50 % to 120 % of the specified speed of rotation to establish rate of flow, pump total head and power input. In the case the variation of speed is within 20 % of the specified speed, the efficiency change is considered negligible.

For NPSH tests, the speed of rotation should lie within the range 80 % to 120 % of the specified speed of rotation, provided the rate of flow lies within 50 % and 120 % of the rate of flow corresponding to the maximum efficiency at the test speed of rotation.

5.8 NPSH tests

5.8.1 General

5.8.1.1 Objective of NPSH tests

The objective of the NPSH test is to verify the pump's NPSHR for the agreed guarantee. This test deals only with measurements relating to the hydraulic performance of the pump (variations of head, flow, power) and not with other effects, which can be caused by cavitation (e.g. noise, vibration, erosion).

Cavitation effects can be detected as a drop in head or power at a given rate of flow. In the case of multistage pumps, the head drop shall be relative to the head of the first stage, which should be measured if accessible. For very low head pumps, a head drop larger than 3 % may be agreed upon.

In most cases, cavitation tests are conducted with clean, cold water. Cavitation tests in water cannot accurately predict the behaviour of the pump with liquids other than clean, cold water.

Air content can have a significant effect on measured NPSHR-values and shall be considered.

5.8.2 NPSH test types

5.8.2.1 Type I test — Determination of NPSH3 for multiple flow rates

In this test, NPSH is reduced progressively until the drop of the total head at constant flow rate reaches 3 %. This value of NPSH is NPSH3 (see Table 10). A minimum of four different suitably spaced flow rates shall be evaluated within the allowable operation range.

5.8.2.2 Type II test — Determination of NPSH3 for a single flow rate

In this test, NPSH is reduced progressively until the drop of the total head of 3 % at constant flow rate can be determined. This value of NPSH is NPSH3 (see Table 10).

5.8.2.3 Type III test — Verification of limited influence of cavitation on the performance at specified NPSHA

Verification is carried out at the specified NPSHA to show that the hydraulic performance of the pump is not affected by cavitation more than 3 % drop of total head.

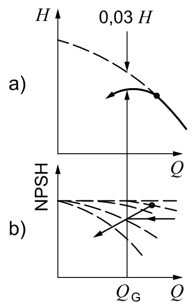
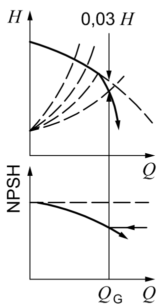
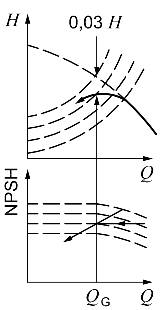
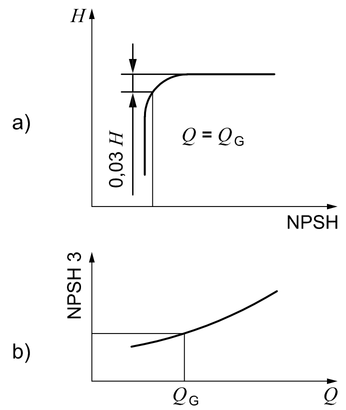
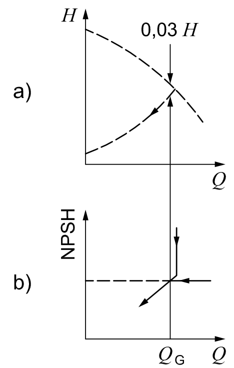
5.8.2.4 Type IV — Verification of guaranteed characteristics at specified NPSHA

The pump meets the requirements if the guaranteed pump total head and power are obtained according to 4.4, under the specified rate of flow and under the specified NPSHA.

5.8.2.5 Tolerance factor for NPSHR

The measured NPSHR value shall not exceed the guaranteed NPSHR value.

Table 10 — Methods of determining NPSH3

Type of installation	Open sump	Open sump	Open sump	Open sump	Open sump	Closed loop	Closed loop	Closed loop	Closed sump or loop
Independent variable	Inlet throttle valve	Outlet throttle valve	Water level	Inlet throttle valve	Water level	Pressure in the tank	Temperature (vapour pressure)	Pressure in the tank	Temperature (vapour pressure)
Constant	Outlet throttle valve	Inlet throttle valve	Inlet and outlet throttle valves	Rate of flow	Rate of flow	Rate of flow	Rate of flow	Inlet and outlet throttle valves	
Quantities that vary with changes to the independent variable	Total head, rate of flow, NPSHA, water level	Total head, rate of flow, NPSHA, water level	Total head rate of flow NPSHA	NPSHA, total head, outlet throttle valve, (for constant rate of flow)	NPSHA, total head; outlet throttle valve	Total head, NPSHA, outlet throttle valve (for constant rate of flow; when total head begins to drop)	NPSHA, head, outlet throttle valve (for constant rate of flow, when head begins to drop)	— NPSHA; — total head and rate of flow, when a certain level of cavitation is reached	
Head characteristic curve versus rate of flow and NPSH NPSH characteristic curve versus rate of flow									

6 Analysis

6.1 Translation of the test results to the guarantee conditions

The quantities required to verify the characteristics guaranteed by the manufacturer are generally measured under conditions more or less different from those on which the guarantee is based.

In order to determine whether the guarantee would have been fulfilled if the tests have been conducted under the guarantee conditions, it is necessary to translate the quantities measured under different conditions to those guarantee conditions.

6.1.1 Translation of the test results into data based on the specified speed of rotation and density

All test data obtained at the speed of rotation, n, in deviation from the specified speed of rotation, n_{sp}, shall be translated to the basis of the specified speed of rotation, n_{sp}.

If the deviation from the test speed of rotation, n, to the specified speed of rotation, n_{sp}, does not exceed the permissible variations stated in 5.7.2, the measured data on the rate of flow, Q, the pump total head, H, the power input, P, can be converted by means of Formulae (27), (28), (29) and (30):

$$Q_T = Q \frac{n_{sp}}{n} \tag{27}$$

$$H_T = H \left(\frac{n_{sp}}{n} \right)^2 \tag{28}$$

$$P_T = P \left(\frac{n_{sp}}{n} \right)^3 \cdot \frac{\rho_{sp}}{\rho} \tag{29}$$

$$\eta_T = \eta \tag{30}$$

Additionally, the results obtained for the NPSHR can be converted by means of Formula (31):

$$\text{NPSHR}_T = \text{NPSHR} \left(\frac{n_{sp}}{n} \right)^x \tag{31}$$

As a first approximation for the NPSH, the value $x = 2$ may be used if the specified conditions given in 5.7.2 for the speed of rotation and the rate of flow have been fulfilled and if the physical state of the liquid at the impeller inlet is such that no gas separation can affect the operation of the pump. If the pump operates near its cavitation limits or if the deviation of the test speed from the specified speed exceeds the specifications given in 5.7.2, the phenomena can be influenced by, for instance 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 2 have been observed and an agreement between the parties is mandatory to establish the conversion formula to be used.

In the case of combined motor pump units or if the guarantees are with respect to an agreed frequency and voltage instead of an agreed speed of rotation (see 4.2), the rate of flow, pump total head, power input and efficiency data are subject to the above-mentioned translation laws, provided n_{sp} is replaced with the frequency f_{sp} and n with the frequency f. Such translation, however, shall be restricted to cases where the selected frequency during the test varies by no more than 1 %. If the voltage used in the test is no more than 5 % above or below the voltage on which the guaranteed characteristics are based, the other operational data require no change.

If the above-mentioned deviations, i.e. ±1 % for frequency and ±5 % for voltage, are exceeded, it is necessary for the purchaser and the manufacturer to arrive at an agreement.

6.1.2 Test carried out with NPSHA different from that guaranteed

Pump performance at a high NPSHA cannot be accepted, after correction for speed of rotation within the permitted ranges in 5.7.2, to indicate performance at a lower NPSHA.

On the other hand, pump performance at a low NPSHA may be accepted, after correction for speed of rotation within the permitted ranges given in 5.7.2, to indicate performance at a higher NPSHA, provided the absence of cavitation has been checked in accordance with 5.8.2.1, 5.8.2.2 or 5.8.2.3.

6.1.3 Performance curve

Curves of best fit to the measured points represent the performance of the pump. Separate curves shall be made for head versus flow rate, power versus flow rate and efficiency versus flow rate. These curves shall be deemed to determine the tested pump's performance and shall be used to evaluate the test results as given in 4.4.

6.2 Obtaining specified characteristics

6.2.1 Reduction of impeller diameter

If it appears from the tests that the characteristics of the pump are higher than the specified characteristics, a reduction of the impeller diameter is generally carried out.

If the difference between the specified values and the measured values is small, it is possible to avoid a new series of tests by applying proportionality rules, which allow the evaluation of the new characteristics.

The application of this method and the practical conditions for reducing the impeller diameter shall be the subject of a mutual agreement.

6.2.2 Requirement for retesting after reducing impeller diameters

If it is necessary to dismantle a pump after the performance test for the sole purpose of trimming the impeller to meet the acceptance level and if the type number K (see 3.2.24) is $\leq 1,5$, no retest is required, unless the reduction in diameter exceeds 5 % of the tested diameter.

Annex A
(normative)

Test arrangements

A.1 General

The best measuring conditions are obtained if, in the measuring sections, the flow has

— an axially symmetrical velocity distribution,

— a uniform static pressure distribution, and

— freedom from swirl induced by the installation.

It is possible to prevent a very bad velocity distribution or swirl by avoiding any bend or a combination of bends, any expansion or any discontinuity in the transverse profile in the vicinity (less than four diameters) of the measuring section.

