



American National Standard for

Rotodynamic Submersible Pumps

for Hydraulic Performance, Hydrostatic Pressure,
Mechanical, and Electrical Acceptance Tests



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Approved September 1, 2017
American National Standards Institute, Inc.

American National Standard

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Published By

Hydraulic Institute
6 Campus Drive, First Floor North
Parsippany, NJ 07054-4406

www.Pumps.org

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Printed in the United States of America

ISBN 978-1-935762-47-8



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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Hydraulic Institute are to promote the advancement of the pump manufacturing industry and further the interests of the public and to this end, among other things:

- a) Develop and publish standards.
- b) Address pump systems.
- c) Expand knowledge and resources.
- d) Educate the marketplace.
- e) Advocate for the industry.

Purpose of Standards and Guidelines

- a) Hydraulic Institute Standards and Guidelines are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser, and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.
- b) Use of Hydraulic Institute Standards and Guidelines is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the standards.

Definition of a Standard of the Hydraulic Institute

Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

“An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and service for which designed.”

Definition of a Hydraulic Institute Guideline

A Hydraulic Institute Guideline is not normative. The guideline is tutorial in nature, to help the reader better understand the subject matter.

Comments from users

Comments from users of this standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be directed to the Technical Director of the Hydraulic Institute. If appropriate, the inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

Revisions

American National Standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

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This document does not contain a complete statement of all requirements, analyses, and procedures necessary to ensure safe or appropriate selection, installation, testing, inspection, and operation of any pump or associated products. Each application, service, and selection is unique with process requirements that shall be determined by the owner, operator, or its designated representative.

Units of measurement

Metric units of measurement are used, and corresponding US customary units appear in parentheses. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Because values given in metric units are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this standard. If no such statement is provided, metric units shall govern.

Consensus

Consensus for this American National Standard was achieved by use of the canvass method. The following organizations, recognized as having an interest in the standardization of pumps, were contacted prior to the approval of this revision of the standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

Brown and Caldwell	Patterson Pump Company
Deltares	Pentair - Berkeley
DuPont	Pentair - Fairbanks Nijhuis
ekwestrel corp.	PumpsPositive
Flowserve Corporation	Rotating Equipment Repair Inc.
Fluid Sealing Association	Sulzer
Healy Engineering, Inc.	Taco Comfort Solutions
Hidrostal AG	WECTEC LLC
John Anspach Consulting	WEG Electric Corp.
Kemet Inc.	Weir Minerals North America
Las Vegas Valley Water District	Weir Specialty Pumps
Mechanical Solutions, Inc.	Xylem AWS

Committee list

Although this standard was processed and approved for submittal to ANSI by the canvass method, a working committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Paul J. Ruzicka, Xylem Inc. - Applied Water Systems
Vice-chair – James E. McKee, Pentair - Berkeley

Committee members

Timothy Albers
Frank Ennenbach
Christopher Felix
Lane Larsen
James E. McKee
Paul W. Moulton
Craig S. Redmond
Jan Schyberg
Arnold R. Sdano
Ernest C. Sturtz
Jerry J. Szofer
Jamie Watkins

Company

Nidec Motor Corporation
Sulzer Pumps Ltd.
Xylem Inc. - Applied Water Systems
Weir Specialty Pumps
Pentair - Berkeley
AECOM
Gorman-Rupp, Mansfield Division
Xylem Inc. - Water Solutions
Pentair - Fairbanks Nijhuis
CDM Smith
Yeomans Chicago Corporation
Crane Pumps & Systems, Inc.

Alternate:

Al Iseppon
Pentair

11.6 Submersible pump tests

11.6.1 Introduction

This revision of ANSI/HI 11.6 brings the standard into harmony with ANSI/HI 14.6 *Rotodynamic Pumps for Hydraulic Performance Acceptance Tests*, using the symbols and equations as contained in that standard.

Minor revisions were also made to the specification for the input power to the motor when testing the submersible pump that reflect good quality power as supplied by utilities. Additionally, new requirements of the electrical input power measurement devices are now specified in the document and are in alignment with the findings from the HI 40.6 committee for the Department of Energy (DOE).

11.6.1.1 Purpose

This standard is intended to provide uniform procedures for performance, hydrostatic, net positive suction head required (NPSHR), submersible motor integrity, and vibration testing of submersible pumps; and data recording and reporting of the test results. It is intended to define test procedures that may be invoked by contractual agreement between a purchaser and manufacturer. It is not intended to define a manufacturer's standard practice.

11.6.1.2 Scope

This standard applies to customer acceptance testing of submersible pumps driven by electric motors, unless otherwise agreed or specified. A *submersible pump* is defined as a close-coupled pump/motor unit designed to operate submerged in the pumped liquid. This definition includes submersible pumps operating in either a wet-pit or dry-pit environment. A standard test measures pump performance from pump inlet to pump outlet and electrical input power. It does not include accessory items, such as outlet elbows, inlet fittings, or valves, unless specified by a contractual agreement. This standard also includes the acceptance criteria for original equipment manufacturer (OEM) factory and permanently installed pump vibration testing.

ANSI/HI 11.6 is intended to be used for pump acceptance testing at pump test facilities, such as manufacturers' pump test facilities or laboratories only. Industry experience shows that it is very difficult to perform measurements accurate enough to satisfy the acceptance requirements in this standard when testing is performed in the field.

Information in the standard may be applied to pumps of any size and to any pumped liquids behaving as clean cold water. This standard does not deal with the structural details of the pump or with the mechanical properties of their components.

a) Submersible pump designs included are:

- 1) Semipermanent/pull-up/wet-pit types.
- 2) Dry-pit/dry-installed types.
- 3) Portable/flexible outlet types.
- 4) Chopper/cutter/grinder types.
- 5) Close-coupled types.
- 6) Integral electric motor types.
- 7) Direct current or battery powered motors
- 8) Fractional horsepower (hp)

b) The following pump types are excluded:

- 1) Nonrotodynamic (positive displacement [PD] and progressive cavity [PC] types).
- 2) Lineshaft.
- 3) Mixers and agitators.
- 4) Deep-well pumps/bore-hole pumps.
- 5) Pumps not powered by an electric motor.

Prior to the test, the purchaser and manufacturer shall agree on the type of acceptance test(s) to be performed.

It is not the intent of this standard to limit or restrict tests to only those described herein. Variations in test procedures may exist without violating the intent of this standard. *Exceptions may be taken if agreed on or specified by the parties involved without sacrificing the validity of the applicable parts of this standard.*

This standard is limited to the testing of submersible pumps with clean water. The tests conducted under this standard must be performed and reported by qualified personnel. This standard is intended for testing under controlled conditions, such as an OEM factory test or an independent qualified hydraulic laboratory test. Some information is given for replication in a field-test environment.

