ANSI/HI 11.6-2012

American National Standard for

Rotodynamic Submersible Pumps

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

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Hydraulic Institute
6 Campus Drive
First Floor North
Parsippany, New Jersey
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Sponsor
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American National Standard

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Foreword (Not part of Standard)

The Hydraulic Institute's Submersible Pump Committee was charged with updating and reaffirming the 2001 standard. The committee, which consists of major manufacturers and users, has decided to view the submersible pump as an integrated unit from the acceptance test point of view. This change and the adaptation of the same test acceptance grades as HI's new rotodynamic pump test standard and the new ISO 9906 pump test standard constitute the major changes. Minor updates, corrections, and refinements have also been made.

This submersible pump test standard represents a major departure from the previous submersible pump test standard (ANSI/HI 11.6 – 2001) *in that the submersible pump is guaranteed and tested as a complete close-coupled unit.* If pump efficiency or pump power has been guaranteed, then the pump wire-to-water efficiency or electric input power is guaranteed and tested, in addition to the mandatory flow and head test.

This standard does not identify the various sources of losses within the boundary of the submersible pump unit. When a manufacturer offers an efficiency guarantee for a submersible pump, or an input power guarantee, that guarantee encompasses the entire pump unit. This standard specifies how acceptance testing shall be performed and it defines pump acceptance. The overall pump efficiency can be precisely determined by dividing the output hydraulic (useful or water horsepower) power delivered by the pump with the electrical input power delivered to the electric motor. The user of this standard must understand that any attempt to calculate an individual component's efficiency (such as pump, motor, cooling system, seal, or bearing efficiency, to name a few) will only yield data of approximate magnitude and must not be used to judge a submersible pump unit's acceptance.

It is not meaningful to compare pump test results from a submersible pump test based on this standard with test results from tests performed to the old ANSI/HI 11.6 or any other pump test standards. See Appendix A for an explanation of the difference between wire-to-water efficiency and pump hydraulic efficiency. Formulas used to estimate a submersible pump's hydraulic efficiency can also be found in this appendix.

The pump acceptance test grades incorporated into this document are the result of a collaborative effort made by Europump and the Hydraulic Institute.

The work to harmonize ISO and ANSI/HI standards aims at creating a single world pump test standard that is supported by Europump and the Hydraulic Institute.

The points below summarize the major differences between this standard and the current ANSI/HI standard and ISO 9906, respectively:

- Old: Has two test acceptance levels, A and B. New: Has three levels of acceptance: grade 1 with tighter tolerance band that can be applied in three acceptance grades (1U, 1E, 1B); grade 2 with a broader tolerance band can be applied in two acceptance grades (2B, 2U); and grade 3 with even broader tolerance band. Acceptance grades 1U and 2U have no negative tolerance.
- Grade 1U corresponds closely with the old ANSI/HI grade A.
- Grade 1B corresponds closely with the old ANSI/HI grade B.
- The new standard defines industry-specific default test acceptance grades for cases where the user has not defined an acceptance grade.
- Users in all parts of the world will be working with identical technical requirements and test acceptance grades.

Scope

The purpose and aims of the Institute are to promote the continued growth of pump knowledge for the interest of pump users and pump manufacturers and to further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation and other problems of the industry, and to this end, among other things:

a) To develop and publish standards for pumps;

b) To collect and disseminate information of value to its members and to the public;

c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;

d) To increase the amount and to improve the quality of pump service to the public;

e) To support educational and research activities;

f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the buyer and/or the user and to assist the buyer in selecting and obtaining the proper product for a particular need.

2) Use of Hydraulic Institute Standards 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."

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 sent to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding the content of an Institute Standard or an answer provided by the Institute to a question such as indicated above, the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the Appeals Process.

Revisions

The 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.

Units of measurement

Metric units of measurement are used; and corresponding US customary units appear in brackets. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Since 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 standard was achieved by use of the canvass method. The following organizations, recognized as having an interest in the Submersible Pump Test Standard, 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.

4B Engineering
A.W. Chesterton Company
Baldor Electric Company
Bechtel Power Corporation
Black & Veatch (B & V)
Brown and Caldwell
ekwestrel corp
Flowserve Corporation
GIW Industries, Inc.
Healy Engineering, Inc.
ITT - Water & Wastewater
John Anspach Consulting
John Crane Inc.
Kemet Inc.
LVVWD - Las Vegas Valley Water District
Moving Water Industries (MWI)
MWH Americas, Inc.
National Pump Company
Orange County Sanitation District
Patterson Pump Company
Pentair Water - Aurora Pump
Pentair Water – Fairbanks Morse Pump Corporation
Sulzer Pumps (US) Inc.
Wasserman, Horton - Consultant
Weir Floway, Inc.
Weir Minerals North America
Weir Specialty Pumps
Xylem

Submersible Committee Members

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

Chair (2006 - 2011) – Stefan Abelin	ITT - Water & Wastewater
Chair (2011) – Paul Ruzicka	Xylem
Vice-chair – Arnold Sdano	Pentair Water - Fairbanks Morse Corporation

Committee Members	**Company**
Graeme Addie	GIW Industries, Inc.
Tom Angle	Formerly of Weir Specialty Pumps
John Anspach	John Anspach Consulting
Julian Atchia	SJE-Rhombus®
Jason Davis	Pentair Water – Myers
Randal Ferman	ekwestrel corp
Jason Fletcher	Crane Pumps & Systems, Inc.
Michael Mueller	Flowserve Corporation
Mark Rosebraugh	Yeomans Chicago Corporation
Aleksander Roudnev	Weir Minerals North America
Constantino Senon	MWH Americas, Inc.
Jay Shah	Hydro, Inc.
Ernest Sturtz	CDM-Smith
Charles Warren	Metso Minerals Industries, Inc.

Alternate Members	**Company**
Carl Frizzell	CDM-Smith
Gary Leander	Weir Minerals North America

Additional Contributors	**Company**
John Kelly	Yeomans Chicago Corporation
Yuri Khazanov	InCheck Technologies Inc
Terry Rouse	Formerly of Wilo USA LLC

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11.6 Submersible pump tests

11.6.1 Test

11.6.1.1 Scope

This standard applies to customer acceptance testing of submersible pumps driven by induction 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 suction flange to discharge flange and electrical input power. It does not include accessory items, such as discharge elbows, suction fittings, or valves, unless specified by a contractual agreement.

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 discharge types

   4) Chopper/cutter/grinder types

   5) Close-coupled types

   6) Integral electric motor types

b) The following pump types are excluded:

   1) Fractional horsepower (hp)

   2) Nonrotodynamic (PD, PC types)

   3) Line shaft

   4) Mixers and agitators

   5) Deep well pumps/bore-hole pumps

Prior to the test, the buyer 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 original equipment manufacturer (OEM) factory test, or an independent qualified hydraulic laboratory test. Some information is given for replication in a field-test environment.

11.6.1.2 Objective

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 buyer and manufacturer. It is not intended to define a manufacturer's standard practice.

11.6.2 Test types

This standard describes the following tests:

a) 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:

b) Hydrostatic test.

c) Net positive suction head (NPSH) test.

d) Submersible motor integrity test.

e) Vibration test.

11.6.2.1 Routine production tests

Pump manufacturers include routine testing as part of their production process. 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 without any record retention. 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 buyer 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 buyer 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 buyer 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 buyer or buyer'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 buyer can serve many useful functions. There are various ways of witnessing a test.

11.6.2.3.1 Witnessing by the buyer's representative

A representative of the buyer 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 buyer's representative

The buyer or his representative may remotely witness pump performance testing. With a remote camera system, the buyer 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 fresh water corrected to 20 °C (68 °F). 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 Terminology

The following terms are used to designate test parameters or are used in connection with pump testing:

11.6.4.1 Symbols

See Table 11.6.4.1.