Generally, the effect of the inlet flow conditions increases with the type number K of the pump. If $K > 1{,}2$ it is recommended to simulate the site conditions.

NOTE For standard test arrangements leading from open sumps with a free surface or from large stilling vessels in a closed circuit, the recommended minimum inlet straight length, L (especially for grade 1) is determined by the expression: $L/D = K + 5$, where D is the pipe diameter.

This expression is also valid for an arrangement which includes, at a distance, L upstream, a simple right angle bend, which is not fitted with guide vanes. Under these conditions, flow straighteners are not necessary in the pipe between the bend and the pump. However, in a closed circuit where there is neither an open sump nor a stilling vessel immediately upstream of the pump, it is necessary to ensure that the flow into the pump is free from swirl induced by the installation and has a normal symmetrical velocity distribution.

Significant swirl can be avoided by

— careful design of the test circuit upstream of the measuring section,

— judicious use of a flow straightener, and

— suitable arrangement of the pressure tappings to minimize their influence on the measurement.

It is recommended not to install a throttle valve in the inlet pipe. In case this cannot be avoided, for instance for cavitation tests, the straight pipe length between the valve and the pump inlet should be ensured that the pipe is totally filled with liquid and that pressure and velocity distributions at the inlet measuring section are uniform. This may be achieved by use of a suitable flow straightening device and/or a long straight pipe of at least 12 D of the length of the pump inlet.

A.2 Measurement principles

The pump total head is calculated in accordance with its definition given in 3.2.15. Expressed as a height of pumped liquid column, it represents the energy transmitted by the pump.

The various quantities specified in the definition of head in 3.2.7 should. as a rule. be determined in the inlet section, S_1, and the outlet section, S_2, of the pump (or of the pump set and fittings, which are the subject of the tests). For convenience and measurement accuracy, the measurements are generally carried out in cross-sections $S_{1'}$ and $S_{2'}$ some way upstream from S_1 and downstream from S_2 (see Figure A.1). Thus, account shall be taken of the friction losses in the pipe, i.e. H_{J1} between $S_{1'}$ and S_1 and H_{J2} between S_2 and $S_{2'}$ (and eventually of the local head losses), and the pump total head is given by

$$H = H_{2'} - H_{1'} + H_{J1} + H_{J2}$$

where $H_{1'}$ and $H_{2'}$ are the total head at $S_{1'}$ and $S_{2'}$.

A.4 defines the measuring sections in various types of installations and a method for estimating the head losses.

A.3 Various measurement methods

Depending on the installation conditions of the pump and on the layout of the circuit, the pump total head may be determined either by measuring separately the inlet and outlet total heads or by measuring the differential pressure between inlet and outlet and adding the difference in velocity head, if any (see Figure A.1).

Total heads may also be deduced either from pressure measurements in conduits or from water level measurements in open sumps. For these cases, Figure A.3 and Figure A.4 deal with the selection and arrangement of the measuring section.

A.4 Pump tested on a standardized installation

A.4.1 Inlet measuring section

If a pump is tested in a standard test arrangement as described in A.1, the inlet measuring section shall normally be located at a distance of two diameters upstream from the pump inlet flange, where the length of the inlet pipe allows it. If this length is not available (for instance, in the case of a short bell-mouth), in the absence of a prior agreement, the available straight length should be divided so as to take the best possible advantage of the local conditions upstream and downstream of the measuring section (for instance, in the ratio two diameters upstream to one downstream).

The inlet measuring section should be located in a straight pipe section of the same diameter and coaxial with the pump inlet flange so that the flow conditions are as close as possible to those recommended in A.1. If a bend is present a short distance upstream of the measuring section and if only one or two pressure tappings are in use (grades 2 and 3 tests), these should be perpendicular to the plane of the bend.

For grades 2 and 3 tests, if the ratio of the inlet velocity head to the pump total head is very low (less than 0,5 %) and if the knowledge of the inlet total head itself is not very important (such is not the case for NPSH tests), it may be sufficient that the pressure tapping (see A.4.3) be located on the inlet flange itself and not at two diameters upstream.

The inlet total head is derived from the measured gauge head, from the height of the measuring point above the reference plane and from the velocity head calculated as if a uniform velocity distribution prevailed in the inlet pipe.

Errors in the measurement of pump inlet head can occur at partial flow due to pre-swirl. These errors can be detected and should be corrected as follows.

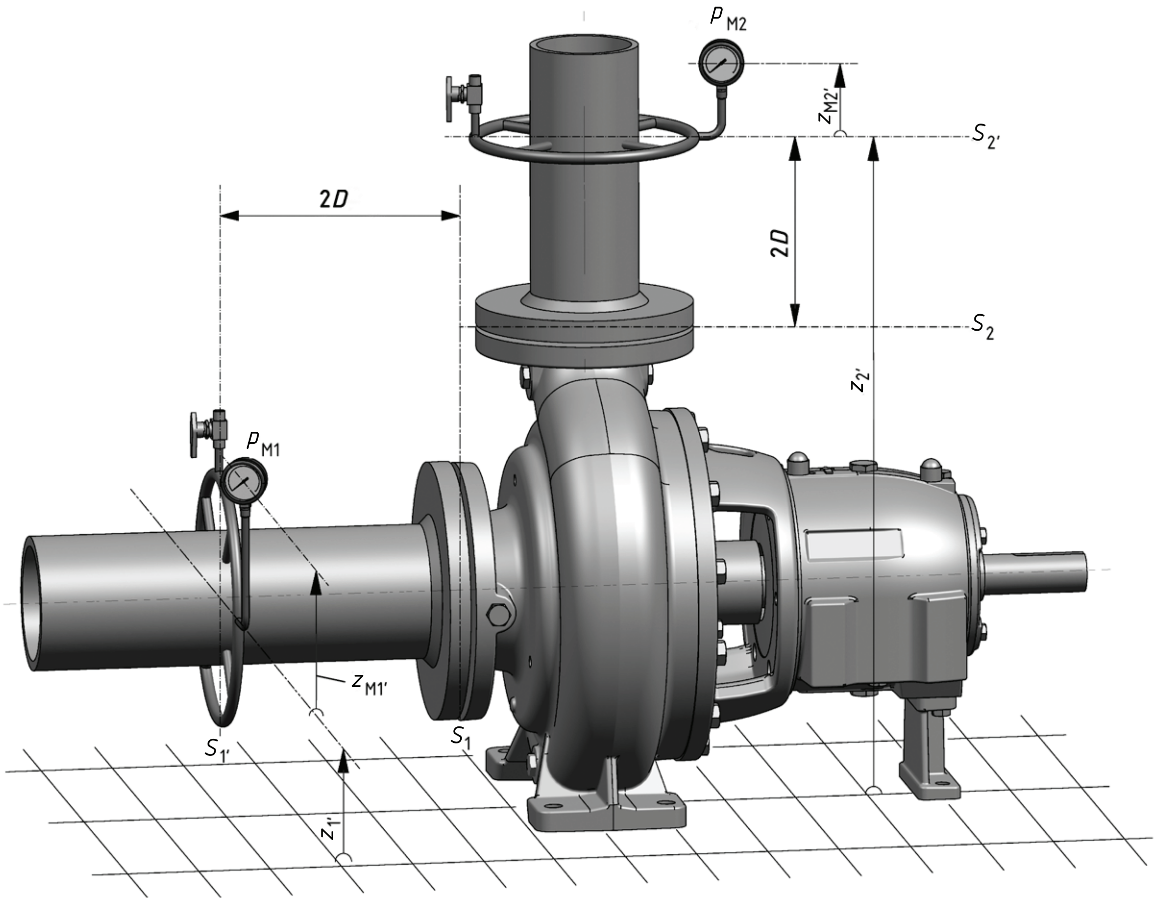
a) If the pump draws from a free surface open sump where the water level and the pressure acting on it are constant, the head loss between the open sump and the inlet measuring section, in the absence of pre-swirl, follows a square law with rate of flow. The value of the inlet total head should follow the same law. If the effects of pre-swirl lead to a departure from this relationship at low rates of flow, the measured inlet total head should be corrected to take this difference into account (see Figure A.2).

b) If the pump does not draw from an open sump with a constant level and head, another measuring section shall be selected sufficiently far upstream where the pre-swirl is known to be absent and it is then possible to reason about the head losses between the two sections (but not directly about the inlet total head) in the same way as above.

$$H = H_2 - H_1$$

$$H = z_2 - z_1 + \frac{p_2 - p_1}{\rho \cdot g} + \frac{U_2^2 - U_1^2}{2g} \tag{A.1}$$

$$H = z_{2'} - z_{1'} + z_{M2'} - z_{M1'} + \frac{p_{M2'} - p_{M1'}}{\rho \cdot g} + \frac{U_{2'}^2 - U_{1'}^2}{2g} + H_{J2} + H_{J1} \tag{A.2}$$

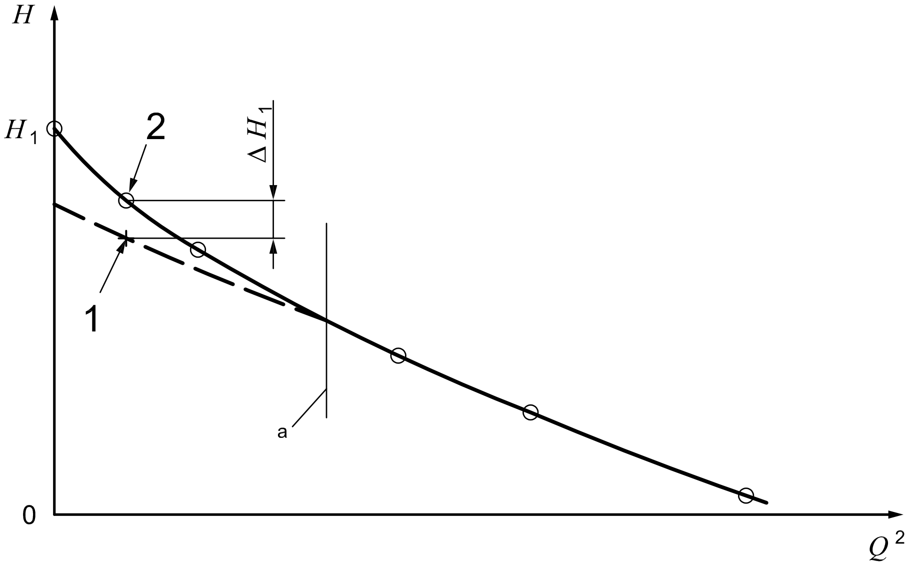


Key

1 line of total head (total energy)

NOTE In this case for a horizontal shaft, $z_1 = z_D = z'_1$.