11.6.1.3 Symbols, units, and subscripts

11.6.1.3.1 Symbols and units

See Table 11.6.1.3.1.

Table 11.6.1.3.1 — Symbols

Symbol	Term	Metric Unit	Abbr.	US Customary Unit	Abbr.
A	area	millimeter squared	mm ²	inch squared	in ²
D	diameter	millimeter	mm	inch	in
e	overall uncertainty, relative value	percent	(%)	percent	(%)
f	frequency	cycle/second (hertz)	1 s ⁻¹ (Hz)	cycle/second (hertz)	1 s ⁻¹ (Hz)
g	gravitational acceleration	meter/second squared	m/s ²	foot/second squared	ft/s ²
h	head	meter	m	foot	ft
h _j	losses in terms of head of liquid	meter	m	foot	ft
H	pump total head	meter	m	foot	ft
K	fitting loss coefficient	dimensionless	—	dimensionless	—
K	hydrostatic pressure factor	dimensionless	—	dimensionless	—
I	current	ampere	A	ampere	A
n	rotational speed	revolution/minute	rpm	revolution/minute	rpm
NPSHA	net positive suction head available	meter	m	foot	ft
NPSHR	net positive suction head required	meter	m	foot	ft
NPSH3	net positive suction head required for 3% head reduction at first stage	meter	m	foot	ft
p	pressure	kilopascal	kPa	pound/square inch	psi
P	power	kilowatt	kW	horsepower	hp
PF	power factor	cos φ	PF	dimensionless	PF
Q	rate of flow	cubic meter/second	m ³ /s	US gallon/minute	gpm
R	electrical resistance	ohm	Ω	ohm	Ω
s	specific gravity	dimensionless	—	dimensionless	—
t	temperature	degree Celsius	°C	degree Fahrenheit	°F
t	time	second	s	second	s
τ	torque	newton-meter	N•m	pound-foot	lb-ft
U	velocity	meter/second	m/s	foot/second	ft/s
V	electrical potential	volt	V	volt	V
z	elevation gauge distance above or below datum	meter	m	foot	ft
β	orifice or meter ratio	dimensionless	—	dimensionless	—
Δ	difference	varies	—	varies	—
η	efficiency	percent	%	percent	%
π	pi = 3.1416	dimensionless	—	dimensionless	—
ρ	density	kilogram/cubic meter	kg/m ³	pound mass/cubic foot	lbm/ft ³
ω	angular velocity	radian/second	—	radian/second	—
ν	kinematic viscosity	millimeter squared/second	mm ² /s	foot squared/second	ft ² /s

11.6.1.3.2 Subscripts

See Table 11.6.1.3.2.

Table 11.6.1.3.2 — Subscripts

Subscript	Term	Subscript	Term
1	inlet	m	test condition or model
1'	inlet measuring section	max	maximum
2	outlet	min	minimum
2'	outlet measuring section	OA	overall unit
abs	absolute	P	power
atm	atmospheric	p	specific condition or prototype
b	barometric	<i>p</i>	submersible pump
dvr	driver input	sp	specified
G	guarantee	t	theoretical
g	gauge	v	velocity
gr	combined pump/motor unit (overall)	vp	vapor pressure
H	pump total head	w	water
L	liquid level	x	at any section
M	manometer	η	efficiency

11.6.2 Test types

This standard describes the following tests:

- Pump tests 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. A typical performance test consists of measurement of flow, head, and power input to submersible pump motor.

Optional tests as follows when specified:

- Hydrostatic test.
- Net positive suction head (NPSHR) test.
- Submersible motor integrity test.
- Vibration test.

11.6.2.1 Routine production tests

Pump manufacturers include routine testing as part of their production process. This internal testing provides verification of pump assembly and functionality to prevent release of defective units. These tests are often done on a sampling basis for higher volume of production, lower horsepower units. They are usually of a pass–fail nature. These routine tests differ among manufacturers and may or may not include:

- a) Impeller balance test.
- b) Leak integrity test.
- c) Dry-run, no-load test.
- d) Abbreviated single-point performance test.
- e) Motor electrical integrity test.
- f) Moisture and/or temperature sensor(s) integrity test.

11.6.2.2 Nonwitnessed factory pump test

11.6.2.2.1 Factory test

Nonwitnessed factory tests are performed without the presence of a purchaser representative. The pump manufacturer is responsible for the data collection and judgment of pump acceptance. The advantages of this test are 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), then a factory nonwitnessed test may be acceptable.

11.6.2.2.2 Certified factory test

Nonwitnessed certified factory tests are performed without the presence of a purchaser representative. The pump manufacturer is responsible for compliance with this test standard. The pump manufacturer conducts the test, passes judgment on pump acceptance, and produces a certified and signed pump test document including the data. The advantage of this test is the same as the nonwitnessed test. Compared to a witnessed test, this test is substantially less expensive and often leads to accelerated pump delivery to the end user.

11.6.2.3 Witnessed factory pump test

The purchaser or purchaser's designated representative(s) may witness any test when specified in the contract.

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.

11.6.2.3.1 Witnessing by the purchaser's representative

A representative of the purchaser physically attends the testing. The representative signs off on the raw test data to certify that the test is performed satisfactorily. Final acceptance of the pump performance may or may not 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 observe operation of the pump during testing prior to pump shipment to the jobsite. Disadvantages of witness testing can be extended delivery times and additional cost. With today's "just-in-time" manufacturing methods, scheduling of witness testing requires flexibility on the part of the witness, and may lead to additional costs if the schedule of the witness causes delays in manufacturing.

11.6.2.3.2 Remote witnessing by the purchaser's representative

The purchaser or its representative may remotely witness pump performance testing. 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 analyzed during the test, and the results can be discussed and submitted for approval. The advantage of this type of testing are savings in travel costs.

11.6.3 Test conditions

Unless otherwise specified, the flow rate, head, efficiency, and NPSHR are based on manufacturer's facility or laboratory tests using clean water corrected to 20 °C (68 °F). Clean water means water to be used for testing with a maximum kinematic viscosity of $1.5 \times 10^{-6} \text{ m}^2/\text{s}$ ($1.6 \times 10^{-5} \text{ ft}^2/\text{s}$) and a maximum density of $10,000 \text{ kg/m}^3$ (62.4 lb/ft^3). If the facility cannot test at rated conditions because of limitations such as power, electrical frequency, or flow capability, the pump may be tested at between 80% and 120% of rated speed (i.e., it is acceptable to test 50-Hz pumps at 60 Hz or vice versa, if the motor is capable and/or has enough power). Test results shall be converted to the specified rated conditions using the formulae shown in Appendix B. No adjustment for efficiency is allowed.