Table 11.6.4.1 — Symbols

Symbol	Term	Metric Unit	Abbr.	US Customary Unit	Abbr.	Conversion Factor[a]
A	area	millimeter squared	mm^2	inch squared	in^2	645.2
β	orifice or meter ratio	dimensionless	—	dimensionless	—	1
D	diameter	millimeter	mm	inch	in	25.4
Δ	difference	varies	—	varies	—	varies
η	efficiency	percent	%	percent	%	1
f	frequency	cycle/second (hertz)	$1\ s^{-1}$ (Hz)	cycle/second (hertz)	$1\ s^{-1}$ (Hz)	1
g	gravitational acceleration	meter/second squared	m/s^2	foot/second squared	ft/s^2	0.3048
γ	specific weight	kilonewton/cubic meter	kN/m^3	pound/cubic foot	lb/ft^3	0.1571
h	head	meter	m	foot	ft	0.3048
H	total head	meter	m	foot	ft	0.3048
I	current	ampere	A	ampere	A	1
n	rotational speed	revolution/minute	rpm	revolution/minute	rpm	1
NPSHA	net positive suction head available	meter	m	foot	ft	0.3048
NPSHR	net positive suction head required	meter	m	foot	ft	0.3048
NPSH3	net positive suction head required for 3% head reduction at first stage	meter	m	foot	ft	0.3048
ν	kinematic viscosity	millimeter squared/second	mm^2/s	foot squared/second	ft^2/s	92,900
π	pi = 3.1416	dimensionless	—	dimensionless	—	1
p	pressure	kilopascal	kPa	pound/square inch	psi	6.895
P	power	kilowatt	kW	horsepower	hp	0.746
PF	power factor	cos φ	—	dimensionless	—	1
Q	rate of flow	cubic meter/second	m^3/s	US gallon/minute	gpm	63.09×10^{-1}
ρ	density	kilogram/cubic meter	kg/m^3	pound mass/cubic foot	lbm/ft^3	16.02
R	electrical resistance	ohm	Ω	ohm	Ω	1
s	specific gravity	dimensionless	—	dimensionless	—	1
t	temperature	degree Celsius	°C	degree Fahrenheit	°F	(°F - 32)/1.8
τ	torque	newton-meter	N•m	pound-foot	lb-ft	1.356
U	velocity	meter/second	m/s	foot/second	ft/s	0.3048
V	electrical potential	volt	V	volt	V	1
ω	angular velocity	radian/second	—	radian/second	—	1
y	specific energy	joule/kilogram	J/kg	British thermal unit/pound	Btu/lbm	2326.06
Z	elevation gauge distance above or below datum	meter	m	foot	ft	0.3048

[a] US customary units multiplied by the conversion factor equals the metric units.

11.6.4.2 Subscripts

See Table 11.6.4.2.

Table 11.6.4.2 — Subscripts

Subscript	Term	Subscript	Term
1	test condition or model	max	maximum
2	specific condition or prototype	min	minimum
a	absolute	mot	submersible motor
atm	atmospheric	OA	overall unit
b	barometric	p	submersible pump
d	discharge	s	suction
dvr	driver input	t	theoretical
G	guarantee	v	velocity
g	gauge	vp	vapor pressure
gr	combined pump/motor unit (overall)	w	water

11.6.4.3 Definitions

11.6.4.3.1 Rated (specified) condition point

Rated condition point applies to the flow rate, head, speed, NPSHR, and, optionally, either power or efficiency of the pump as specified by a contractual agreement.

11.6.4.3.2 Best efficiency point (BEP)

The flow rate and head 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.)

11.6.4.3.3 Shut-off head

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.

11.6.4.3.4 Type number *K*

Type number K is a dimensionless quantity calculated at the point of best efficiency, which is defined by the following formula:

$$K = \frac{2\pi n Q'^{0.5}}{(gH')^{0.75}} = \frac{\omega Q'^{0.5}}{(y')^{0.75}}$$

where Q' is the volume rate of flow per eye and H' is the head of the first stage.

Pump type number K may be characterized as pump specific speed expressed in consistent SI units. Specific speed n_s (metric units) is related to K through expression $n_s = n \cdot (Q^{0.5})/(H^{0.75}) = 52.93 \cdot K$, assuming gravitational acceleration g = 9.81 m/s^2. For specific speed Ns (US customary units), the expression is $Ns = 2733.72 \cdot K$.

11.6.4.3.5 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: 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/m^3 or 0.9982 kg/L (62.3 lb/ft^3). 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.

11.6.4.3.6 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.

11.6.4.3.7 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 11.6.4.3.7a.

b) For vertical submersible pumps, it is the plane defined by the largest diameter at the inlet to the impeller vanes, Figure 11.6.4.3.7b.

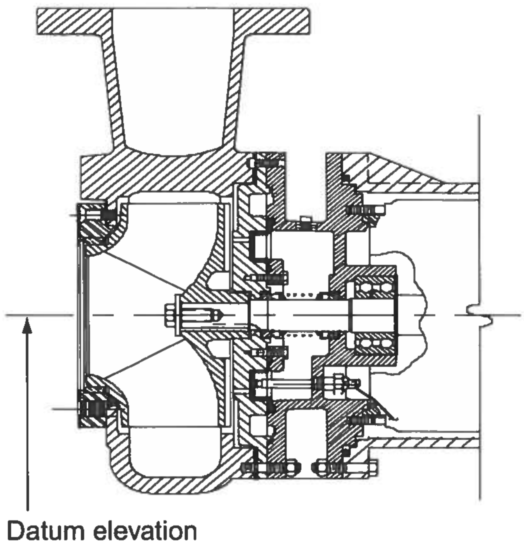


Figure 11.6.4.3.7a — NPSH datum for horizontal pumps

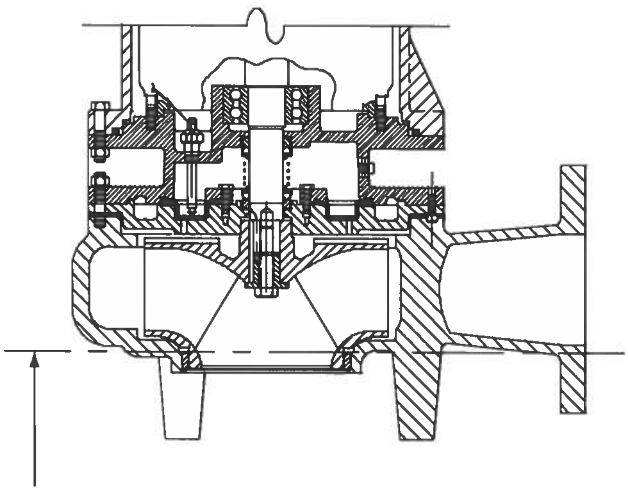


Figure 11.6.4.3.7b — NPSH datum for vertical pumps

11.6.4.3.8 Head (h)

The energy per unit mass of fluid, divided by acceleration due to gravity, g.

11.6.4.3.8.1 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.

(Metric) $h_g = \frac{p_g}{9.81 \times s}$

(US customary units)
$$h_g = \frac{144 \times p_g}{62.3 \times s}$$
$$= \frac{2.31(p_g)}{s}$$
$$= 2.31(p_g)\text{, for water at 68 °F}$$

11.6.4.3.8.2 Velocity head (h_v)

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

$$h_v = \frac{U^2}{2g}$$

11.6.4.3.8.3 Elevation head (Z)

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.

11.6.4.3.8.4 Total suction head (h_s)

The total suction head (h_s) is the algebraic sum of the suction gauge head, the suction velocity head, and the suction elevation head:

$$h_s = h_{gs} + h_{vs} + Z_s$$

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

The velocity head (h_{vs}) 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 suction piping:

$$h_{vs} = 0$$

$$h_s = Z_w$$

Where:

Z_w = Vertical distance of the sump free water surface from datum.

11.6.4.3.8.5 Total discharge head (h_d)

The total discharge head (h_d) is the algebraic sum of the discharge gauge head (h_{gd}), discharge velocity head (h_{vd}), and the discharge elevation head (Z_d). The total discharge head is computed for the liquid velocity at the discharge pressure tap, and the elevation head, measured at the pressure gauge:

$$h_d = h_{gd} + h_{vd} + Z_d$$

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

11.6.4.3.8.6 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 discharge head and the total suction head.

a) Where positive suction head exists, the total head is the total discharge head minus the total suction head:

$$H = h_d - h_s$$

or

$$H = (h_{gd} + h_{vd} + Z_d) - (h_{gs} + h_{vs} + Z_s)$$

Combining terms, the general expression for total head is:

$$H = (h_{gd} - h_{gs}) + (h_{vd} - h_{vs}) + (Z_d - Z_s)$$

b) For pumps submerged in sumps:

$$H = h_{gd} + h_{vd} + Z_d - Z_w$$

11.6.4.3.8.7 Atmospheric head (h_{atm})

Local atmospheric pressure expressed in meters (feet).

11.6.4.3.8.8 Net positive suction head available (NPSHA)

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

$$NPSHA = h_{sa} - h_{vp}$$

Where:

h_{sa} = Total suction head in meters (feet) absolute

$= h_{atm} + h_s$

or

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

11.6.4.3.8.9 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.

11.6.4.3.9 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.