Figure A.1 — Isometric illustration of the determination of the pump total head



Key

1 real value

2 value of H_1 affected by pre-swirl

[a] Onset of pre-swirl.

Figure A.2 — Correction of inlet total head

A.4.2 Outlet measuring section

The outlet measuring section should be arranged in a straight pipe section coaxial with the pump outlet flange and of the same diameter. If only one or two pressure tappings are used (grades 2 and 3 tests), the pressure tappings should be perpendicular to the plane of the volute or of any bend existing in the pump casing (see Figure A.3).

The outlet measuring section should be located at a distance of two diameters from the pump outlet flange. For pumps with outlet velocity head smaller than 5 % of the pump total head, the outlet measuring section for grade 2 and grade 3 tests may be located at the outlet flange.

The outlet total head is derived from the measured gauge head, from the height of the measuring point above the reference plane and from the velocity head calculated as if a uniform velocity distribution prevailed in the discharge pipe. The determination of the total head can be influenced by a swirl of the flow induced by the pump or by an irregular velocity or pressure distribution; the pressure tapping can then be located at a greater distance downstream. The head losses between the outlet flange and the measuring section shall be taken into account (see A.4.9).

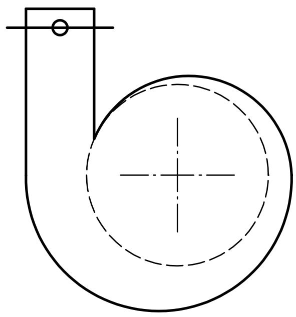
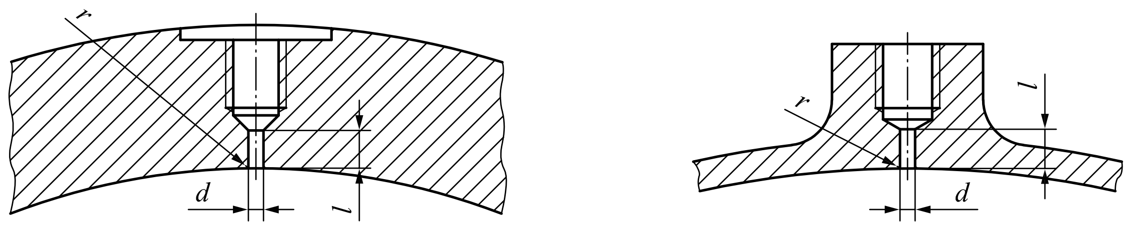


Figure A.3 — Pressure tapping perpendicular to the plane of the volute or to the plane of a bend, respectively

A.4.3 Pressure tappings



$l \geq 2{,}5\ d$ $r \leq d/10$

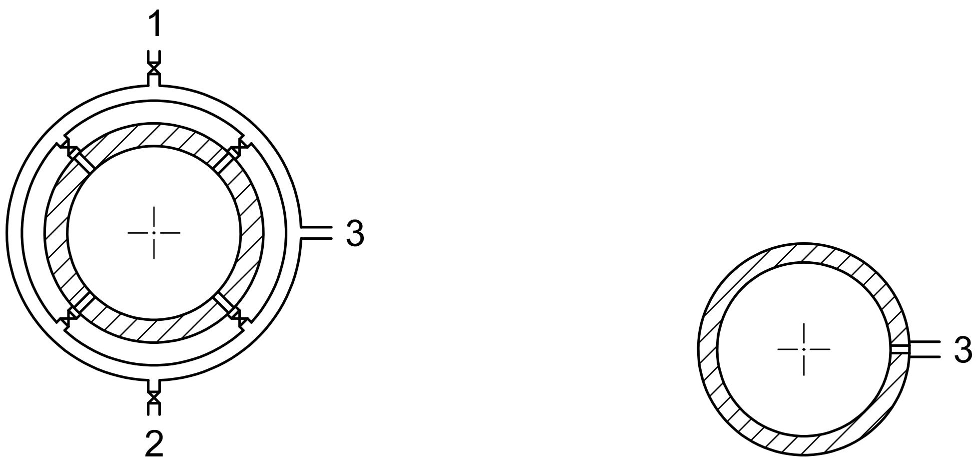
where d = 3 to 6 mm or 1/10 pipe diameter, whichever value is the smaller

a) **Thick wall** b) **Thin wall**

Figure A.4 — Requirements for static pressure tappings

For grade 1 tests, four static pressure tappings shall be provided symmetrically disposed around the circumference of each measuring section, as shown in Figure A.5 a).

For grades 2 and 3 tests, it is normally sufficient to provide not more than one static pressure tapping at each measuring section, but if flow can be affected by a swirl or an asymmetry two or more may be necessary [see Figure A.5 b)].



a) Grade 1 — Four pressure tappings connected by a ring manifold

b) Grades 2 and 3 — One pressure tapping (or two in opposite position)

Key

1 vent

2 drain

3 connecting pipe to the pressure measuring instrument

Figure A.5 — Pressure tapping for grade 1, 2 and 3 tests

Except in the particular case where their position is determined by the arrangement of the circuit, the pressure tapping(s) should not be located at or near the highest nor the lowest point of the cross-section.

Static pressure tappings shall comply with the requirements shown in Figure A.4 and shall be free from burrs and irregularities and flush with, and normal to, the inner wall of the pipe.

The diameter of the pressure tappings shall be between 3 mm and 6 mm or equal to one tenth (1/10) of the pipe diameter, whichever is the smaller. The length of a pressure tapping hole shall not be less than two and a half times its diameter.

The bore of the pipe containing the tappings shall be clean, smooth and resistant to chemical reaction with the liquid being pumped. Any coating, such as paint applied to the bore, shall be intact. If the pipe is welded longitudinally, the tapping hole shall be displaced as far as possible from the weld.

If several pressure tappings are used, the pressure tappings shall be connected through shut-off cocks to a ring manifold of cross-sectional area not smaller than the sum of the cross-sectional areas of the tappings, so that the pressure from any tapping may be measured, if required. Before making observations, the pressure with each individual tapping successively open, shall be taken at the normal test condition of the pump. If one of the readings shows a difference of more than 0,5 % of the total head with respect to the arithmetical mean of the four measurements or if it shows a deviation of more than one times the velocity head in the measuring section, the cause of this spread shall be ascertained and the measuring conditions rectified before the test proper is started.

If the same pressure tappings are used for NPSH measurement, this deviation shall not exceed 1 % of the NPSH value or one times the inlet velocity head.

Pipes connecting pressure tappings to possible damping devices (see 4.3.2) and to instruments shall be at least equal in bore to the bore of the pressure tappings. The system shall be free from leaks.

Any high point in the line of the connecting pipes shall be provided with a purging valve to avoid trapping of air bubbles during measurements.

Wherever possible, it is recommended that transparent tubing be used to determine whether or not air is present in the tubing. ISO 2186 gives indications as to the connecting pipes.

A.4.4 Correction for height difference

Correction of the pressure reading, p_M, for height difference $(z_\mathrm{M} - z)$ between the middle of the measuring section and the reference plane of the pressure measuring instrument shall be carried out using Formula (A.3):

$$p = p_\mathrm{M} + \rho_\mathrm{f} \cdot g \cdot (z_\mathrm{M} - z) \qquad \text{(A.3)}$$

where ρ_f is the density of the liquid in the connecting pipe.

A.4.5 Simulated test arrangements

If from the reasons given in A.1 to A.4.4, it is agreed to test a pump under simulated site conditions, it is important that at the inlet of the simulated circuit the flow be, as far as possible, free from significant swirl induced by the installation and have a symmetrical velocity distribution. All necessary provisions shall be made to ensure these conditions are achieved.

If necessary, for grade 1 tests, 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 suitable means, such as a flow straightener adapted for the fault of the flow to be corrected (swirl or asymmetry). Specifications of the most widely used types of flow straighteners can be found in ISO 7194. However, care shall be taken to ensure that the conditions of test are not affected by the head losses associated with some straightening devices.

A.4.6 Pumps tested with fittings

If specified in the contract, standard tests may 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.

Measurements shall be taken in accordance with A.1.

If the tests are carried out on the combination of the pump and the whole or part of its upstream and downstream connecting fittings, these being considered an integral part of the pump, the provisions of A.1 apply to the inlet and outlet flanges of the fittings instead of the inlet and outlet flanges of the pump. This procedure debits against the pump all head losses caused by the fittings.