For combined motor pump units or when the guarantees are with respect to an agreed frequency and voltage instead of an agreed speed of rotation, the rate of flow, pump total head, power input, and efficiency data are subject to the above-mentioned translation rules, provided that n_2 is replaced by the frequency f_2 and n_1 by the frequency f_1 . 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.

11.6.4 Definitions

11.6.4.1 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 will touch or pass through a tolerance band surrounding the guarantee point as defined by the applicable acceptance grade, see Table 11.6.5.4 and Figures 11.6.5.4a and b.

A guarantee point shall be defined by a guarantee flow Q_G and a guarantee head H_G .

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

- | | | |
|--|---|--|
| <ul style="list-style-type: none"> a) 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}. | } | (Defined in Section 11.6.5.4 and Figures 11.6.5.4.2a, b, and c.) |
| <ul style="list-style-type: none"> b) The maximum required net positive suction head (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, may require larger tolerance bands to be agreed on by the purchaser and manufacturer/supplier.

11.6.4.2 Best efficiency point (BEP)

The flow rate at which the pump hydraulic efficiency (η) is a maximum. (Note: this point may not be located at the same point as the best “wire-to-water” efficiency.)

11.6.4.3 Shut-off head

The pump head at the condition of zero flow where no liquid is flowing through the pump, but the pump is primed and operating and the discharge valve is closed.

11.6.4.4 Flow rate (Q)

The flow rate (Q) of a pump is the total volume throughput per unit of time. It assumes no entrained gases at the stated operating conditions.

The unit of volume must be one of the following:

- a) Metric units: cubic meters or liters.
- b) US customary units: US gallons or cubic feet.

The density of water at a temperature of 20 °C (68 °F) shall be taken as 998.2 kg/m³ or 0.9982 kg/L (62.3 lbm/ft³). No specific volume corrections are required if the temperature of the clean, fresh water used for testing is maintained between 10 and 30 °C (50 and 86 °F). For other temperatures, proper density corrections must be made using values from the ASME Steam Tables.

11.6.4.5 Speed (n)

The speed (n) of a submersible pump is the number of revolutions of the shaft in a given unit of time. Speed is expressed as revolutions per minute.

11.6.4.6 NPSH datum

The datum is defined as the horizontal plane through the center of the impeller described by the external points of the entrance edges of the impeller blades. In the case of the double inlet pumps with vertical or inclined axis, it is the plane through the higher center. The manufacturer should indicate the position of the plane with respect to precise reference points on the pump.

The datum is defined as follows:

- a) For horizontal submersible pumps, it is the centerline of the pump shaft, Figure 11.6.4.6a.

- b) For vertical submersible pumps, it is the plane defined by the largest diameter at the inlet to the impeller vanes, Figure 11.6.4.6b.

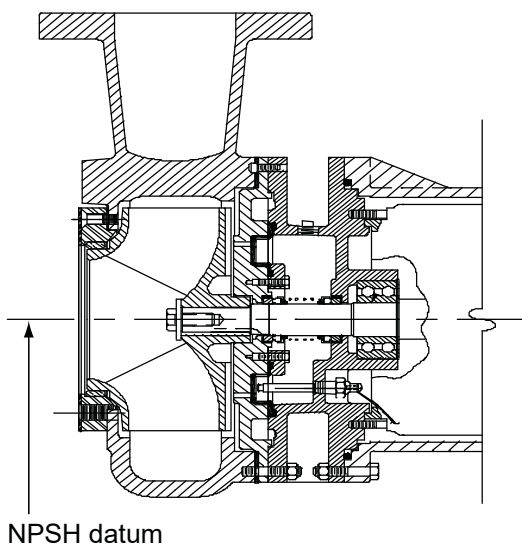


Figure 11.6.4.6a — NPSH datum for horizontal pumps

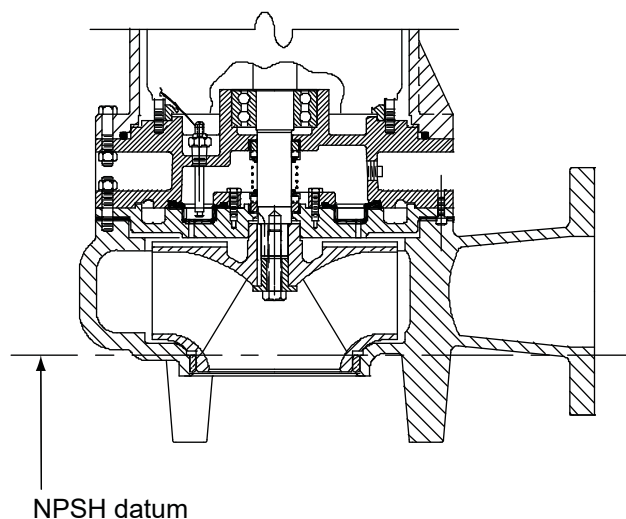


Figure 11.6.4.6b — NPSH datum for vertical pumps

11.6.4.7 Head (h)

Head (h) is the energy per unit mass of fluid, divided by acceleration due to gravity, g .

11.6.4.7.1 Gauge pressure in terms of head (h_g)

The energy per unit mass of fluid, divided by acceleration due to gravity, g , determined by a pressure gauge or other pressure-measuring device.

$$h_x = \frac{p_{MX}}{\rho g} = \frac{p_{MX}}{\gamma}$$

When testing with water at 20 °C (68 °F):

$$\text{(Metric units)} \quad h_x = \frac{p_{MX}}{\rho \times 9.81}$$

$$\begin{aligned} \text{(US customary units)} \quad h_x &= \frac{144 \times p_{MX}}{62.3 \times s} \\ &= \frac{2.31 \times p_{MX}}{s} \\ &= 2.31 \times p_{MX}, \text{ for water at } 68 \text{ }^\circ\text{F} \end{aligned}$$

11.6.4.7.2 Velocity head (h_{vx})

Velocity head (h_{vx}) is the kinetic energy per unit mass of the liquid in movement, divided by g . Velocity head is expressed by the following equation:

$$h_{vx} = \frac{U_x^2}{2g}$$

11.6.4.7.3 Elevation head (z_x)

Elevation head (z_x) is the energy per unit mass of fluid, divided by acceleration due to gravity, g , due to its elevation relative to a datum level, measured to the liquid surface or center of the pressure gauge.