11.6.4.3.9.1 Submersible motor input power (P_{mot})

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

(Metric) $P_{mot} = \text{kW}$

(US customary units) $P_{mot} = \text{hp} = \dfrac{kW}{0.746}$

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_{mot}. Losses attributable to variable-speed drives and nonsinusoidal power supplies are excluded when measuring P_{mot}.

11.6.4.3.9.2 Pump output power (P_w)

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

When the specific weight of the liquid is 0.9982 kg/L (62.3 lb/ft^3), which is the value for water at a standard temperature of 20 °C (68 °F), then:

(Metric) $P_w = \dfrac{Q \times H}{0.1022}$, where P_w is in kilowatts

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

11.6.4.3.10 Efficiency (η)

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

11.6.4.3.10.1 Overall efficiency (η_{OA})

The overall efficiency (η_{OA}) 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.

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

11.6.5 Performance test

11.6.5.1 Purpose and scope

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 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 supplier and buyer. 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 supplier and the buyer, 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 discharge
- 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
- When a number of identical pumps are to be purchased, the number of pumps to be tested shall be determined by the buyer and supplier

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:

a) A suction pressure gauge, compound gauge, or pressure transducer suitable for measuring the complete range of pressures, whether positive or negative. A suction throttling device may also be required for NPSH testing (used for dry-pit submersible pumps only).

b) A discharge pipe or hose with a flow throttling device.

c) A discharge pressure gauge or pressure transducer for measuring the complete range of pressures.

d) 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.

e) A means for measuring the temperature of the test liquid.

f) The diameter of the suction (dry-pit pumps only) and discharge pipes, where pressure readings are taken, must be determined so that proper velocity head calculations can be made.

g) Flow-measuring device(s).

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

a) Input current per phase.

b) Input voltage, phase to phase (or line to neutral for single phase).

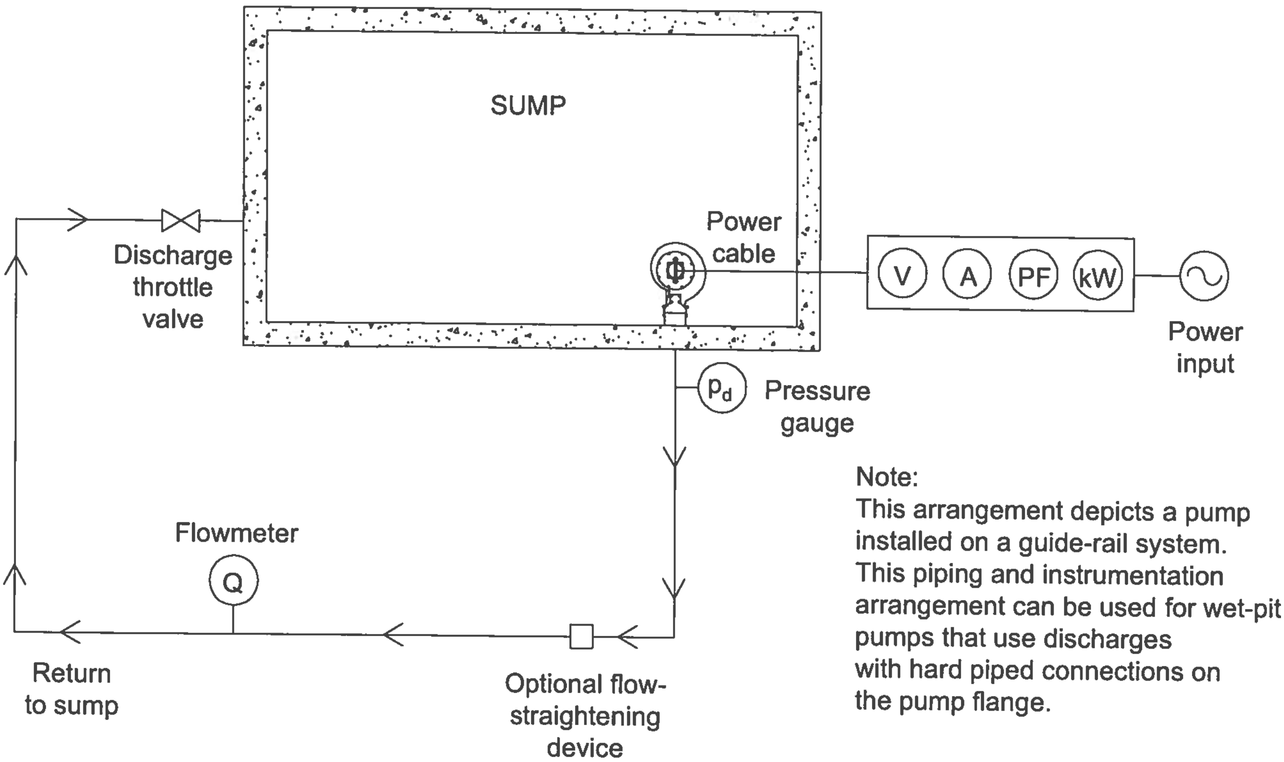
c) Number of phases.

d) Input frequency.

e) Input power (kW).

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 suction flow must be uniform and free of swirl and undue disturbances. Refer to ANSI/HI 9.6.1 for more information on NPSH margin. Pumps tested with suction piping may require a flow-straightening device placed near the pump suction nozzle.



Note:
This arrangement depicts a pump installed on a guide-rail system. This piping and instrumentation arrangement can be used for wet-pit pumps that use discharges with hard piped connections on the pump flange.