Nevertheless, if the guarantee is on the performance of the pump only, the friction head losses and possibly local head losses between the inlet total head measuring section and the inlet flange, H_{J1}, and between the outlet flange and the outlet total head measuring section, H_{J2}, shall be determined in accordance with the method described in A.4.9 and taken into account in the calculation of the pump total head.

A.4.7 Pumping installation under submerged conditions

Where a pump, or a combination of a pump and its fittings, is tested or installed in conditions where the standard pipe connection, as described in A.1, cannot be made owing to inaccessibility or submergence, measurements shall be taken in accordance with the following requirements.

Pumps of this type cannot be tested in standard arrangements as described in A.1; their installation conditions are shown schematically in Figure A.6.

The inlet total head is equal to the height above the reference plane of the free surface level of the liquid from which the pump draws, plus the head equivalent to the gauge pressure prevailing above this surface.

According to the circumstances, the outlet total head can be determined either by a pressure measurement in the discharge pipe (see A.4.2) or if the pump outlet into a free surface open sump, by a level measurement in this open sump. In this case, and provided the liquid is really at rest near the level measuring point, the outlet head is equal to the height above the reference plane of the free surface level of the liquid in which the pump discharges plus the head equivalent to the gauge pressure prevailing above this surface.

This procedure debits against the pump all the head losses arising between the measuring sections.

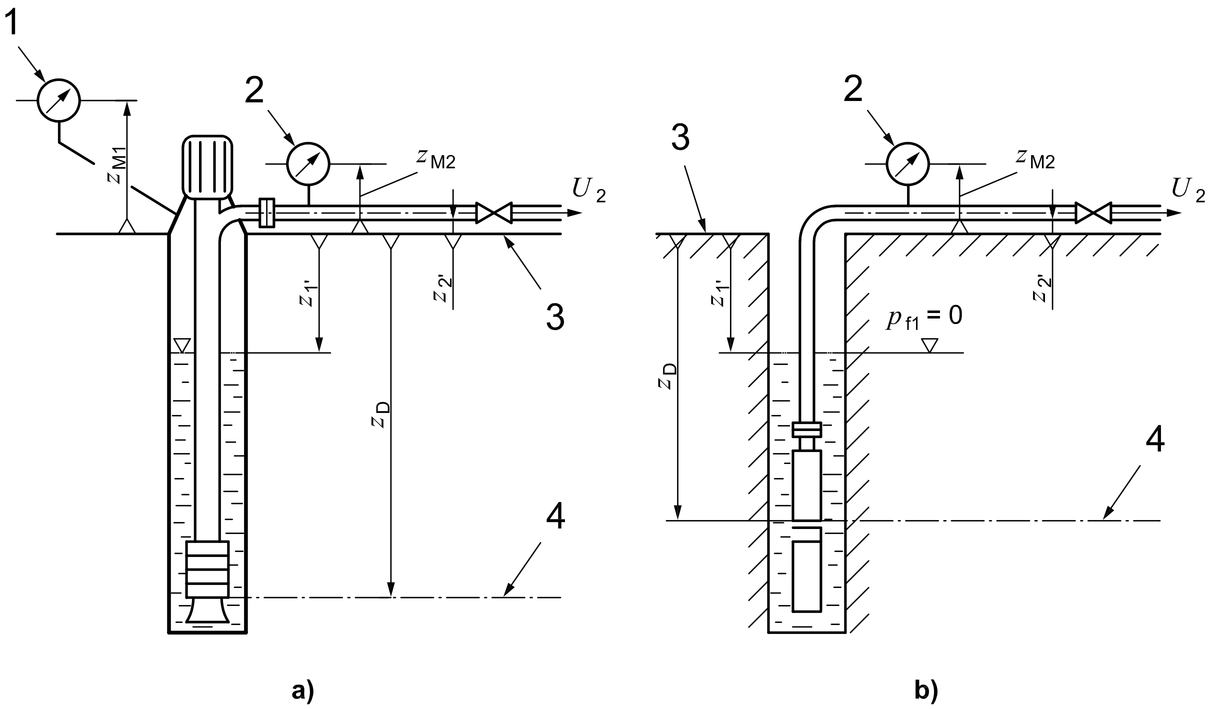
If necessary, the friction head losses between the measuring sections and the contractual limits of the pump can be determined in accordance with the method described in A.4.9. The local head losses due to the singularities of the circuit and to various fittings (inlet filter, non-return valve, delivery elbow, valve, expanders, etc.) shall, as far as possible, be specified if drafting the contract, by the party which provides these fittings. If this appears impossible, the purchaser and the manufacturer shall agree the value to be adopted before the acceptance tests.

As deep well pumps [see Figure A.6 a)] are generally not tested with their whole vertical pipes, unless the acceptance test is carried out on site, the friction head losses in the missing parts shall be evaluated and specified to the purchaser by the manufacturer. If it appears necessary to verify the specified characteristics by an on-site test, this shall be specified in the contract.

For tests of pumps of this kind, the guarantees can apply also to the fittings.

$$H_1 = z_{1'} + \frac{p_{M1}}{\rho g} + \frac{\rho_{f1}}{\rho}(z_{M1} - z_{1'}) \qquad \text{(A.4)}$$

$$H_2 = z_{2'} + \frac{p_{M2}}{\rho g} + \frac{\rho_{f2}}{\rho}(z_{M2} - z_{2'}) + \frac{U_2^2}{2g} \qquad \text{(A.5)}$$



Key

1 pressure reading p_{M1}

2 pressure reading p_{M2}

3 reference plane

4 NPSH datum plane

$H_1 = z_{1'}$

$$H_2 = z_{2'} + \frac{p_{M2}}{\rho g} + \frac{\rho_{f2}}{\rho}(z_{M2} - z_{2'}) + \frac{U_2^2}{2g}$$

Figure A.6 — Measurement of pump total head, H, for various types of submerged pumps

NOTE Borehole and deep-well pumps cannot usually be tested with their complete lengths of delivery main and, consequently, the loss of head in the portions omitted and the power absorbed by any shafting therein, cannot be taken into account. The thrust bearing is more lightly loaded during the test than it is in the final installation.

A.4.8 Self-priming pumps

In principle, the priming ability of self-priming pumps shall always be verified at the contractual static suction head with the attached inlet piping equivalent to that in the final installation. If the test cannot be carried out in the described manner, the test arrangement to be used shall be specified in the contract.

A.4.9 Friction losses at inlet and outlet

The guarantees given in 4.4 refer to the pump inlet and outlet flanges, and the pressure measuring points are in general at a distance from these flanges (see A.1 to A.4.7). It can, therefore, be necessary to add to the measured pump total head, the head losses due to friction (H_{J1} and H_{J2}) between the measuring points and the pump flanges.

Such a correction should be applied only if

— $H_{J1} + H_{j2} \geq 0{,}005\ H$ for grades 2 and 3 or

— $H_{J1} + H_{j2} \geq 0{,}002\ H$ for grade 1.

If the pipe between the measuring points and the flanges is unobstructed, straight, of constant circular cross-section and of the length, L, then:

$$H_J = \lambda \frac{L}{D} \frac{U^2}{2g} \tag{A.6}$$

The value of λ should be derived from

$$\frac{1}{\sqrt{\lambda}} = -2 \log_{10}\left[\frac{2{,}51}{\mathrm{Re}\sqrt{\lambda}} + \frac{k}{3{,}7D}\right] \tag{A.7}$$

where

k is the pipe equivalent uniform roughness;

D is the pipe diameter;

$\frac{k}{D}$ is the relative roughness (pure number)

Table A.1 — Equivalent uniform roughness k for pipes

Commercial pipe (new) material	Equivalent uniform roughness, k, of the surface mm
Glass, drawn brass, copper or lead	smooth
Steel	0,05
Asphalted cast iron	0,12
Galvanized iron	0,15
Cast iron	0,25
Concrete	0,30 to 3,0
Riveted steel	1,0 to 10,0

If the pipe is other than unobstructed, straight and of constant circular cross-section, the correction to be applied shall be the subject of special agreement in the contract.

Annex B
(informative)

NPSH test arrangements

B.1 General

The tests described in 5.8.2 can be conducted by any of the methods indicated in Table 10 and in any of the installations described in the following clauses.

It is possible to vary two control parameters and thus keep the rate of flow constant during a test, but this is usually more difficult.

B.2 Characteristics of the circuit

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

It shall be ensured that cavitation and the bubbles and degassing produced by cavitation in the pump do not affect the functioning of instrumentation, particularly the flow measuring device.

The measuring conditions on the cavitation test rig whether this be the same as that used for the determination of the efficiency curves or not, shall conform to the conditions specified in A.1 and 5.8.

The types of installations described in B.5 may necessitate special regulating valves at inlet and outlet to avoid cavitation in these items influencing results.

Cavitation in the flow through a throttle valve can sometimes be prevented by using two or more throttle devices connected in series or by arranging for the throttle valve to discharge directly into a closed vessel or a large diameter tank interposed between the throttle and the pump inlet. Baffles and means of extracting air from such a vessel can be needed, especially when the NPSH is low.

If a throttle valve is partially closed, it is necessary to make sure that the pipe is full of liquid and pressure and velocity distributions at the inlet measuring section are uniform. This may be achieved by use of a suitable flow straightening device and/or long straight pipe of at least 12 D length at the pump inlet.

B.3 Characteristics of the test liquid

As far as possible, free gas shall be removed from water before testing. In case it is necessary to avoid de-gassing in any part of the pump, the water of the circuit should not be supersaturated.

B.4 Determination of the vapour pressure

The vapour pressure of the test liquid entering the pump shall be determined with appropriate uncertainty to comply with Table 3 If the vapour pressure is derived from standard data and the measurement of the temperature of the liquid entering the pump, the necessary accuracy of temperature measurement shall be demonstrated.