11.6.4.7.4 Total inlet head (h_1)

The total inlet head (h_1) is the algebraic sum of the inlet gauge head, the inlet velocity head, and the inlet gauge elevation head, and, where applicable, the head losses in the inlet pipe from the gauge tap to the pump inlet:

$$h_1 = h_{1'} + h_{v1} + z_{1'} - h_{j1}$$

The gauge head (h_1) is positive when the inlet gauge reading is above atmospheric pressure, negative when the reading is below atmospheric pressure. When test arrangements require the use of inlet piping and/or an inlet elbow (which are not an integral component of the pump, but are located between the point of inlet gauge attachment and the pump), the gauge head (h_{gs}) reading shall be corrected for the head losses attributable to these inlet piping components.

The velocity head (h_{v1}) shall be calculated for the liquid velocity at the point of gauge attachment.

On pumps submerged in an open sump or open wet well, where there is no inlet piping:

$$h_v = 0$$

$$h_1 = z_L$$

11.6.4.7.5 Total outlet head (h_2)

The total outlet head (h_2) is the algebraic sum of the outlet gauge head ($h_{2'}$), outlet velocity head (h_{v2}), the outlet gauge elevation head ($z_{M2'}$), plus any losses between the pump outlet and outlet pressure tap. The total outlet head is computed for the liquid velocity at the outlet pressure tap, and the elevation head, measured at the pressure gauge:

$$h_2 = h_{2'} + h_{v2} + z_{2'} + h_{j2}$$

When test arrangements require the use of outlet piping and/or a outlet elbow (which are not an integral component of the pump, but are located between the pump and the point of outlet gauge attachment), the gauge head (h_{gd}) reading shall be corrected for the head losses attributable to these piping components.

11.6.4.7.6 Pump total head (H)

This is the measure of the energy per unit mass of liquid, divided by acceleration due to gravity, g , imparted to the liquid by the pump, and is therefore the algebraic difference between the total outlet head and the total inlet head.

a) Where positive head exists at the pump inlet, the total head is the total outlet head minus the total inlet head:

$$H = h_2 - h_1$$

or

$$H = (h_{2'} + h_{v2} + z_{2'} + h_{j2}) - (h_{1'} + h_{v1} + z_{1'} - h_{j1})$$

Combining terms, the general expression for total head is:

$$H = (h_{2'} - h_{1'}) + (h_{v2} - h_{v1}) + (z_{2'} - z_{1'}) + (h_{j2} + h_{j1})$$

b) For pumps submerged in sumps:

$$H = h_{2'} + h_{v2} + z_L + h_{j2}$$

11.6.4.7.7 Atmospheric head (h_{atm})

This is the local atmospheric pressure expressed as head in meters (feet) of liquid pumped.

11.6.4.7.8 Net positive suction head available (NPSHA)

Net positive suction head available (NPSHA) is the absolute inlet total head of liquid absolute at the pump inlet and referred to the NPSH datum, less the absolute vapor pressure of the liquid in head of liquid pumped:

$$NPSHA = h_{1abs} - h_{vp}$$

Where:

$$\begin{aligned} h_{1abs} &= \text{Total inlet head, in meters (feet) absolute} \\ &= h_{1atm} + h_1 \end{aligned}$$

or

$$NPSHA = h_{atm} + h_1 - h_{vp}$$

11.6.4.7.9 Net positive suction head required (NPSHR) (NPSH3)

NPSHR is the minimum NPSH given by the manufacturer/supplier 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).

NPSH3 is defined as the value of NPSHR at which the first-stage total head drops by 3% due to cavitation.

11.6.4.8 Power (P)

Nameplate power for a submersible pump is typically given as motor shaft power. This allows for an easy comparison of approximate pump size to any nonsubmersible pump. Because a submersible pump is built as an integrated unit that includes a motor, it is easy and natural to measure and use input electric power to determine pump performance. Conversely, it is difficult to measure output shaft power as the shaft is inaccessible. This standard uses electrical input power (kW) as the parameter to be measured when overall efficiency or pump power is guaranteed.

11.6.4.8.1 Submersible motor input power (P_{gr})

The net electric input power to the submersible motor is expressed in kilowatts.

$$P_{gr} \text{ in horsepower} = \frac{kW}{0.746}$$

Losses attributable to electrical cabling and any externally powered devices that may be necessary to operate the submersible pump unit shall be included when measuring P_{gr} . Losses attributable to variable-speed drives and nonsinusoidal power supplies are excluded when measuring P_{gr} .

11.6.4.8.2 Pump output power (P_w)

The net hydraulic power imparted to the liquid by the submersible pump is called *water power*.

$$P_w = \rho \times g \times Q \times H$$

When the density of the liquid is 9982 kg/m³ (62.3 lbm/ft³), which is the value for water at a standard temperature of 20 °C (68 °F), then:

$$\text{(Metric units)} \quad P_w = \frac{Q \times H}{0.1022}, \text{ where } P_w \text{ is in kilowatts}$$

$$\text{(US customary units)} \quad P_w = \frac{Q \times H}{3960}, \text{ where } P_w \text{ is in water horsepower}$$

11.6.4.9 Efficiency (η)

Efficiency (η) is the ratio of the output power to input power.

11.6.4.9.1 Combined motor/pump efficiency (η_{gr})

The overall efficiency (η_{gr}) is the ratio of the output hydraulic power to the electric input power. This ratio is also referred to as the *wire-to-water efficiency*. When a submersible pump efficiency guarantee is made in this standard, it is the overall efficiency that is the basis for pump acceptance.

$$\eta_{gr} = \frac{P_w \times 100}{P_{gr}}, \text{ in percent}$$

11.6.5 Performance test

11.6.5.1 General

The purpose of the performance test is to verify the hydraulic, electrical, and mechanical operation of a submersible pump relative to a specified condition point. The performance test serves three purposes. The first is to document the hydraulic performance of the pump. The second is to verify the electrical characteristics of the submersible motor during the performance test. The third is to ensure the mechanical integrity of the pump unit.

The specified and contractually agreed on rated point (duty point), hereafter called the *guarantee point*, shall be evaluated against one acceptance tolerance grade. For a pump performance test, this guarantee point must always specify guaranteed rate of flow (Q_G) and guaranteed pump total head (H_G). Optional guaranteed parameters may include NPSHR and either efficiency or maximum motor input power. When applicable, these optional test guarantee parameters need to be specified for those tests, see respective Test Sections 11.6.6, 11.6.7, 11.6.8, and 11.6.9.

The acceptance grade tolerance applies to the guarantee point only. Other specified duty points, including their tolerances, shall be per separate agreement between the manufacturer and purchaser. If other specified duty points are agreed on, but no tolerance is given for these points, then the default acceptance level for these nonguarantee points shall be grade 3B. A guarantee point can be detailed in a written contract, in a customer-specific pump performance curve, or in similar written and project-specific documentation.