Figure 11.6.5.2a — Sample wet-pit performance test setup

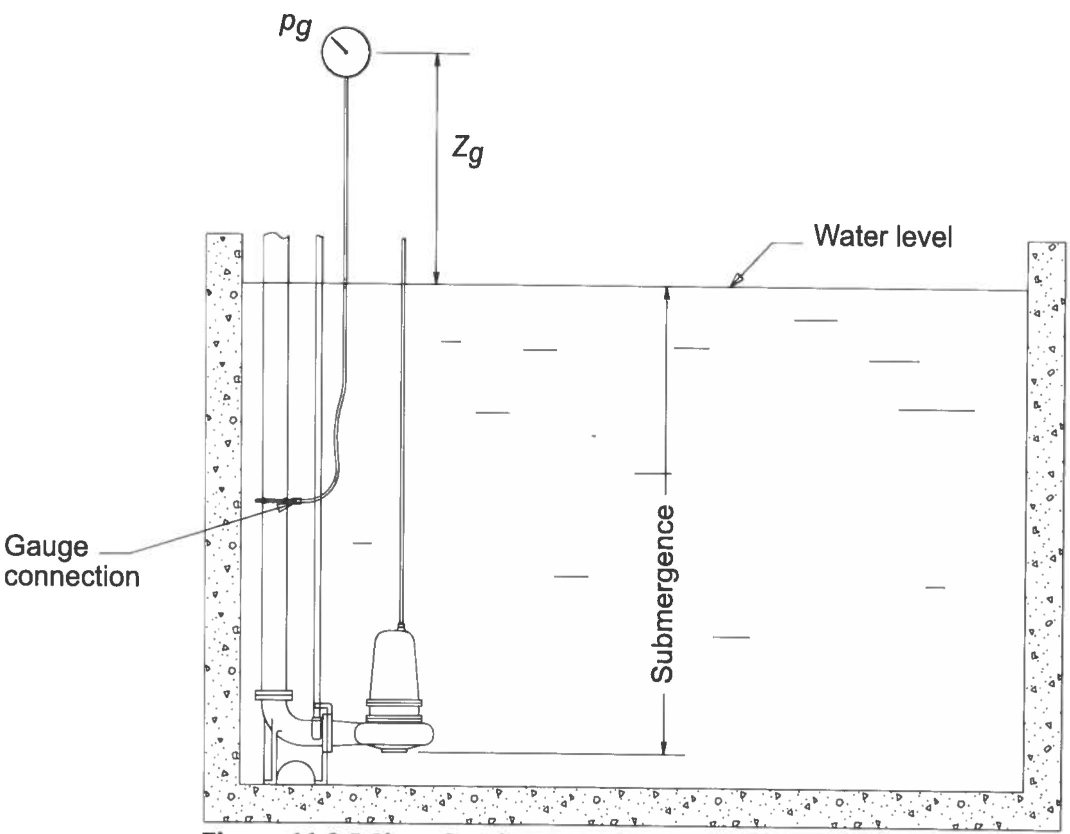


Figure 11.6.5.2b — Suction submergence wet-pit test

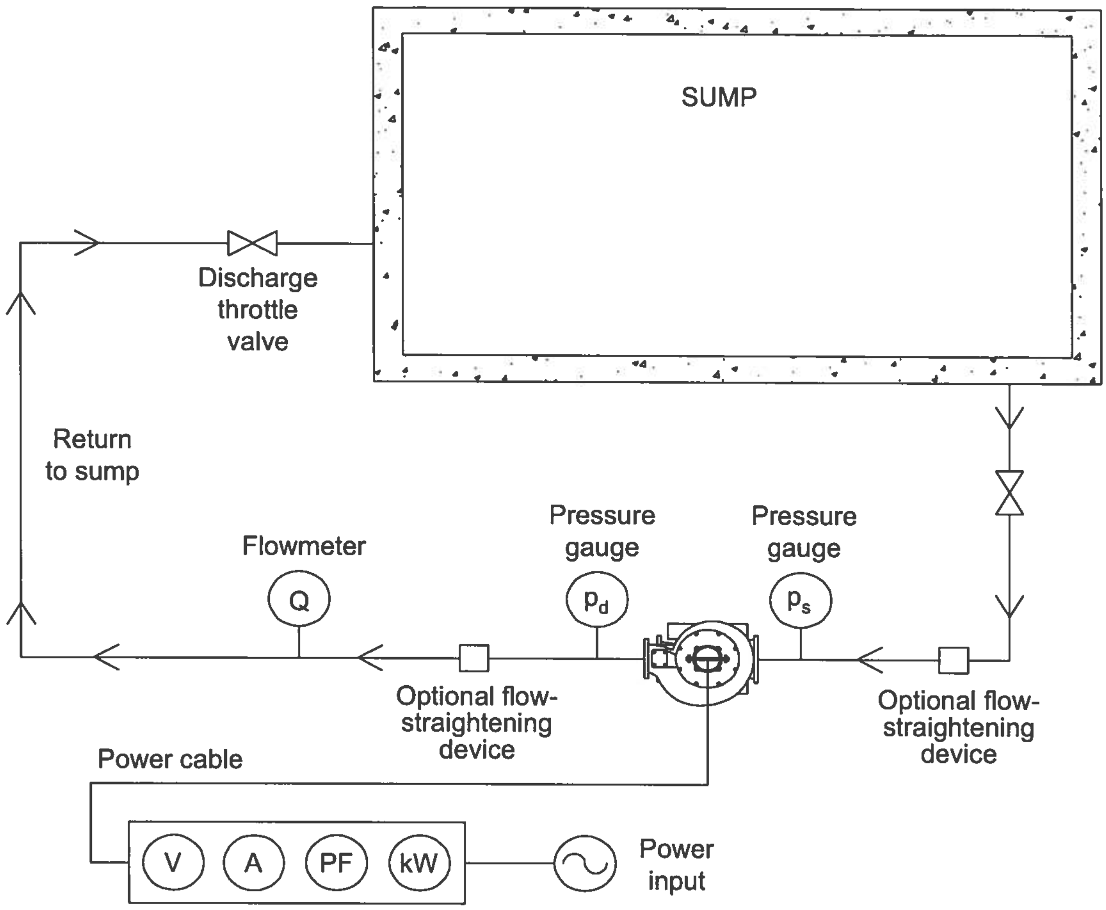


Figure 11.6.5.2c — Sample dry-pit performance test setup

11.6.5.3 Test procedure

The submersible pump shall be installed in a piping arrangement that allows the 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 must not exceed 1% from the average line voltage.

The duration of the test shall be sufficient to obtain repeatable results. All measurements shall be made under steady state conditions. 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 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.

Data readings shall be taken to allow determination of:

a) Total head (H).

b) Rate of flow (Q).

c) Electrical input power (P).

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 discharge 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. A suction elbow fitting and/or a bell mouth may be needed on the pump suction, as determined by the manufacturer.

11.6.5.4 Acceptance criteria

The manufacturer guarantees that, for the guarantee point, 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 service factor or as agreed on when operating at the guarantee point (based on motor nameplate rating).

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 bandwidth for flow and head; the same is true for grades 2 and 3. The buyer and supplier 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 14.6.4. Guarantee point acceptance grades for pump head, flow, power, and efficiency are provided in Table 11.6.5.4.

The buyer and supplier 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 a pump unit's head, flow, power, and efficiency are provided in Table 11.6.5.4. All tolerances are percentages of values guaranteed.

For pumps with motor nameplate power of up to 10 kW (13.5 hp), but larger than 1 kW (1.35 hp), the tolerance factors given in Table 11.6.5.4 are often too stringent. If not otherwise agreed on between manufacturer and buyer, the tolerance factors shall be as follows for pumps falling within this range:

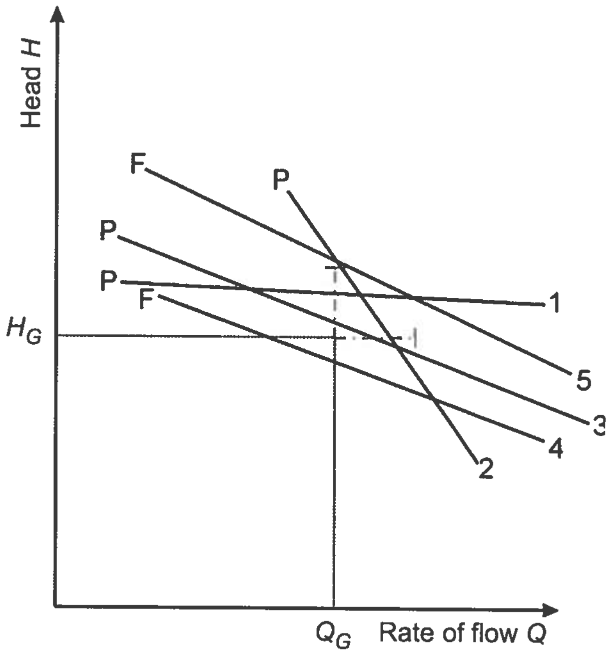
rate of flow	t_Q	$= \pm 10\%$
pump total head	t_H	$= \pm 8\%$

The tolerance factor on efficiency t_η (if guaranteed), shall be calculated as follows:

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

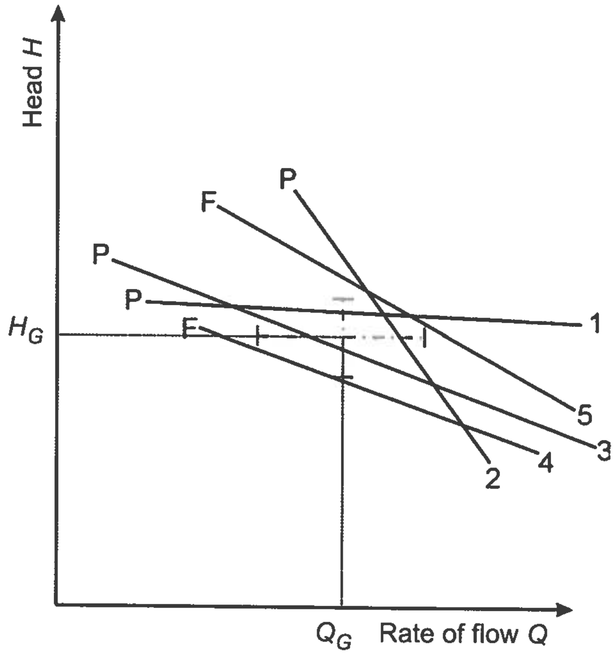
The tolerance factor on input power t_P (if guaranteed), will be calculated using the following formula:

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



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

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.

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 will always give one single point of reference for evaluation, and the line can be seen as a fair approximation of the system curve that the pump will eventually operate against.

Note 2: If power is guaranteed, then the actual upper flow and/or head tolerance limit may be reduced, depending on the power guarantee.

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–η] or Q–P 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 buyer's intended service for the pump. The buyer 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 buyer and supplier have agreed to a guarantee point, and no test acceptance grade has been specified.

11.6.5.5 Records and reports

Complete written or computer records of all test information shall be kept on file and remain available for a minimum of five years by the manufacturer.