The source of standard data to be used shall be agreed between the manufacturer and purchaser.

The active element of a temperature-measuring probe shall be not less than one eighth (1/8) of the inlet pipe diameter from the wall of the inlet pipe. If the immersion of the temperature-measuring element in the inlet flow is less than that required by the instrument manufacturer, a calibration at that immersion depth is required.

Care shall be taken to ensure that temperature measuring probes inserted into the pump inlet pipe do not influence the measurements of inlet pressure.

B.5 Types of installation

B.5.1 Closed loop arrangement

The pump is installed in a closed pipe loop, in which by altering the pressure, level or temperature, the NPSH is varied without influencing the pump head or rate of flow until cavitation occurs in the pump. Arrangements for cooling or heating the liquid in the loop can be needed in order to maintain the required temperature and a gas separation tank can also be required (as an example, see Figure B.1).

A liquid recirculation loop can be necessary to avoid unacceptable temperature difference in the test tank.

The tank shall be of sufficient size and so designed as to prevent the entrainment of gas in the pump inlet flow. Additionally, stilling screens can be needed in the tank if the average velocity exceeds 0,25 m/s.

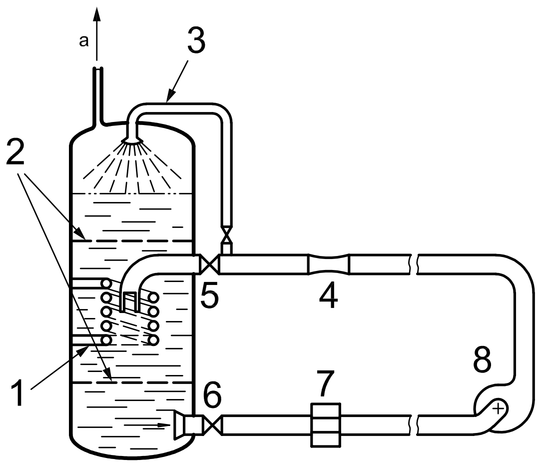
NOTE Cooling by means of a coil can be replaced by an injection of cool water above the liquid free surface and extraction of heated water.

B.5.2 Open sump with level control

The pump draws liquid through an unobstructed inlet pipe from a sump, in which the level of the free liquid surface may be adjusted (see Figure B.2).

B.5.3 Open sump with throttle valve

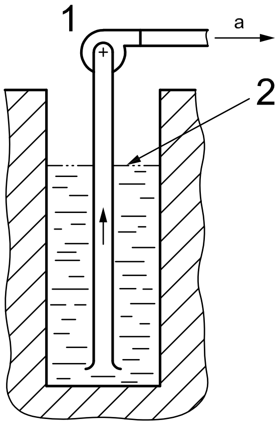
The pressure of the liquid entering the pump is adjusted by means of a throttle valve installed in the inlet pipe at the lowest practicable level (see Figure B.3).



Légende

1 cooling or heating coils
2 stilling screens
3 spray nozzle for liquid de-aeration
4 flowmeter
5 flow control valve
6 isolating valve
7 measuring point for gas content
8 test pump
[a] To vacuum or pressure control.

Figure B.1 — Cavitation tests — Variation of NPSH by means of a closed loop controlling head and/or temperature



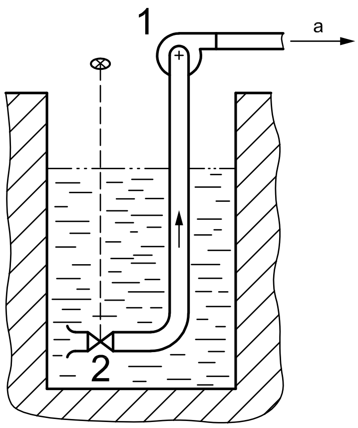
Légende

1 test pump

2 adjustable water level

a To flow control valve and flowmeter.

Figure B.2 — Cavitation tests — Variation of NPSH by control of liquid level at pump inlet sump



Légende

1 test pump

2 inlet pressure control valve

a To flow control valve and flowmeter.

Figure B.3 — Cavitation tests — Variation of NPSH by means of an inlet pressure control valve

Annex C
(informative)

Calibration intervals

The frequency of instrument calibration depends upon usage as well as the design of the equipment. Table C.1 is based on experience with general usage of instruments. If historical data exists to support a longer calibration interval, they shall be acceptable to all parties. If an instrument is physically abused or overloaded, it shall be calibrated before being used.

Table C.1 — Instrument calibration intervals

(years)

Equipment	Period	Equipment	Period
Rate of flow		**Input power**	
Weigh tank	1	Dynamometer	0,5
Volumetric tank	10	Torque meter	1
Venturi, nozzle,	[a]	Calibrated motor	NR[c]
Orifice, weir			
Turbine	1	Wattmeter	1
Electromagnetic	1[b]	Gears	10
Ultrasonic	0,5	**Head**	
Current meter	2	Bourdon tube	0,33
Pump speed		Dead weight	NR
Tachometer	3	Manometer	NR
Electronic (gear teeth)	NR[c]	Transducers	0,33
Frequency responsive		**Temperature**	
Devices			
Magnetic	10	Electric	2
Optical	10	Mercury	5
Stroboscopes	5		

[a] Not required, unless a change of a critical dimension is suspected.

[b] Secondary (electronic processor). The primary section should be recalibrated every five years.

[c] Unless electrical or mechanical failure.

Annex D
(informative)

Measurement equipment

D.1 Head measurement equipment

D.1.1 General

The selection of measurement instrumentation is the responsibility of the organization performing the test. All selected measurement devices should conform to the uncertainty requirements specified in 4.3 and be calibrated within the time periods specified in Annex C. The following are listed acceptable methods and instruments for measuring of the quantities associated with the performance testing.

D.1.2 Spring pressure gauges

A spring pressure gauge uses the mechanical deflection of a loop of tube, plain or spiral (Bourdon dial gauge) or a membrane to indicate pressure.

If this type of apparatus is used to measure the pressure at inlet or outlet, it is recommended that

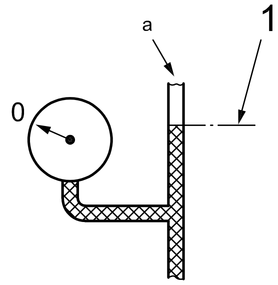
a) each apparatus be used within its optimum measuring range (above 40 % of its full scale),

b) the interval between two consecutive scale graduations be between 1,5 mm and 3 mm, and

c) such divisions correspond to a maximum of 5 % of the pump total head.

The calibration of this measuring apparatus shall be checked regularly.

Figure D.1 shows an arrangement for determining the reference plane of spring pressure gauges.



Key

1 reference plane of the manometer

a Open to atmosphere.

Figure D.1 — Arrangement for determination of reference plane of spring pressure gauges

D.1.3 Electronic pressure transducers

There is a large diversity of pressure transducers, absolute or differential, based upon the variation of various mechanical and/or electrical properties. They may be used, provided the required accuracy, repeatability and reliability are achieved, the transducer is used within its allowable measuring range and the transducer together with its electronic equipment are calibrated regularly by comparison with a pressure device of higher accuracy and reliability.

D.2 Measurement of rotating speed

Wherever possible, the speed of rotation should be measured by counting revolutions for a measured interval of time. Typically, this is accomplished by using a direct indicating tachometer, an optical or magnetic counter, or a stroboscope.

Where the speed of rotation cannot be directly measured (for example submersible pumps), it is usually sufficient to check the grid frequency and voltage. Furthermore, the speed can be derived by measuring the vibration frequency.

In the case of a pump driven by an alternating current motor, the speed of rotation can also be estimated using the electrical supply frequency and motor slip data.

D.3 Measurement of flow rate

D.3.1 General

Any flow measuring system may be used for measurement of pump rate of flow, provided:

a) the entire flow passing through the pump also passes through the instrument, and

b) it can be demonstrated that the instrument meets the requirements of Tables 3 and 5 and Annex C.

The piping upstream of the flow meter should be straight, having the same diameter as the flow meter and having a length of at least 10 times the pipe diameters. The piping downstream of the flow meter has the same requirements, except that it can have a length of down to 5 times the pipe diameters. The lengths are measured from flange to flange.

D.3.2 Measurement by weighing

ISO 4185 indicates all the necessary information for the measurement of the liquid rate of flow by the weighing method.

The weighing method, which gives only the value of the average rate of flow during the time taken to fill the weighing tank, may be considered the most accurate method of flow rate measurement. This procedure is mainly used for calibration of other flow meters.

D.3.3 Volumetric method

ISO 8316 indicates all the necessary information for the measurement of the liquid rate of flow by the volumetric method.

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

D.3.4 Differential pressure devices

The construction, installation and use of orifice plates, nozzles and Venturi tubes are the subject of ISO 5167-1, whilst ISO 2186 gives specifications on connecting piping for the manometer. Orifice plates are the subject of ISO 5167-2, nozzles and Venturi nozzles of ISO 5167-3, and Pitot tubes of ISO 5167-4.

IMPORTANT Attention should be drawn particularly to the minimum straight lengths to be adhered to upstream of the differential pressure device; these are specified in ISO 5167-1 for various configurations of piping. If it is necessary to place the differential pressure device downstream of the pump (which is not covered in the tables referred to), the pump may be considered for the purpose of this International Standard to create a disturbance in the flow equivalent to a single 90° bend either in the same plane as the pump volute or the last stage of a multistage pump or the outlet branch of the pump.