If not otherwise agreed on between the manufacturer and the purchaser, the following shall apply:

- Acceptance grades according to Table 11.6.5.4.3

- Tests shall be carried out on the test stand of the manufacturer's works with clean, cold water by the methods and in the test arrangements specified in this standard
- The pump performance shall be guaranteed between the pump's inlet and outlet
- Pipe and fittings (bends, reducers, and valves) outside of the pump are not a part of the guarantee, unless specifically agreed on prior to the test

11.6.5.2 Test setup

This section contains general guidelines for pump test setup to ensure accurate and repeatable test results. Refer to Figures 11.6.5.2a, 11.6.5.2b, and 11.6.5.2c for typical test arrangements for wet-pit and dry-pit submersible pumps. The manufacturer will select a suitable test setup unless specified by the purchaser.

The pump performance test setup may use, but is not limited to, the following:

- An inlet pressure gauge, compound gauge, or pressure transducer suitable for measuring the complete range of pressures, whether positive or negative
- An inlet throttling device may also be required for NPSHR testing (used for dry-pit submersible pumps only)
- An outlet pipe or hose with a flow throttling device
- A pressure gauge or pressure transducer at the outlet for measuring the complete range of pressures
- A means for measuring the input power, voltage, and current to the pump must be provided and be suitable for measuring the complete range of these parameters, with proper considerations for line power factor
- A means for measuring the temperature of the test liquid
- The diameter of the inlet (dry-pit pumps only) and outlet pipes, where pressure readings are taken, must be determined so that proper velocity head calculations can be made
- Flow-measuring device(s)

The pump performance test shall include monitoring and recording of the following electrical parameters:

- Input frequency
- Number of phases
- Input voltage per phase
- Input current per phase
- Power factor
- Input power (kW)

The measurements of electrical parameters are to be in accordance with IEEE Std 112 Test Method A for three-phase motors and IEEE Std 114 for single-phase motors. However the definition of steady state and the voltage requirements in this document governs. See Section 11.6.5.3 for the definition of steady state and for voltage requirements.

It is not necessary to monitor pump speed since submersible pumps are tested as a combination of pump and motor. Overall pump unit efficiency (wire to water) is used for determining efficiency acceptance (optional guarantee). All instruments shall be calibrated in accordance with Table 11.6.10.1.6.

The NPSHA on the test stand must exceed the NPSHR of the pump, with a sufficient margin throughout the test range, and the pump inlet flow must be uniform and free of swirl and undue disturbances. Refer to ANSI/HI 9.6.1 *Rotodynamic Pumps Guideline for NPSH Margin* for more information on NPSH margin. Pumps tested with inlet piping may require a flow-straightening device placed upstream of the pump inlet.

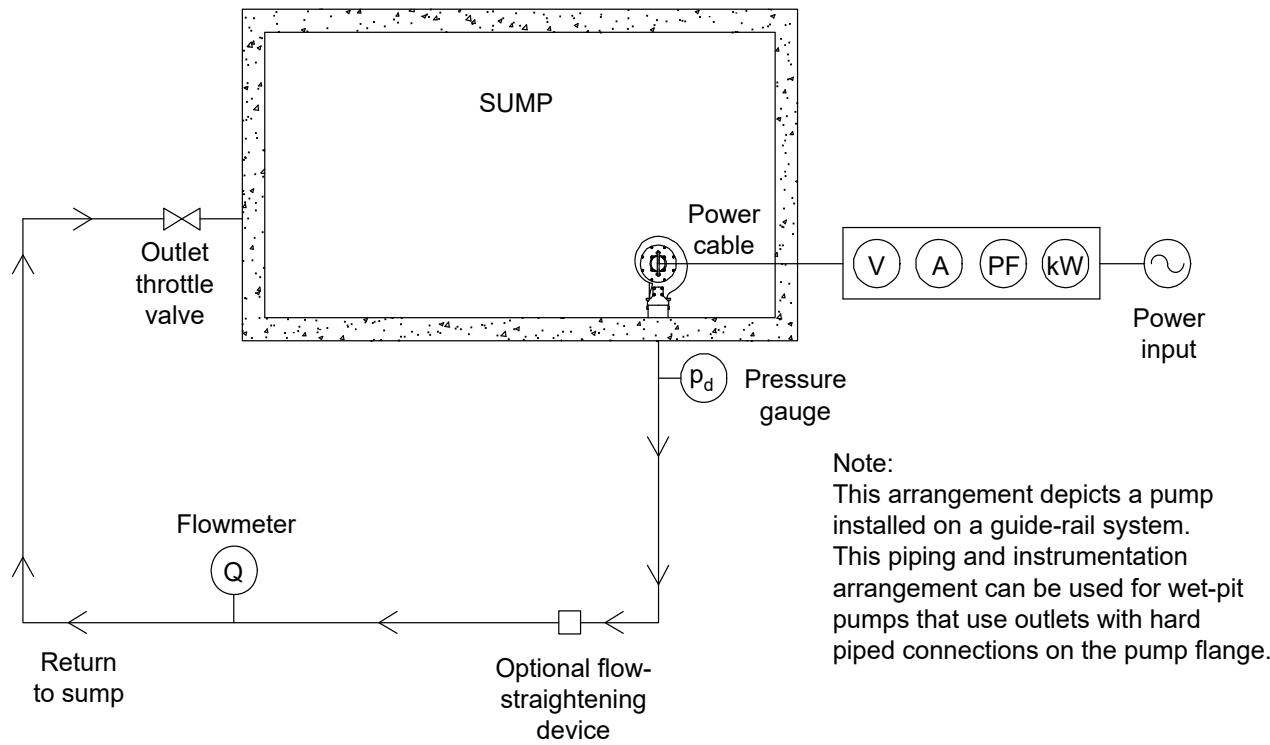
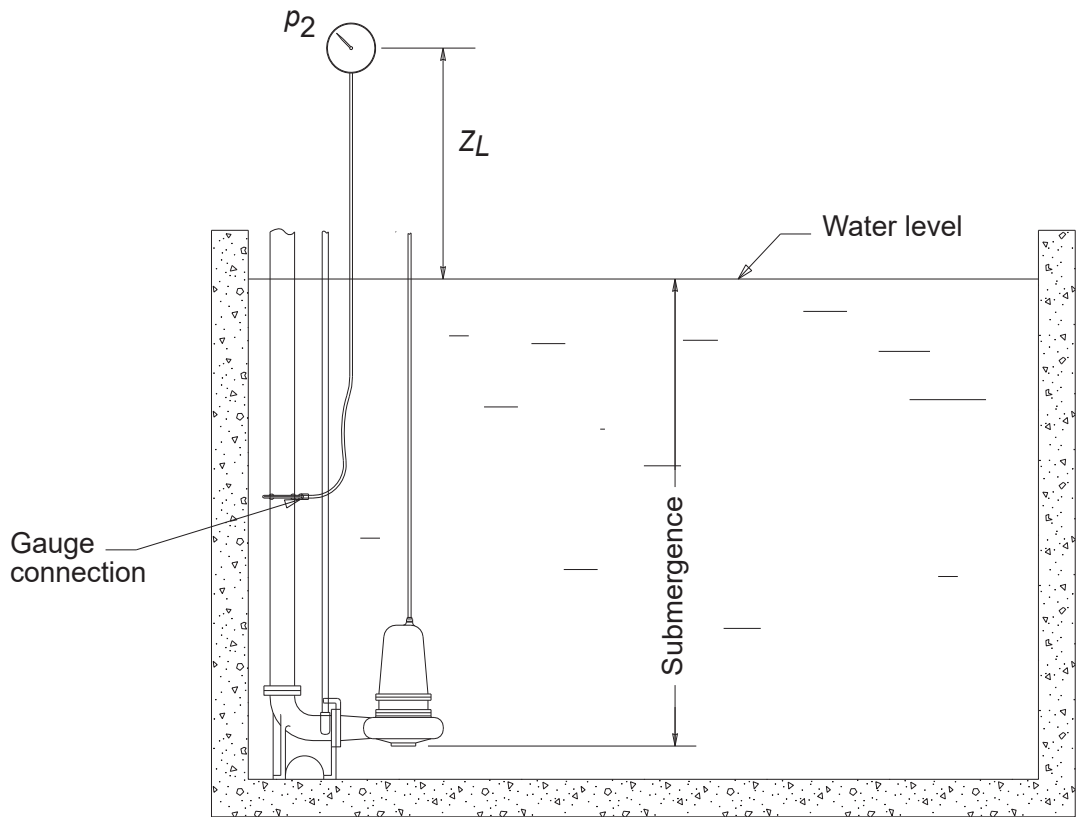