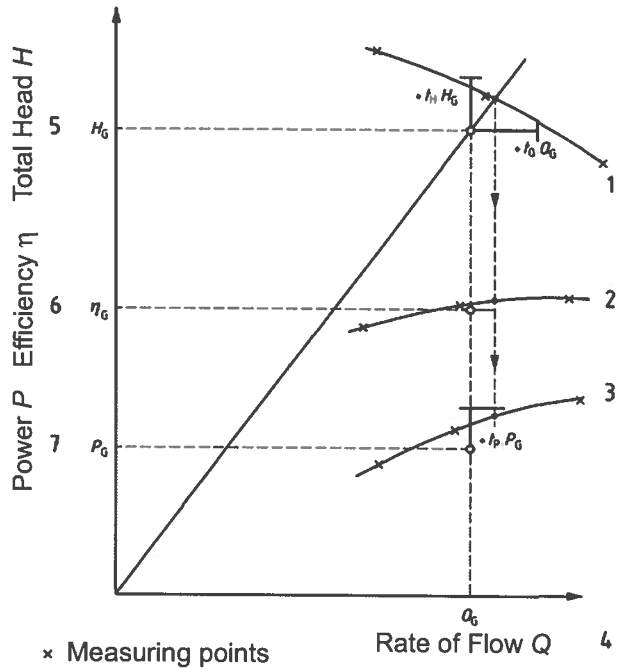
Table 11.6.5.4 — Pump test acceptance grades and corresponding tolerance band

		Grade	Grade 1			Grade 2		Grade 3
		Δt_Q	10%			16%		18%
		Δt_H	6%			10%		14%
Test parameter	Guarantee requirement	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]	Optional (either/or)	t_n (%)	– 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.

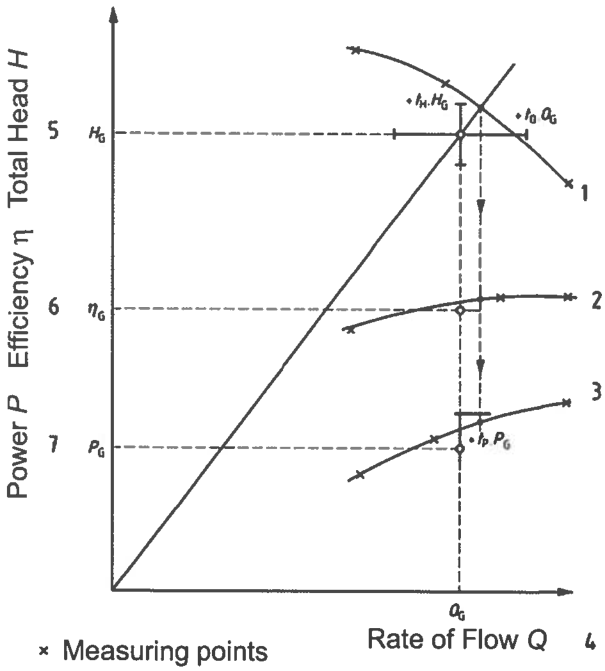
NOTE: All tolerances are percentages of values guaranteed.

Other specified duty points, including their tolerances, shall be per separate agreement between the supplier and buyer. 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.



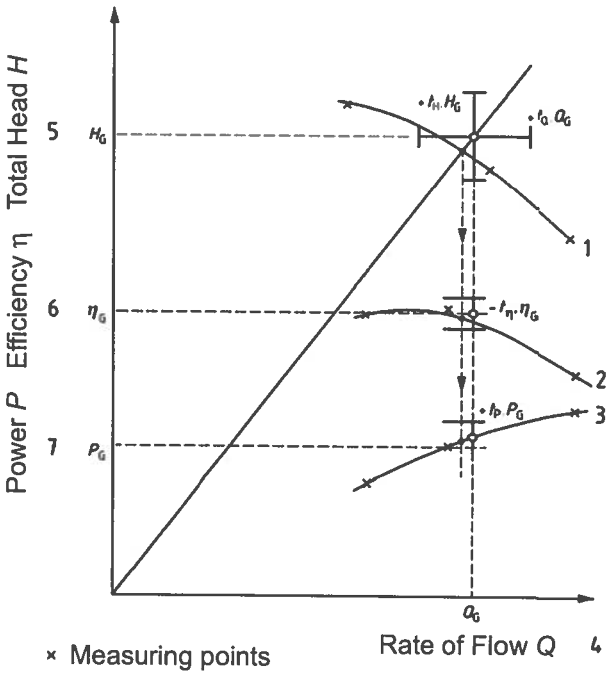
× Measuring points
1: $H(Q)$ 2: $\eta(Q)$ 3: $P(Q)$
∘ Guarantee point
• Constructed result

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



× Measuring points
1: $H(Q)$ 2: $\eta(Q)$ 3: $P(Q)$
∘ Guarantee point
• Constructed result

Figure 11.6.5.4.2b — Tolerance field for acceptance grade 1E



× Measuring points
1: $H(Q)$ 2: $\eta(Q)$ 3: $P(Q)$
∘ Guarantee point
• Constructed result

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

Table 11.6.5.4.3 — Default acceptance grade

Application	Driver rated power	
	>10 to 100 kW (13 to 134 hp)	>100 kW (>134 hp)
Municipal Water	2B	1B
Municipal Wastewater	2B	1B
Electric Power Industry	1B	1B
Cooling Tower	2B	2B
Portable Dewatering	3B	3B
Irrigation	3B	2B
Stormwater	2B	2B
All Other Applications Not Listed	3B	2B

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

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.

11.6.5.5.1 Pretest data requirements

The following data must be documented prior to running the test:

a) Pump model number, size, serial number, impeller identification, horsepower, speed, amperage, and voltage.

b) Identity of test person(s).

Other types of tests may require the following information (as agreed to prior to test):

c) Ambient conditions, such as temperature and barometric pressure.

d) A record of test facility dimensions, such as tank internal dimensions, pipe internal dimensions and lengths, gauge location(s), and liquid level (submergence) relative to datum.

e) Record of auxiliary equipment, such as vibration monitors, temperature sensors, leakage detectors, etc.

11.6.5.5.2 Presenting results

The total head, overall efficiency, and power input are usually plotted as ordinates on the same sheet with flow rate as the abscissa, as shown on Figure 11.6.5.5.2. The test curve shall clearly identify that the plotted efficiency is pump overall efficiency. Test speed correction is typically not done since the pump and motor are a unit, but if it is, it shall be clearly noted on the curve.

11.6.5.5.2.1 Performance curve

Curves of best fit to the measured points will 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, as applicable.

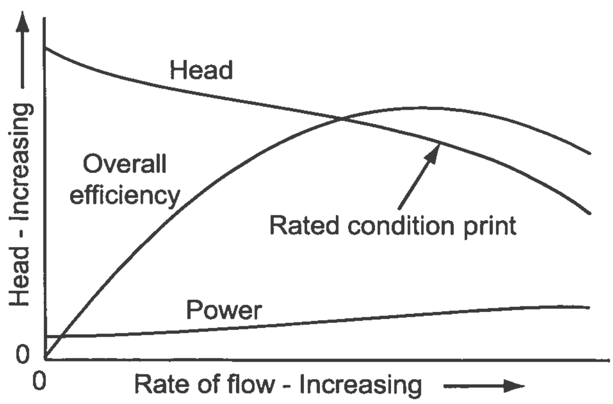


Figure 11.6.5.5.2 — Pump performance (data plotted at test speed)

11.6.5.5.2.2 Reduction of impeller diameter

When it appears from the tests that the characteristics of the pump are higher than the specified characteristics, a reduction of the impeller diameter may be carried out.

The application of this method and the practical conditions for reducing the impeller diameter shall be carried out assuming a constant rotating speed as found on the motor nameplate or be the subject of a mutual agreement.

11.6.5.5.2.3 Determination of reduced impeller diameters

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

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, then no retest will be required unless the reduction in diameter exceeds 5% of the tested diameter.

11.6.6 Hydrostatic test

This section specifies the factory hydrostatic test procedure to be applied to pressure-containing parts of the submersible pumps within the scope of this standard, including any auxiliary equipment making up a pump unit.

Requirements are included for applying a hydrostatic test to separate zones within a pump that are subject to different pressures.

11.6.6.1 Definitions

For purposes of this document, the following definitions apply:

- *Pressure-containing parts* means any part or assembly of parts that is normally subjected to a pressure differential.
- *Rated pressure* is specific to the component or assembly to be tested. If not specified otherwise, it is the maximum allowable working pressure (reference ANSI/HI 1.1 – 1.2) for those pressure-containing parts under test. It can also be specified as the working pressure (reference ANSI/HI 1.1 – 1.2) or a pressure defined by contract.
- *Containment of liquid* means only prevention of its escape through the external surfaces of the pumps or pump components, normally to atmosphere.
- *Item(s) to be tested* means any part, component, subassembly, pump, or pump unit that is to be the subject of hydrostatic pressure test.

NOTE: A mechanical seal assembled into a pump or into a separate subassembly, together with an end plate to connect the stationary elements of the seal to the stationary parts of the pump, will not be considered an item to be tested but may be subjected to the test pressure.