Also, the diameter of the pipe and the Reynolds number shall fall within the ranges specified in ISO 5167-1 for each type of device.

It shall be ensured that the flow measuring apparatus is not influenced by cavitation or degassing, which can occur for example at a control valve. The presence of air can usually be detected by operating the air vents on the measuring device.

It shall be possible to check the differential pressure measurement apparatus by comparison with other measuring apparatus. If all the requirements of the relevant standards are met, the discharge coefficients given in the relevant standards can be used without calibration.

D.3.5 Thin plate weirs

The specifications for the construction, installation and utilization of rectangular or triangular thin-plate weirs are given in ISO 1438, and ISO 3846 indicates prescription for the level measuring device.

IMPORTANT Particular attention is to be drawn to the great sensitivity of these devices to the upstream flow conditions and, thus, to the necessity to comply with the prescriptions for the approach channel.

For the application of this International Standard, the smallest scale division of all instruments used for the measurement of the head over the weir shall not be more than that corresponding to 1,5 % of the rate of flow to be measured.

D.3.6 Velocity area methods

These methods are the subject of ISO 748, ISO 2537, ISO 3354 and ISO 3966, which deal with discharge measurements in closed conduits by means of current meters and Pitot static tubes, respectively. These International Standards give all the necessary specifications concerning conditions of application, choice and operation of the apparatus, measurement of local velocities and calculation of the rate of flow by integration of the velocity distribution.

The complication of these methods does not justify their use for grades 2 and 3 tests, but they are sometimes the only ones that can be applied if testing pumps with large rates of flow for grade 1 test.

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

D.3.7 Electromagnetic method

Requirements for an electromagnetic flow meter shall be in accordance to ISO 6817, ISO 9104 and ISO 9213.

Electromagnetic flow meters are used for measuring the volumetric flow rate of electrically conductive liquids, with and without solids. Unlike many other methods of measuring flow, this device has no moving parts and, therefore, it can be made to withstand almost any pressure without leakage and handle almost any liquid with an appropriate lining. It is also desirable because there is no more pressure loss through the flow meter than through a pipe of the same length and diameter.

For the greatest reliability of flow measurement, the meter should be installed in the piping system in such a manner that it is always flowing full of liquid. A partially full pipe gives inaccurate flow measurement readings.

The electromagnetic flow meter cannot differentiate entrained gas from the process liquid and, therefore, gas bubbles cause the meter to read inaccurately high. Care should be taken to eliminate gas bubbles if accuracy of liquid flow rate is required.

This type of flow meter can, under the best of conditions, have an accuracy of ±0,25 % to ±1,0 % of rate for flow for velocities greater than 0,5 m/s. At lower velocities, measurement error increases, but the readings are repeatable.

D.3.8 Ultrasonic method

Requirements for ultrasonic velocity meter shall be in accordance with ISO 6416.

Ultrasonic flow meters are very sensitive to the velocity distribution and shall be calibrated in their actual conditions of operation.

D.3.9 Tracer and other methods

These methods, applied to the measurement of the flow rate in the pipes, are the subject of ISO 2975 (all parts), the different parts of which cover both dilution method (constant rate injection) and transit time method, each method using either radioactive or chemical tracers.

Some apparatuses, such as vortex or variable area flow meters, may be used, provided they are calibrated beforehand by means of one of the primary methods described in this annex. If installed permanently on a test facility, the possibility of a periodic check of their calibration shall be taken into account.

The calibration shall bear on the whole of the flow meter and the associated measuring system. The calibration should normally be carried out in the actual operating conditions (head, temperature, water quality) prevailing during the tests; attention shall be paid to the fact that the flow-meter is not affected by cavitation during the tests.

As for the velocity area methods, the tracer methods are justified only for grade 1 tests.

IMPORTANT The tracer methods should only be used by specialized staff and the use of radioactive tracers is subject to certain constraints.

D.4 Measurement of pump power input

D.4.1 General

Pump power input may be determined by dynamometers, torque meters, calibrated motors and wattmeters or other devices that can be demonstrated to meet the requirements of Table 5 and Annex C.

Where the power input to an electric motor coupled to an intermediate gear, or the speed of rotation and torque measured by a torque meter between gear and motor are used as a means for determining the pump power input, the method for determining the losses due to the reduction gear shall be stated in the contract.

If necessary, see ISO 5198 for more information on the methods described in D.4.2 to D.4.5.

D.4.2 Torque measurement

Torque should be measured by a suitable dynamometer or a torque meter capable of complying with the requirements of 4.3. Zeroing or tare readings for the unloaded dynamometer should be taken when operating at the test speed. Measurement of torque and speed of rotation should, within practical limits, be simultaneous.

D.4.3 Electric power measurements

Where the electrical power input to an electric motor coupled directly to the pump is used as a means of determining the pump power input, the motor should be operated only under conditions where the efficiency is known with sufficient accuracy. Motor efficiency should be determined in accordance with the recommendations of IEC 60034-2-1, IEC 60034-2-2, or IEEE 112 method B and is to be stated by the motor manufacturer or derived through a unit specific motor test. This efficiency does not take into account motor cable losses or thrust bearing losses beyond those created by the motor thrust loads alone.

If testing with a non-calibrated job motor, only the wire-to-water efficiency can be accurately reported. If previously agreed to by the customer and manufacturer, a non-calibrated job motor can be used for testing and the motor’s guaranteed efficiency should be used to estimate the pump efficiency.

The electric power input to a three-phase alternating current motor should be measured by a two-wattmeter, a three-wattmeter or a polyphase wattmeter method. The use of multiple single-phase wattmeters or a wattmeter measuring two or three phases simultaneously, or integrating watt-hour-meters are allowed. In the case of a direct current motor, either a wattmeter or an ammeter and a voltmeter may be used. The type and grade of accuracy of the indicating instruments for measuring electrical power should be in accordance with IEC 60051-2, IEC 60051-3, IEC 60051-5 and IEC 60051-7, and should meet the requirements of 4.3.

D.4.4 Special cases

D.4.4.1 Pumps with inaccessible ends

In the case of combined motor-pump units (for example submersible pump or monobloc pump, or separate pump and motor with overall efficiency guarantee), the power of the unit shall be measured at the motor terminals, if accessible. If a submersible pump is involved, the measurement shall be effected at the incoming end of the cables; cable losses shall be taken into account and specified in the contract. The efficiency given shall be that of the combined unit proper, excluding the cable and the starter losses.

D.4.4.2 Deep-well pumps

In this case, the power absorbed by the thrust bearing and the vertical shafting and bearings shall be taken into account.

Since deep-well pumps in general are not tested with the entire stand pipe attached, unless the acceptance test is performed at site, the thrust and vertical shaft bearing losses shall be estimated and stated by the manufacturer.

D.4.4.3 Motor pump units with common axial bearing (other than close coupled pumps)

In this case, if the power and the efficiency of the motor and those of the pump shall be determined separately, the influence of the axial thrust and possibly of the weight of the pump rotor on the losses in the thrust bearing shall be taken into account.

D.4.5 Measurement of pumping unit overall efficiency

To determine the efficiency of a pumping unit, only the power input and output should be measured, with the driver working under conditions specified in the contract. In this test, neither the proportion of losses between driving agent and pump nor any losses associated with intermediate machinery, such as gear box or variable speed device, are established .

Annex E
(informative)

Tests performed on the entire equipment set — String test

Generating a pump curve requires the measurement of head, capacity and power. From this information the efficiency of the pump can be calculated. The hydraulic efficiency shown on the pump curve has always been related to the shaft input power. The published efficiency is the hydraulic power produced by the pump divided by the mechanical input power to the pump shaft. Thus, the efficiency published is only that of the pump, not of any other component. From a testing standpoint, the most accurate way to obtain the power data is by direct measurement of the shaft torque and revolutions per minute (r/min). This is typically done using a torque transducer and a tachometer. These values are then used for calculating the power input to the pump.

A less accurate method, but one that may be specified, is carrying out a “string” test using the complete assembly with the motor, pump and drive (gear box, belt drive, etc.). The accuracy of this test is expected to be lower than in a case where the pump is tested by itself. In this instance, the power measured is the input power to the motor. The input power to the pump shaft is then calculated by taking into account the published motor and drive efficiencies. Since these efficiencies are not known precisely, this method of calculating pump input power is less accurate than in a case where the shaft torque and revolutions per minute are directly measured.

If a variable frequency drive (VFD) is used as a part of the string, it becomes virtually impossible to obtain an accurate value of input power to the pump shaft. A wattmeter cannot accurately measure the power from the VFD to the motor because of the non-sinusoidal wave form generated by the VFD. A wattmeter can measure the input power to the VFD. But if the input power to the VFD is measured, it is necessary to know the efficiency of the VFD in order to calculate VFD output power to the motor. This information can be available, but it adds yet another degree of error since the motor efficiency changes due to the non-sinusoidal wave form of the output power from the VFD. (Although many VFDs provide a measurement of output power, the value of this measurement is only approximate and is generally not accurate enough for acceptance testing. This reading also does not take into account the reduction in motor efficiency in cases of operation on VFD power.)

NOTE 1 A variable frequency drive is based on the inverter technology.

The need for string testing with a VFD can come from two requirements. The first is if the customer wishes to use his/her VFD on the string test. The second is if a string test is required and the customer wishes to have curves produced at a number of different speeds. In both instances, the suggested procedure is to conduct one test without using a VFD by running the motor directly across the line. This allows a complete head-capacity-efficiency curve to be produced at nominal speed. The VFD can then be connected to the motor and head-capacity curves can be produced at the required speeds without any power data being measured.