Figure 11.6.5.2a — Sample wet-pit performance test setup



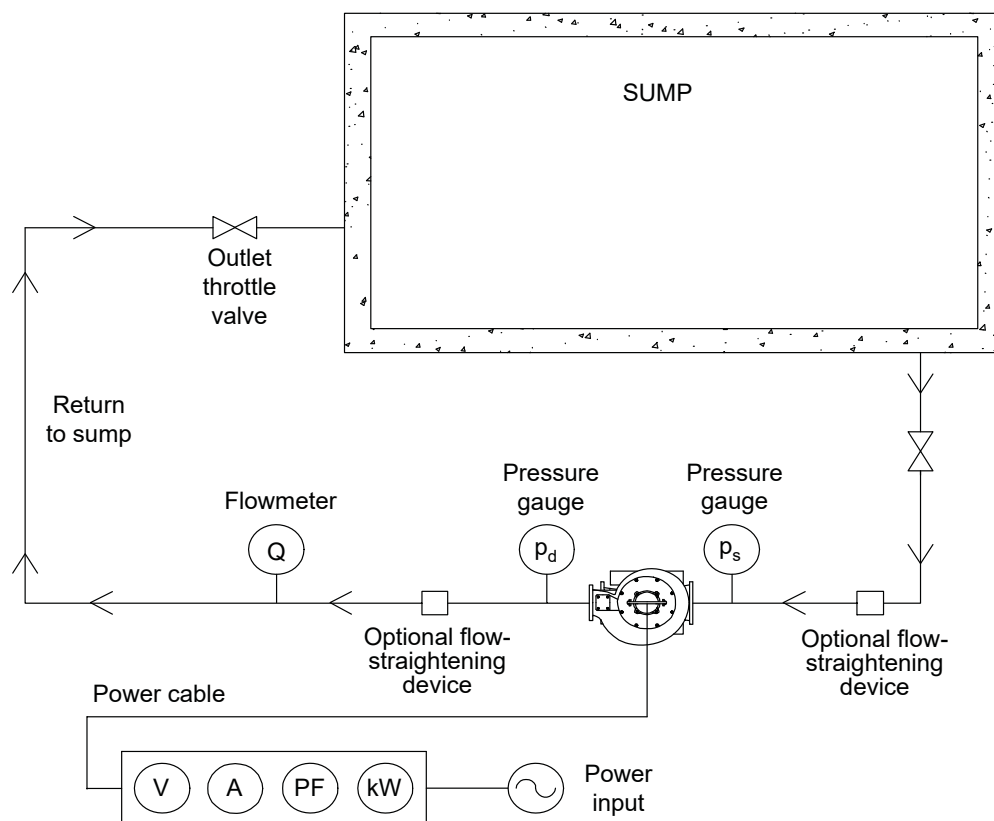


Figure 11.6.5.2c — Sample dry-pit performance test setup

11.6.5.3 Test procedure

The submersible pump shall be installed in a piping arrangement that allows the pump to be tested over a range of flows. Line voltage must be within 5% of the nameplate rating and maximum phase-to-phase voltage unbalance is preferred to be within 1% of average line voltage, but shall not exceed 3% of average line voltage.

The duration of the test shall be sufficient to obtain repeatable results. The pump shall operate at the expected BEP rate of flow for a period of time as determined by the manufacturer to allow the motor and pump temperatures to become stable enough to permit repeatable results.

All measurements shall be made under steady state conditions (no vortexing, no cavitation, and with stabilized readings after any change in flow setting). Steady state is achieved when the mean value of all measured quantities required for the test data point remain constant within the permissible amplitudes of fluctuations defined in Table 11.6.10.1.3 for two consecutive readings taken more than 5 seconds apart. Tests are to 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 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 NPSHR tests.

Data readings shall be taken to allow determination of:

- Total head (H).
- Rate of flow (Q).
- Electrical input power (P_{GR}).

As an alternate to the test setup shown in Figure 11.6.5.2b, dry-pit testing may be accomplished by mounting the pump on a outlet connection inside a test pit (sump), provided that the free surface water level is below the lowest point of the submersible motor. This is to ensure that the motor is operating completely in the ambient air at all times during the test. An inlet elbow fitting and/or a bell mouth may be needed on the pump inlet, as determined by the manufacturer.

11.6.5.4 Acceptance criteria

The measured pump curve will touch or pass through a tolerance band surrounding the guarantee point as defined by the applicable acceptance grade, see Table 11.6.5.4 and Figures 11.6.5.4a and b. A guarantee point shall be defined by a guarantee rate of flow (Q_G) and a guarantee total head (H_G). Optionally, the minimum pump efficiency (η_G) or the maximum pump input power (P_G) may be guaranteed for the guarantee point.