11.6.6.2 General

All pressure-containing items shall be hydrostatically pressure tested. The purpose of this hydrostatic test is to demonstrate the absence of leakage through pressure-containing walls of any item under test and from the joints formed by an assembly of items under test, by imposing a defined pressure in excess of the rated pressure for which the item is supplied. See Figure 11.6.6.4.

Pressure-containing chambers that function independently shall be tested separately without pressure being applied to any adjacent chamber.

11.6.6.3 Timing of the test

The manufacturer shall allow sufficient time during manufacture for the test and examination of all items within the scope of this standard. The test may be carried out on an individual item or on a subassembly as a group of items. Normally, the hydrostatic test is carried out:

- After completion of machining
- Prior to the application of coatings, insulation, and overlays (protection of raw parts against rust shall not be considered as a coating)
- Following nondestructive testing, or after special leak tests below a gauge pressure of 0.5 bar

11.6.6.4 Preparation for testing

Items to be subjected to test shall be free from grease, oil, and other contaminants, and any cleaner used shall be compatible with the materials of manufacture of the pump, its auxiliaries, and its intended use.

The items to be tested are to be assembled for the test and all openings are to be sealed off by appropriate means, which may include blind flanges, plugs, closures, and tension rings. Care shall be taken in selecting the closure arrangements so as not to impose forces capable of distorting the items under test nor of otherwise obscuring any leak. Through-bolting shall not be used unless it is part of the construction of the item being tested.

The item to be tested and the gauge lines are to be vented and filled completely with the test liquid. Provisions shall be made to vent all the air at the high points on the item. A typical submersible pump hydrostatic test setup is shown in Figure 11.6.6.4.

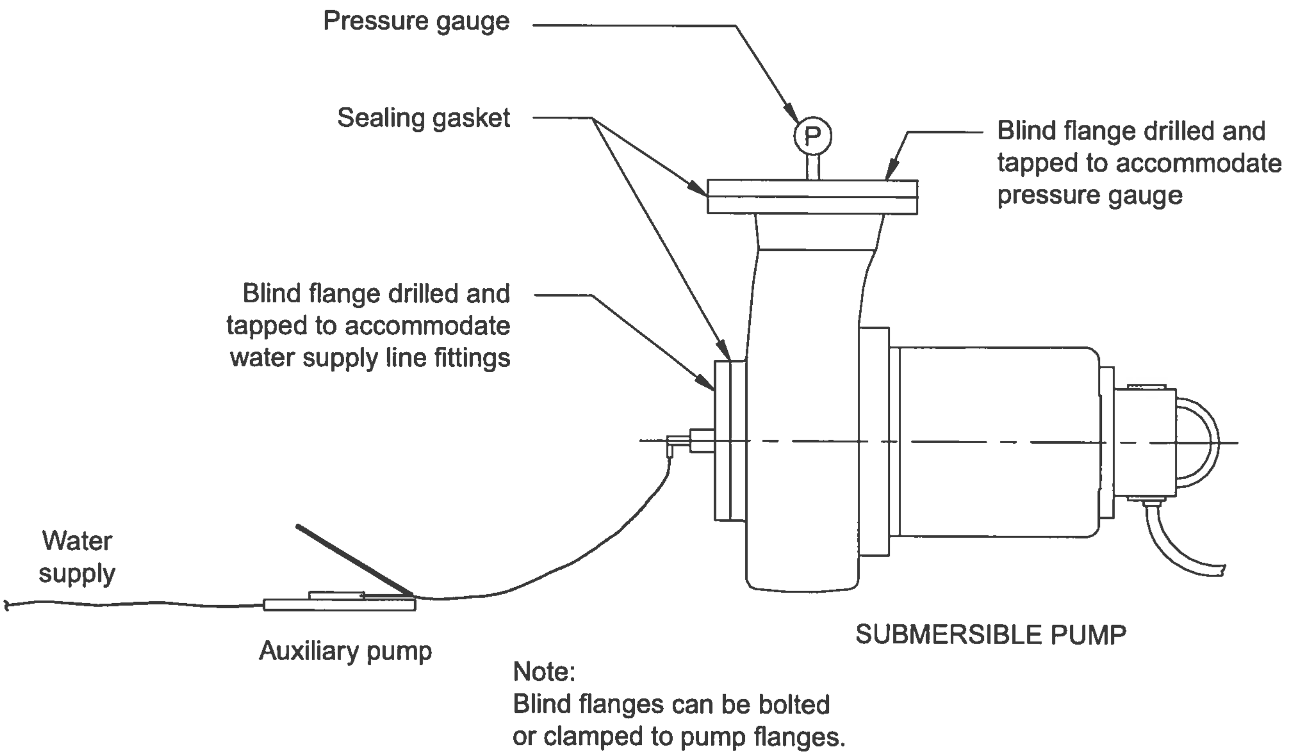


Figure 11.6.6.4 — Hydrostatic pressure test setup

Wherever feasible the mating parts and fasteners used in any assembly shall be those to be used in the delivered pump, otherwise reasons for deviating from this requirement shall be recorded.

11.6.6.5 Test liquid

The hydrostatic test shall be performed using clean water at ambient temperature, with the addition of corrosion preventatives and organic growth inhibitors where necessary. If the properties of the material impose a limit on the test temperature, which affects the test procedure, then this is to be noted on the test record.

11.6.6.6 Test pressure

The hydrostatic test pressure relates to the rated discharge pressure at ambient temperature of the items to be tested.

The hydrostatic test pressure shall be calculated from the formula:

$$P_{test} = K_1 \times K_2 \times P_{rated}$$

Where:

P_{test} = the hydrostatic test pressure

P_{rated} = the rated discharge pressure at operating temperature

K_1 = a factor whose value shall be determined by the pump specification, but shall not be less than 1.3, except for thermoset parts

K_2 = a factor whose value shall be determined by the material strength

$$= \frac{\text{allowable stress at ambient temperature}}{\text{allowable stress at operating temperature}}$$

Due to the irreversible damage that can occur to the reinforcement of thermoset parts that are put under excessive pressure, hydrostatic test pressure shall be 1.1 times the maximum design pressure. The manufacturer should be able to verify through test records that adequate sampling was done to prove that the parts can sustain full hydrostatic test pressure calculated using the above formula. When a full hydrostatic test pressure on thermoset parts is requested, all parties should agree to the consequences of possible irreversible damage.

11.6.6.7 Test procedure

At the start of the hydrostatic pressure test the external walls of the item to be tested shall be dry.

Prior to applying the test pressure, the arrangements used to seal the chambers to be pressurized shall be inspected for proper bolting and enclosure.

The hydrostatic pressure shall be steadily increased in a controlled manner until the test pressure is achieved. The test pressure shall be held essentially constant for the full duration of the test period. Throughout this procedure continuous observation shall be maintained to detect any leakage.

The test pressure shall be maintained for a sufficient time to allow the item being tested to be completely inspected. This will normally be not less than 60 seconds.

Longer time periods will be necessary for large, heavy castings, and for those made from forgings or welded construction. These longer periods shall be determined by the pump specification or as otherwise set out in Table 11.6.6.7 below.

Table 11.6.6.7 — Longer test periods

Items to be tested	Test duration, in minutes
Pumps:	
Pumps rated above 2500 kPa (360 psi)	30
Pumps rated above 1000 kPa (145 psi) and not above 2500 kPa (360 psi)	10
Pumps rated up to 1000 kPa (145 psi)	5
Auxiliary passages:	
Cooling jackets	10

11.6.6.8 Acceptance criteria

The integrity of the item under test is to be regarded as satisfactory if during the test period there are no visible signs of leakage.

Leakage through temporary gaskets or through internal test partitions required for segmental hydrostatic testing is acceptable.

11.6.6.9 Repairs

If the acceptance criteria stated in Section 11.6.6.8 are not met, the cause shall be identified and the manufacturer shall either safely dispose of the item tested or apply suitable corrections. After correction, the hydrostatic test shall be repeated. The methods of correction and any changes to the design shall be recorded.

11.6.6.10 Test records and reports

The manufacturer shall keep a record of the test and its results for a minimum of five years. The record shall contain:

a) Identification of the item tested.

b) Details of the test, including the liquid used, the test pressure, and the test result.

c) Any corrective actions applied, including changes to the design.

d) Other information required by this document to be recorded.

11.6.6.11 Test certificate

If required by the buyer, a test certificate shall be made available. The test certificate shall certify that the hydrostatic test was carried out in accordance with this standard, and that the test item met the acceptance criteria.