NOTE 2 A pump run at “full speed” (line frequency) on a VFD most often does not produce the same pump curve as a direct on line test. The two main reasons for this are that the drive design (and settings) affects the motor torque, thus slightly changing the actual pump speed under load. Secondly, the drive’s actual output frequency is not as exactly as the same as the grid frequency.

Table E.1 gives the qualitative details of correction factors needed to calculate pump efficiency for different configurations. The configurations are shown from the highest to the lowest measurement accuracy.

It is not possible to obtain pump efficiency during a string test of an engine driven pump. In this situation, the pump should be tested separately to obtain accurate shaft power measurements.

From a very basic standpoint, it can be seen that the efficiency (and power consumption) information provided by the pump manufacturer’s curves often only provides the end user with the required power at the pump input shaft. Furthermore, the information is generally provided with the pump being sealed by packing. From an energy consumption standpoint, this information does not provide the user with the true cost to operate the pump.

In fact, it is far more useful to provide “wire to water” efficiency and power consumption curves, but this is rarely requested. Wire to water performance can be measured with all of the configurations given in Table E.1

simply by placing a wattmeter at the input to the motor or VFD. These data allow the end user to know the true power consumption of the pump system and to evaluate the true operating cost of various seal, drive, motor and VFD options.

Table E.1 — Influencing factors for calculating pump efficiency for different configurations

Configuration	Drive	Measurement of power	Measurement of revolutions per minute	Influencing factors	Pump efficiency accuracy
Pump only	Mechanical	Torque transducer	Tachometer	None	Highest ●●●●●●●●●●●
Pump and motor, direct connected	Line power	Wattmeter	Tachometer	a) Motor efficiency	●●●●●●●●●●●
Pump and motor, belt or gear driven	Line power	Wattmeter	Tachometer	a) Motor efficiency b) Transmission efficiency	●●●●●●●●●●● ●●●●●●●●●●● ●●●●●●●●●●●
Pump and submersible motor	Line power	Wattmeter	From motor or vibration data	a) Motor efficiency b) Seal power consumption c) Cooling system power consumption	●●●●●●●●●● ●●●●●●●●●● ●●●●●●●●●● ●●●●●●●●●
Pump and motor, direct connected	Motor plus VFD	Wattmeter input to VFD	Tachometer	a) Motor efficiency b) VFD efficiency c) Motor efficiency correction for VFD power	●●●●●●●●● ●●●●●●●●● ●●●●●●●● ●●●●●●●●
Pump and motor, belt or gear driven	Motor plus VFD	Wattmeter input to VFD	Tachometer	a) Motor efficiency b) Mechanical drive efficiency c) VFD efficiency d) Motor efficiency correction for VFD power	●●●●●●● ●●●●●●● ●●●●●●● ●●●●●● ●●●●●● ●●●●●
Pump and submersible motor	Motor plus VFD	Wattmeter input to VFD	From motor or vibration data	a) Motor efficiency b) Seal power consumption c) Cooling system power consumption d) VFD efficiency e) Motor efficiency correction for VFD power	●●●●● ●●●● ●●●● ●●● ●●● ●●● ●● ●● ●● ● ● Lowest

Annex F
(informative)

Reporting of test results

F.1 Performance test report recommendations

F.1.1 The following example of the content of a performance test report gives a list of pump parameters which are not ncessarily comprehensive. The details should be agreed upon between the manufacturer and customer.

F.1.2 The pump test report should contain detailed information to identify the tested pump and any other equipment that can be subject to test. The report should contain the raw test data for all test points taken. A graph should be drawn where the corrected test points are plotted. A curve fitted to the corrected test points should be drawn on the graph. The guarantee point should be marked and the acceptance criteria should be indicated in the form of a vertical line for head limits (at the flow guarantee point) and a horizontal line for flow limits (at the head guarantee point) (see Figures 2 and 3). The ends of the vertical line should represent the upper and lower limits of head, and the ends of the horizontal line should represent the upper and lower limits of flow. The lines should start at the guarantee point.

The following information should be included in the report (as applicable):

— test date;

— the tested equipment;

— test facility and location;

— the guaranteed data (flow, head, power or efficiency, as applicable);

— the guarantee given;

— ambient and water temperatures;

— barometric pressure;

— driver data;

— if witnessed, name and signature of all witnesses;

— if test point corrections are carried out, the correction method should be outlined;

— comments pertaining to anything noteworthy about the test.

F.2 NPSH test report recomendations

For NPSH reporting, the results of NPSH3 test should be displayed on the performance curve.

F.3 Pump test sheet

The pump test sheet illustrated in this annex is given for guidance for presenting pump test results and to assist in their interpretation. It does not purport to include all the information required from a pump test and modifications can be necessary depending on the type of pump, its application and the mode of calculation.

Test report

Ordered data	Order No.			Order-Pos		
	Type			Item No.		
Guarantee/ data of order	Acceptance test class: ISO 9906 Grade 2			Measured points: 7		
	Q	[m³/h]	16,80	Q	[l/s]	4,67
	H	[m]	52,50	P_N	[kW]	4,16
	η	[%]	51,40	P_{mot}	[kW]	6,30
	n_N	[1/min]	3 500	ρ	[kg/dm³]	0,89
Impeller data	Impeller diameter ∅ [mm] 163			Remaching type A15		
Test conditions	Test bed type: closed			Test medium: cold water		
	∅ Suction side measuring point (ss) [mm] 66,05			∅ Discharge side measuring point (ds) [mm] 40,30		
Motor data	Test motor No. 22C/60					

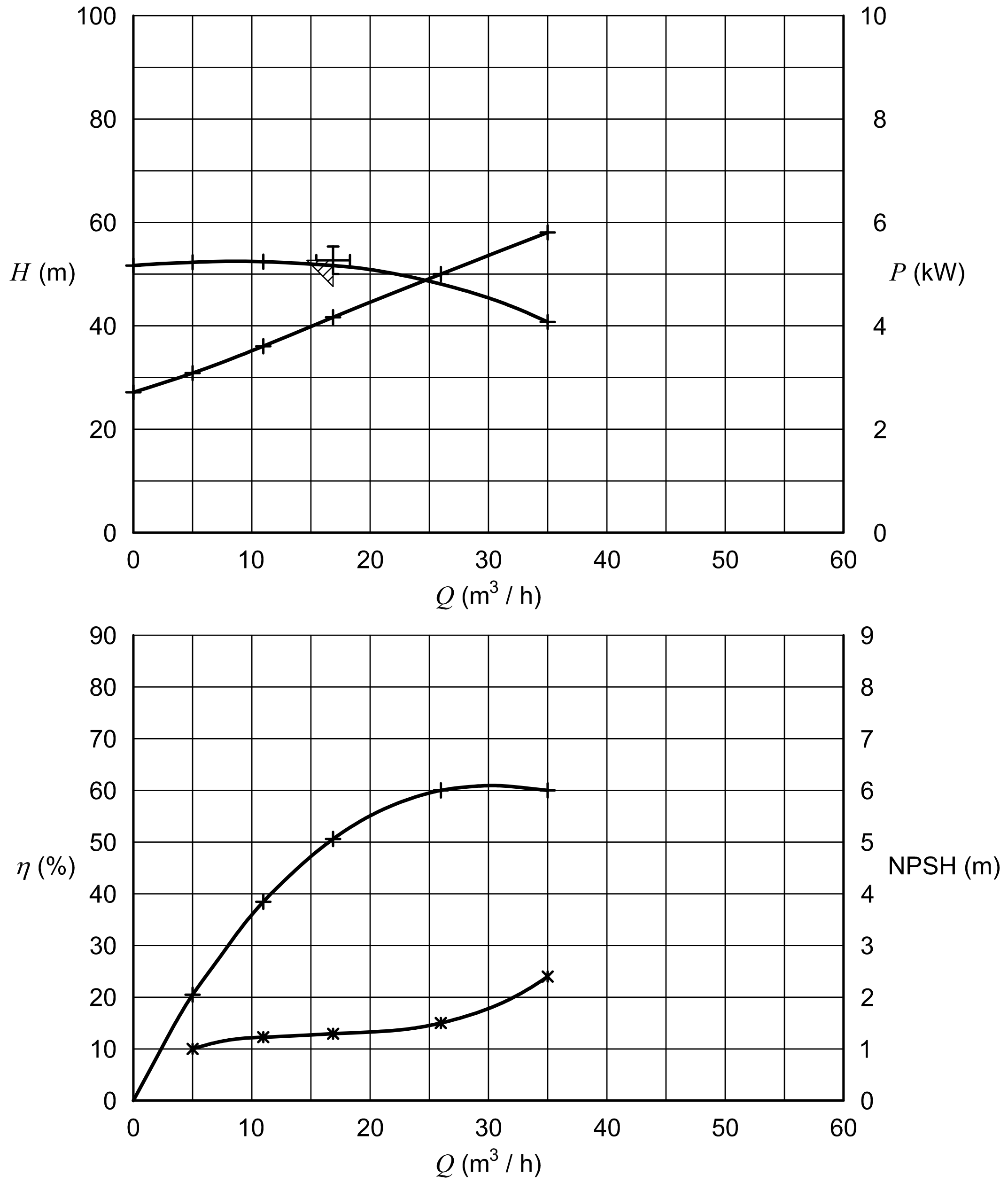
Test speed values											
	Meas. pt./ No.	Dimension	1	2	3	4	5	6	7	8	9
	n	[1/min]	3 584	3 584	3 572	3 567	3 595	3 595	3 584		
	H_{in}	[m]	8,49	8,51	8,23	8,47	8,55	9,00	8,50		
	H_{out}	[m]	61,61	63,15	56,64	48,11	63,70	63,50	61,73		
	$\Delta v^2/2g$	[m]	0,63	0,26	1,47	2,64	0,05	0,00	0,56		
	H	[m]	53,76	54,90	49,88	42,28	55,20	54,50	53,79		
	Q	[m³/h]	17,36	11,25	26,60	35,63	5,12	0,00	16,46		
	Q	[l/s]	4,82	3,12	7,39	9,90	1,42	0,00	4,57		
	P_{mot}	[kW]	5,96	5,25	7,02	8,00	4,59	4,12	6,71		
	P_p	[kW]	5,02	4,36	6,00	6,89	3,74	3,29	5,65		
	η	[%]	50,67	38,64	60,29	59,57	20,62	0,00	50,60		
Values at guaranteed speed											
3 500 min^{-1}	H	[m]	51,26	52,36	47,89	40,71	52,32	51,66	51,29		
	Q	[m³/h]	16,96	10,98	26,07	34,96	4,99	0,00	16,07		
	Q	[l/s]	4,71	3,05	7,24	9,71	1,39	0,00	4,46		
	p ($\rho = 0{,}89$)	[kW]	4,16	3,61	5,02	5,79	3,07	2,70	4,68		
	P_p	[kW]	4,68	4,06	5,64	6,51	3,45	3,04	5,26		
	η	[%]	50,67	38,64	60,29	59,57	20,62	0,00	50,60		