The acceptance tolerance applies to the guarantee point only, not to the entire performance curve. The motor shall not be beyond the limits defined by the manufacturer; the service factor, if defined; or allowable temperature limitations of the motor.

Six pump performance test acceptance grades: 1B, 1E, 1U, 2B, 2U, and 3B, are defined below. Grade 1 is the most stringent, with 1U having a unilateral tolerance band and 1B having a bilateral tolerance band. Grade 1E is also bilateral and is important to those concerned with energy efficiency. Grades 2 and 3 have wider tolerance bands, with 2B and 3B being bilateral and 2U unilateral. Note that all grade 1 tolerances have the same tolerance band-width for flow and head; the same is true for grades 2 and 3. The purchaser and manufacturer can agree to use any grade to judge if a specific pump will meet a guarantee point. If a guarantee point is given, but no acceptance grade is specified, then this standard reverts to a default test acceptance grade, as described in Section 11.6.5.4.3. Guarantee point acceptance grades for pump head, flow, power, and efficiency are provided in Table 11.6.5.4.

Table 11.6.5.4 — Pump test acceptance grades and corresponding tolerance band

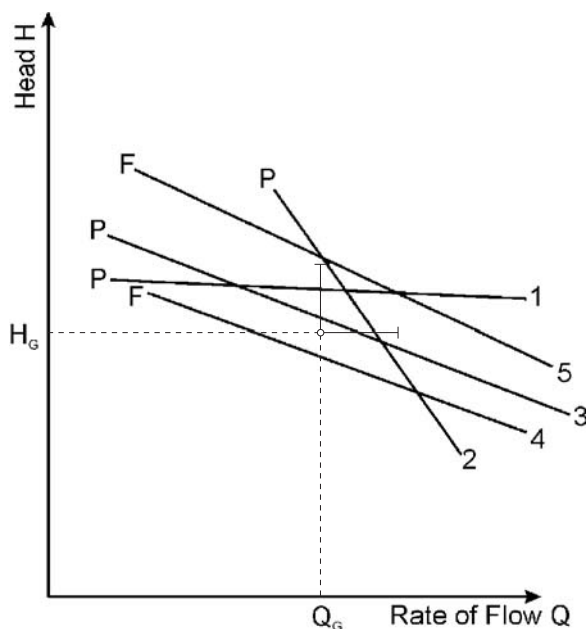
Test parameter	Guarantee requirement	Grade	Grade 1			Grade 2		Grade 3
		Δt_Q	10%			16%		18%
		Δt_H	6%			10%		14%
		Symbol	Acceptance grade					
1B	1E		1U	2B	2U	3B		
Rate of flow	Mandatory	t_Q (%)	± 5%	± 5%	0% to + 10%	± 8%	0% to +16%	± 9%
Total head	Mandatory	t_H (%)	± 3%	± 3%	0% to + 6%	± 5%	0% to +10%	± 7%
Power ^a	Optional (either/or)	t_P (%)	+ 4%	+ 4%	+ 10%	+ 8%	+ 16%	+ 9%
Efficiency ^a		t_η (%)	− 3%	− 0%	− 0%	− 5%	− 5%	− 7%

^a The power and efficiency tolerances are not the result of an exact calculation using the maximum values of a related column. They are instead reflecting real life experience. For grade 1E and 1U, no negative tolerance on efficiency is allowed.

Note: All tolerances are percentages of values guaranteed.

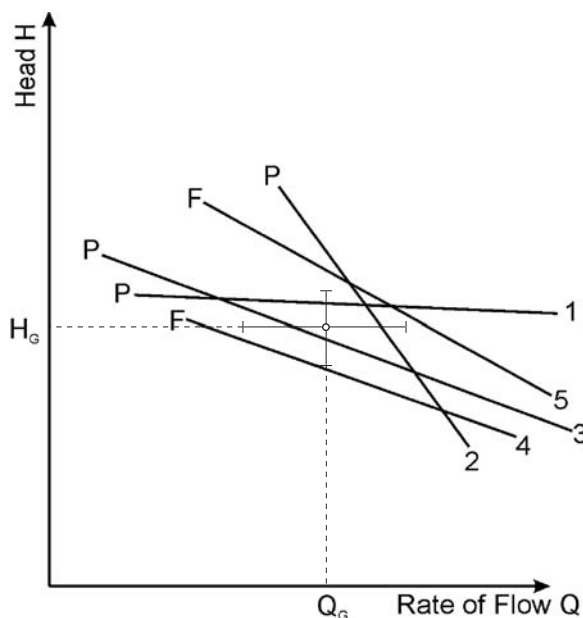
Other specified duty points, including their tolerances, shall be per separate agreement between the manufacturer and purchaser. If other specified duty points are agreed on, but no tolerance is given for these points, then the default acceptance grade for these points shall be grade 3B.

Guarantee point acceptance grades for a pump unit's head, flow, power, and efficiency are provided in Table 11.6.5.4. All tolerances are percentages of values guaranteed.



Curve 1: Crosses the head tolerance band, P = pass
 Curve 2: Crosses the flow tolerance band, P = pass
 Curve 3: Crosses both the head and flow tolerance bands, P = pass
 Curve 4: Does not cross any tolerance band, F = fail
 Curve 5: Does not cross any tolerance band, F = fail

Figure 11.6.5.4a — Unilateral tolerance acceptance example



Curve 1: Crosses the head tolerance band, P = pass
 Curve 2: Crosses the flow tolerance band, P = pass
 Curve 3: Crosses both the head and flow tolerance bands, P = pass
 Curve 4: Does not cross any tolerance band, F = fail
 Curve 5: Does not cross any tolerance band, F = fail

Figure 11.6.5.4b — Bilateral tolerance acceptance example

The purchaser and manufacturer can agree to use any grade to judge if a specific pump will meet a guarantee point. If a guarantee point is given, but no acceptance grade is specified, then this standard reverts to a default test acceptance grade, as described in Section 11.6.5.4.3.

For pumps with a pump power input up to 10 kW (13 hp), but larger than 1 kW (1.3 hp) over the range of operation, the tolerance factors given in Table 11.6.5.4.3 may be too stringent. If not otherwise agreed on between manufacturer and purchaser, the tolerance factors shall be as follows for pumps falling within this range:

rate of flow	$t_Q = \pm 10\%$
pump total head	$t_H = \pm 8\%$

If efficiency is guaranteed, then the tolerance factor on efficiency t_η shall be calculated as follows:

$$t_\eta = -\left[10\left(1 - \frac{P_{gr}}{10}\right) + 7\right] \%, \text{ where } P_{gr} \text{ is the maximum pump input power in kW over the range of operation.}$$

If power is guaranteed, the tolerance factor on power t_P will be calculated as follows:

$$t_P = \sqrt{(7\%)^2 + t_\eta^2}$$

For pumps with pump power input of 1 kW (1.3 hp) and below, special agreements should be made between the parties.