11.6.6.12 Test report

If required by the buyer, the manufacturer/supplier shall supply a report of the hydrostatic test, which shall indicate at least the following information:

a) Identification of the pump.

b) Type and characterizing data (e.g., dimensions) of the item tested.

c) List of any modifications made to the design.

d) Applicable test, quality, and supply standards.

e) Type of test liquid.

f) Test pressure.

g) Test duration.

h) Result of the test.

i) Date when the test was carried out.

j) Signature of the inspector or test controller.

Each item subject to a test report shall be marked uniquely for identification.

In the case of a witnessed test, the acceptance of an item or its release for further manufacturing steps shall be confirmed by the signature of the buyer's representative.

11.6.7 Net positive suction head (NPSH) test

NPSH testing of finished products is complex, time-consuming, and requires a different test setup than the commonly performed pump performance testing (pump, power, and efficiency testing).

Manufacturers of submersible pumps determine the NPSHR by prototype testing, model testing, and calculations using empirical formulas.

Discuss pump minimum submergence and NPSH requirements with the pump manufacturer to determine if an NPSHR test may be desirable.

11.6.7.1 Objective

Determine the NPSH3 for the pump at one or several flows.

11.6.7.2 Test setup

Four typical arrangements are shown for determining the NPSH3 characteristics of pumps. The NPSH is established through the datum elevation of the impeller (refer to Figure 11.6.4.3.7b).

For all arrangements, the flow towards the pump must be uniform and free of undue disturbances. A pump tested with suction piping may require a flow-straightening device before entering the pump. Arrangements for cooling or heating the liquid in the loop may be needed to maintain the required temperature.

In the first arrangement, Figure 11.6.7.2a, the pump is supplied from a constant-level supply through a throttle valve followed by a section of pipe containing straightening vanes or a minimum of seven diameters of straight pipe to straighten flow. This arrangement decreases the turbulence produced by the throttle valve and makes possible a more accurate reading of suction pressure at the pump inlet.

This simple arrangement usually is satisfactory for NPSH greater than 3 m (10 ft), although the turbulence at the throttle valve tends to accelerate the release of dissolved air or gas from the liquid, which takes place as the pressure on the liquid is reduced. A test made with this arrangement usually indicates higher NPSHR than that which can be expected with deaerated liquid.

In the second arrangement, Figure 11.6.7.2b, the pump is supplied from a sump in which the liquid level can be varied to establish the desired NPSHR. Care should be taken to prevent entrained air or vortexing as the liquid level is varied. The priming connection should be installed above the eye of the impeller, either in the discharge pipe or on the pump.

In the third arrangement, Figure 11.6.7.2c, the pump is supplied from a closed tank in which the level is held constant. The NPSHA is adjusted by either varying the air or gas pressure over the liquid, varying the temperature of the liquid, or both.

This third arrangement tends to strip the liquid of dissolved air or gas. It gives a more accurate measurement of the pump performance uninfluenced by the release of air or gas. It is also acceptable to test with a closed loop without the closed tank on the suction side.

In the fourth arrangement, Figure 11.6.7.2d, the entire pump is mounted in an enclosed tank to allow the NPSH testing to be done without the suction piping connection as shown in Figure 11.6.7.2a. The testing for this arrangement is normally done at a constant flow rate while varying the NPSHA by adjusting the air pressure over the liquid in the suction tank. As is the case with the third arrangement, this test setup tends to strip the liquid of dissolved air and yields a more accurate measurement of the pump NPSH characteristics.