Remarks:	Test record No.:	
	Tested:	Customer:

Figure F.1 (*continued*)

Test report											
Ordered data	Order No.					Order-Pos					
	Type					Item No.					
Guarantee/ data of order	Acceptance test class: ISO 9906					Measured points: 5					
	Q	[m³/h]	16,80			Q	[l/s]		4,67		
	H	[m]	52,50			P_N	[kW]		4,16		
	η	[%]	51,40			P_{mot}	[kW]		6,30		
	n_N	[1/min]	3 500			ρ	[kg/dm³]		0,89		
	NPSHR	[m]	1,40								
Impeller data	Impeller diameter ∅ [mm] 163					Remaching type A15					
Test conditions	Test bed type: closed					Test medium: cold water					
	∅ Suction side measuring point (ss) [mm] 66,05					∅ Discharge side measuring point (ds) [mm] 40,30					
Motor data	Test motor No. 22C/60										
Test speed values	NPSH test					Barometric pressure [hPa] 962,59; [m] 9,82					
	Meas. pt./ No.	Dimension	1	2	3	4	5	6	7	8	9
	n	[1/min]	3 575	3 589	3 581	3 569	3 565				
	H_{in}	[m]	–8,12	–8,32	–8,15	–8,05	–7,31				
	H_{out}	[m]	44,44	46,24	46,15	39,33	31,97				
	$\Delta v^2/2g$	[m]	0,61	0,05	0,26	1,47	2,63				
	H	[m]	53,16	54,62	54,56	48,86	41,90				
	Q	[m³/h]	17,06	4,98	11,20	26,59	35,52				
	Q	[l/s]	4,74	1,38	3,11	7,38	9,87				
	$\Delta v^2/2g$	[m]	0,10	0,01	0,04	0,24	0,42				
	θ_W	[°C]	29,28	29,27	29,27	29,32	29,38				
	H_t	[m]	0,42	0,42	0,42	0,42	0,43				
	NPSH	[m]	1,37	1,08	1,28	1,58	2,50				
Values at guaranteed speed											
3 500 min^{-1}	H	[m]	50,96	51,94	52,12	46,99	40,39				
	Q	[m³/h]	16,70	4,86	10,95	26,07	34,87				
	Q	[l/s]	4,64	1,35	3,04	7,24	9,69				
	NPSH	[m]	1,31	1,02	1,22	1,52	2,41				
Remarks:			Test record No.:								
			Tested:				Customer:				

Figure F.1 (*continued*)



	Test record No.:	
	Tested:	Customer:

Figure F.1 — Example of test report

Annex G
(informative)

Special test methods

G.1 General

For certain pump acceptance testing situations, there are other specialized test methods which can be more practical to use. These and other possible methods are typically highly specialized and require experience and intimate knowledge of the respective methods and processes in order to obtain accurate test results. Two examples are given in this annex.

Testing a smaller scale pump model. This method requires that geometrically similar model pumps be constructed such that the entire internal pump geometry is linearly scaled down. The pump test results, including efficiency, can be scaled up to accurately represent the full scale prototype pump. The model should be constructed as large as possible to achieve the best accuracy. An example of an existing test standard is JIS B 8327.

Pump efficiency testing can be performed by precisely measuring the difference in pumped media temperature between the inlet and outlet of the pump. This method is commonly referred to as the “Thermodynamic” test method. For a detailed description of this method, see IEC 60041. In case of an inverter driven test system, the uncertainty of the pump efficiency may be reduced by measuring the pump efficiency directly using the thermodynamic method.

Annex H
(informative)

Witnessed pump test

H.1 Physically witnessed pump test

The purchaser's representative signs off on the raw test data to certify that the test is performed satisfactorily. It is possible for final acceptance of the pump performance to be determined by the witness. The benefit of witness testing depends largely on the effectiveness and expertise of the witness. A witness cannot only ensure the test is conducted properly, but can also observe operation of the pump during testing prior to pump shipment to the job site. A disadvantage of witness testing can be extended delivery times and excessive cost. With just-in-time manufacturing methods, the scheduling of witness testing requires flexibility on the part of the witness and can lead to additional costs if the schedule of the witness causes delays in manufacturing.

H.2 Remotely witnessed pump test

The purchaser can monitor the entire testing remotely in real time. The raw data, as recorded by the data acquisition system, can be viewed and analysed during the test, and the results can be discussed and submitted for approval. The advantages of this type of testing are in travel costs and accelerated pump delivery.

Annex I
(informative)

Conversion to SI units

I.1 General

This annex gives factors for conversion to SI units of some of the quantities expressed in multiples or submultiples of SI units and in units other than SI units. The conversion factor is the number by which the value expressed in various units should be multiplied to find the corresponding value in SI units.

Table I.1 — Conversion factors

Quantity	Symbol of SI unit	Various units		Conversion factor
		Name	Symbol	
(Volume) rate of flow	m^3/s	litre per second	l/s	10^{-3}
		cubic metre per hour	m^3/h	1/3 600
		litre per hour	l/h	1/3 600 000
		litre per minute	l/min	1/60 000
		imperial gallon per minute	gal (UK)/min	$75,77 \cdot 10^{-6}$
		cubic foot per second	ft^3/s	$28,316\,8 \cdot 10^{-3}$
		gallon (US) per minute	gal (US)/min	$63,09 \cdot 10^{-6}$
		barrel (US) per hour (petroleum)	barrel (US)/h	$44,16 \cdot 10^{-6}$
Mass rate of flow	kg/s	tonne per second	t/s	10^3
		tonne per hour	t/h	1/3,6
		kilogram per hour	kg/h	1/3 600
		pound per second	lb/s	0,453 592 37
Pressure	Pa	kilopond per square centimetre	kp/cm^2	98 066,5
		kilogram-force per square centimetre	kgf/cm^2	98 066,5
		bar	bar	10^5
		hectopieze	hpz	10^5
		torr	torr	133,322
		conventional millimetre of mercury	mmHg	133,322
		conventional millimetre of water	mmH_2O	9,806 65
		poundal per square foot	pdl/ft^2	1,488 16
		standard atmosphere	atm	101 325
		pound-force per square inch	lbf/in^2 (psi)	6 894,76
Density	kg/m^3	kilogram per cubic decimetre	kg/dm^3	10^3
		gram per cubic centimetre	g/cm^3	10^3
		pound per cubic foot	lb/ft^3	16,018 5

Table I.1 *(continued)*

Quantity	Symbol of SI unit	Various units		Conversion factor
		Name	Symbol	
Power	W	kilowatt	kW	10^3
		kilopond metre per second	kp · m/s	9,806 65
		I.T. kilocalorie per hour	$kcal_{IT}$/h	1,163
		cheval vapeur	ch	735,5
		horsepower	hp	745,7
		British thermal unit per hour	Btu/h	0,293 071
		kilogram-force metre per second	Kgf · m/s	9,806 65
Viscosity (dynamic viscosity)	Pa · s	poise	P	10^{-1}
		dyne second per square centimetre	Dyn · s/cm^2	10^{-1}
		gram per second centimetre	g/s · cm	10^{-1}
		kilopond second per square metre	kp · s/m^2	9,806 65
		Poundal second per square foot	pdl · s/ft^2	1,488 16
Kinematic	m^2/s	stokes	St = cm^2/s	10^{-4}
viscosity		square foot per second	ft^2/s	$92,903 \cdot 10^{-3}$

Annex J
(informative)

Measurement uncertainty for NPSH test

According to this International Standard, positive tolerances are not permissible for NPSH tests. Moreover, all overall uncertainties should be taken into account to ensure that the specified values are achieved despite the mentioned uncertainties and manufacturing tolerances. In the case of NPSH measurement, this means that neither manufacturing tolerances nor measurement uncertainty should result in non-conformities, e.g. higher NPSH values than agreed upon. For this reason, it is appropriate and necessary to keep the measurement uncertainty and, thus, the instrumental measurement uncertainty (“systematic uncertainties”), as low as possible. Otherwise, requirements regarding the manufacturing tolerances become ever more stringent which can entail a (normally) permanently higher amount of time and work required. This causes a reduced maximum allowable instrumental measurement uncertainty for the NPSH test.

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