11.6.5.4.1 Evaluation of flow and head

If a test is performed at a different frequency, then each test point has to be recalculated to the rated frequency using the affinity rules as shown in Appendix B.

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

The pump rate of flow tolerance shall be applied to the guarantee rate of flow Q_G , at the guaranteed total head H_G .

The pump total head tolerance shall be applied to the guarantee total head H_G , at the guaranteed rate of flow Q_G .

Acceptance is achieved when either flow or head, or both, are found to be within the applicable tolerance band(s). See Figures 11.6.5.4a and b.

11.6.5.4.2 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 ($[Q-H]/[Q-\eta]$ or $Q-P_{gr}$ curves) has been 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 that 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 11.6.5.4.2 a, b, and c.

11.6.5.4.3 Default test acceptance grades for pump application

If a guarantee point is given, but no acceptance grade is specified, this standard reverts to a default test acceptance grade, as shown in Table 11.6.5.4.3, whereby only flow and head will be guaranteed.

The default test acceptance table specifies the applicable acceptance grade for a pump based on the pump motor's rated 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 is agreed on, and is encouraged to do so. When this is done, it takes precedence over any classification provided by this table, and this paragraph and table shall not be used.

NOTE: Table 11.6.5.4.3 only applies to situations where the purchaser and manufacturer have agreed to a guarantee point, and no test acceptance grade has been specified.

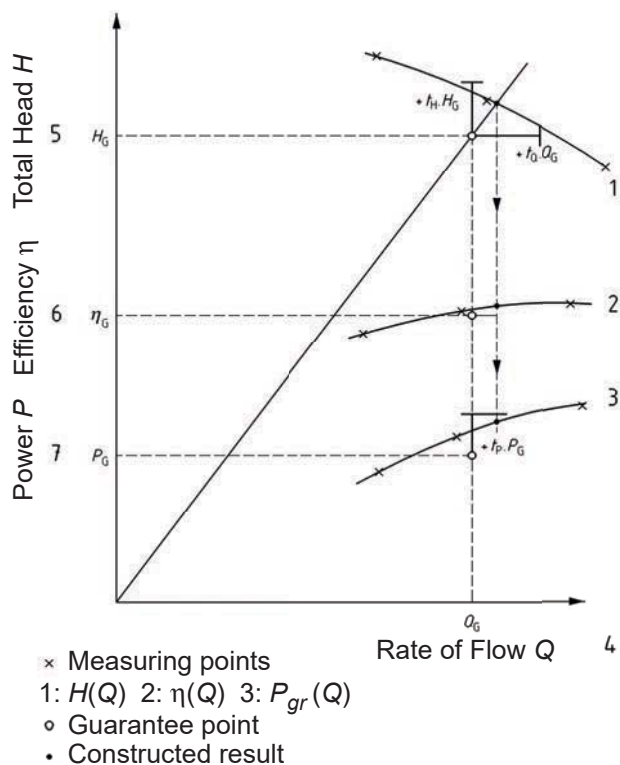


Figure 11.6.5.4.2a — Tolerance field for acceptance grades 1U and 2U

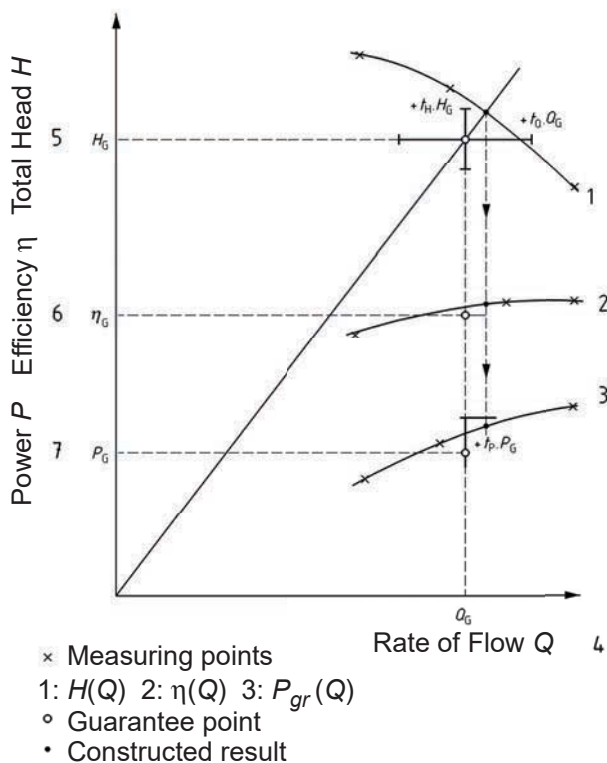


Figure 11.6.5.4.2b — Tolerance field for acceptance grade 1E

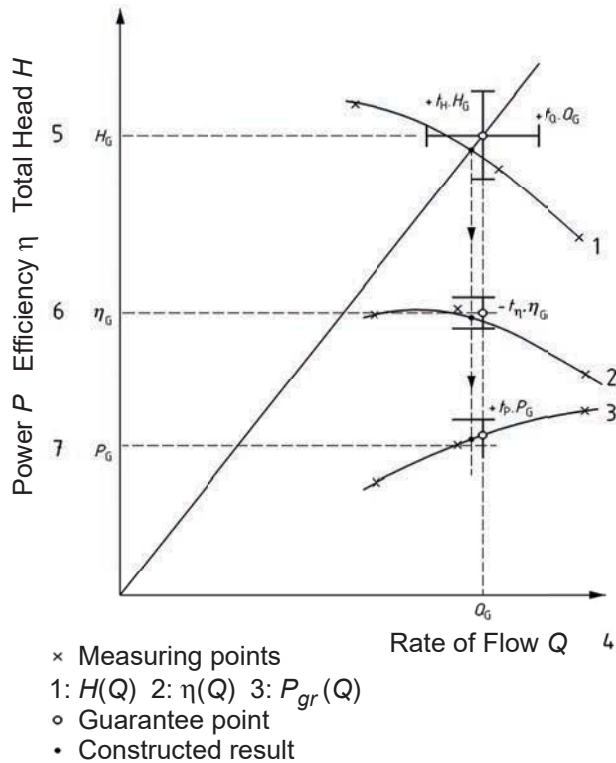


Figure 11.6.5.4.2c — Tolerance field for acceptance grades 1B, 2B, and 3B