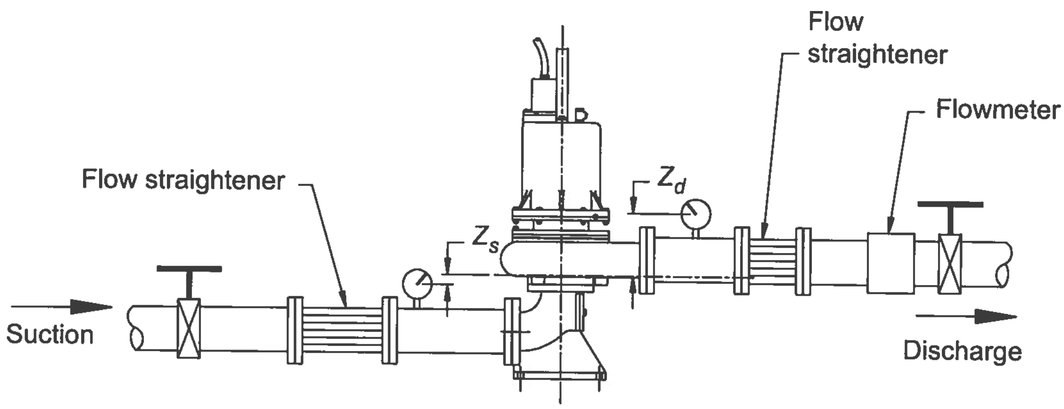


Figure 11.6.7.2a — Suction throttling NPSH test setup

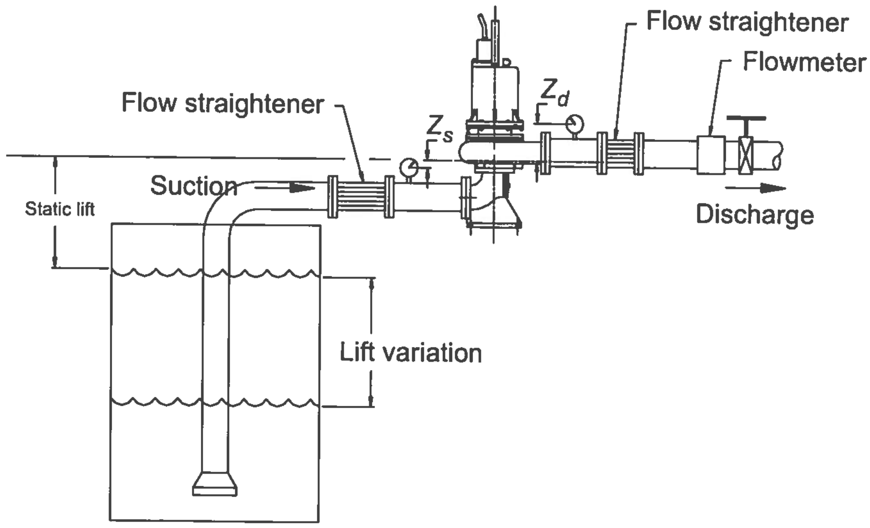


Figure 11.6.7.2b — Variable-lift NPSH test setup

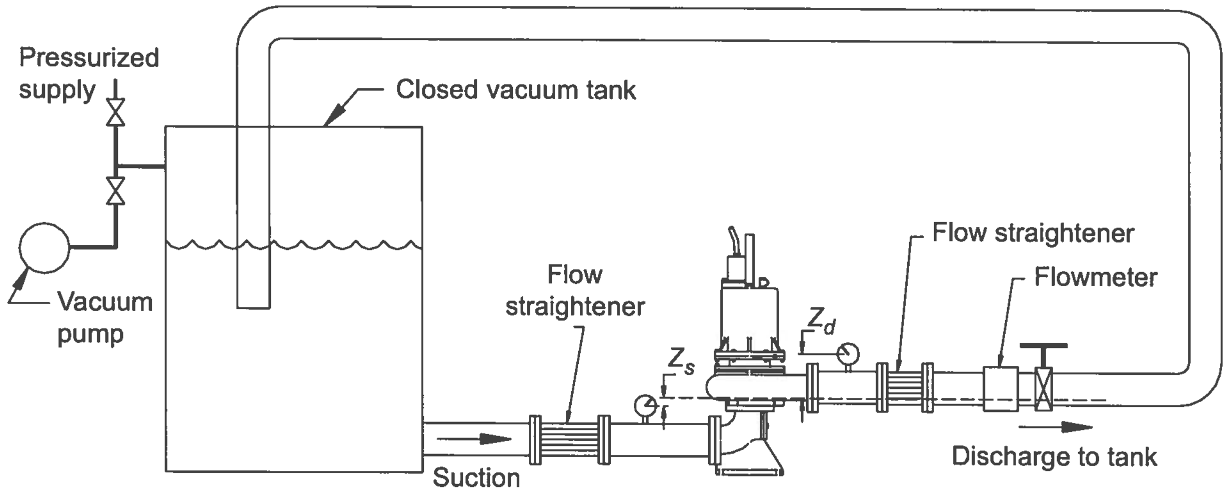


Figure 11.6.7.2c — Closed-loop, dry-pit NPSH test setup

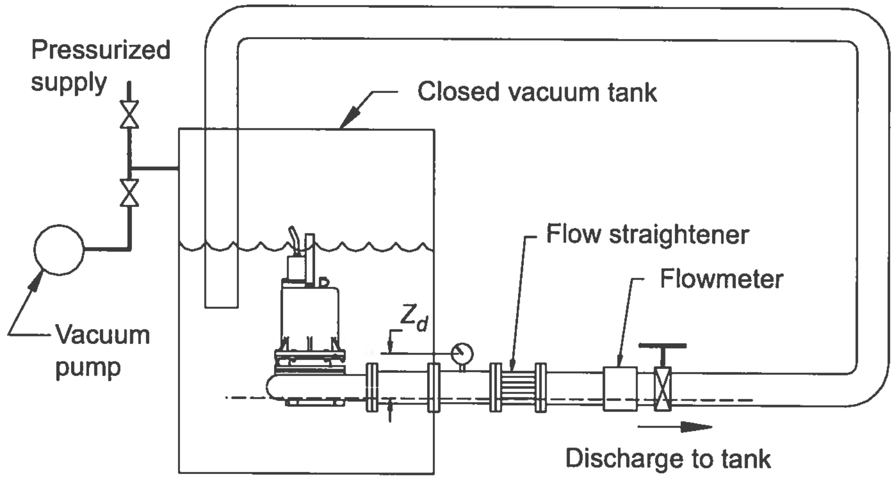


Figure 11.6.7.2d — Closed-loop, wet-pit NPSH test setup

In each of these arrangements, water must be used as the test liquid. Taking the following precautions will minimize aeration:

a) No cascading return flow outlets.

b) Reservoir sized for long retention time to allow air to escape.

c) Inlet line properly located to prevent vortexing.

d) Reservoir baffles to isolate inlet from return line.

e) Tight pipe joints to guard against air leakage into the system.

11.6.7.3 Test procedure

The cavitation characteristics of a pump can be determined by one of the following procedures:

Using one of the test arrangements shown (Figures 11.6.7.2a through 11.6.7.2d), the pump is run at constant flow rate and speed with the suction condition varied to produce cavitation. Plots of head must be made for various NPSHA values.

As NPSHA is reduced, a point is reached where the curves break away from a straight-line trend, indicating a condition under which the performance of the pump may be impaired. The degree of impairment will depend on the specific speed, size, and service of the pump. Figure 11.6.7.3a shows results typical of a test for NPSH at rates of flow both greater and less than the guaranteed point. The 3% drop in head is the standard used to determine NPSH3.

Another technique for determining the NPSH characteristics is to hold the speed and suction head (h_s) constant and to vary the flow rate. For any given suction head, the pump head may be plotted against flow rate. A series of such tests will result in a family of curves, as shown in Figure 11.6.7.3b. Where the curve for any suction head (h_s) breaks away from the envelope by 3%, NPSH3 is established.

It is also possible to measure NPSHR by variable flow rate and variable suction pressure. The point at highest flow rate is obtained by fully opened suction and discharge valves, similar to previous procedures. By throttling with the suction valve, Q and NPSHA are reduced until the line of 3% H-drop is crossed. After that the starting point for the next cavitation drop on the characteristic is set with the discharge valve. Typical results for this type of test are similar to what is shown in Figure 11.6.7.3b.

When it is impractical to conduct a test to the above criteria on large pumps because of size, flow rate, or facility NPSHA, a model test may be used to determine NPSHR characteristics. The relationship between model results and predicted full-size characteristics is described in Section 11.6.11, Model tests.

Accurate determination of the 3% head drop point requires careful control of all factors that influence the operation of the pump. A minimum of five test points bracketing the point of change must be taken, and the data plotted to determine where the 3% head drop occurred.

The NPSHA value required to properly establish the noncavitating performance of a pump should be determined from prior full-scale or model tests of the specific pump in question. If no such prior test results are available, then a recommended NPSHA minimum margin of 1.0 m (3.3 ft) above the predicted NPSHR should be applied unless

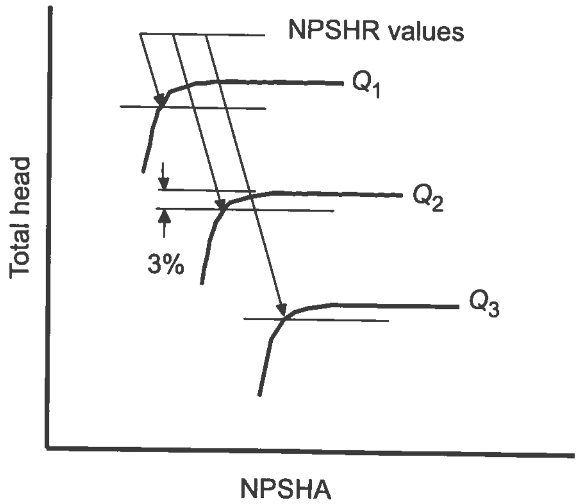


Figure 11.6.7.3a — NPSH test with flow rate held constant

otherwise recommended by the manufacturer. Refer to the latest edition of ANSI/HI 9.6.1 for more information on NPSH margin.

An accurate temperature measurement usually is sufficient to establish the vapor pressure, but the degree of aeration of the water may have a considerable influence on performance. Consistent results are more readily obtained when the water is deaerated.

Cases may arise in which the limitations of the factory test facilities preclude the securing of sufficient NPSHA to produce the installation NPSHA. In such cases, the NPSHR may be obtained by an increase in the pump speed with a corresponding increase in pumping head and flow rate instead of by a reduction in NPSHA, provided that the motor can handle the increased load. Please refer to Appendix B for details on using the affinity rules as they relate to NPSHR testing.

11.6.7.4 Acceptance criteria

Any change in performance at a given flow rate, or change in sound or vibration, may be an indication of cavitation. However, due to the difficulty in determining just when the change starts, a drop in head of 3% is the acceptance criteria when determining NPSHR. The pump meets the NPSHR guarantee if the measured NPSHR value is less than or equal to the NPSHR guaranteed by the manufacturer, i.e., there is no positive tolerance factor allowed for the guaranteed NPSHR value.

11.6.7.5 Records

Complete written or computer records must be kept on file by the test facility and be available to the buyer for five years. This record must include:

a) Identification of tested pump by model, size, and serial number.

b) Test-stand NPSHA, measured NPSHR.

c) Date of test.

d) Identity of test person(s).

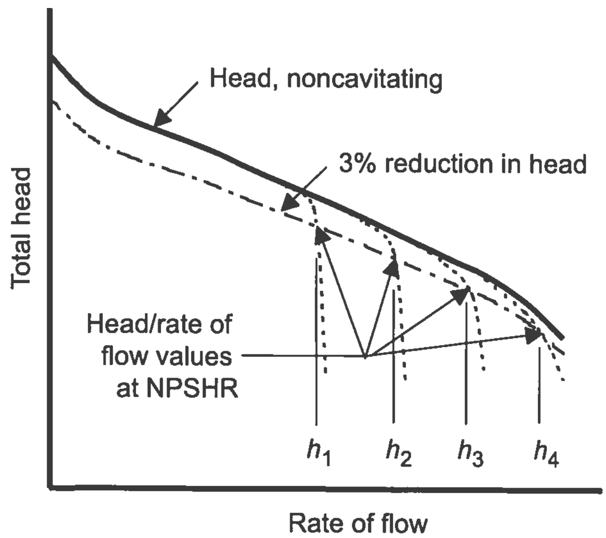


Figure 11.6.7.3b — NPSH test with suction head held constant

11.6.8 Submersible motor integrity tests

11.6.8.1 Objective

The selected tests are designed to verify the sealing and electrical integrity of a submersible motor.

11.6.8.2 Test setups and procedures

Both a mechanical and an electrical integrity test shall be performed to comply with Section 11.6.8.

One or more of the following methods can be used to verify the mechanical integrity of the unit:

a) Housing pressure check.

b) Vacuum check.

c) Electrical megohmmeter insulation resistance check (must be done after being run fully submerged).

One or more of the following methods can be used to verify the electrical integrity of the unit:

a) Electrical continuity and winding resistance test.

b) Electrical megohmmeter insulation resistance check.

c) Hi-pot electrical test (Note: this test will degrade the insulation and should be specified with caution).

11.6.8.2.1 Housing pressure test

Pressurizing the housing(s) with a limited amount of air pressure can check the sealing system of a typical submersible motor assembly. Attach a pressure "T" assembly to the housing (see Figure 11.6.8.2.1). Add up to 100 kPa (~15 psi) of pressurized air to the assembly. **CAUTION: For safety reasons, do not exceed 100 kPa (~15 psi) of pressurized air.** Isolate the pressurized housing and remove the air supply. Watch the gauge and note any reduction in housing pressure. The gauge reading must remain stable (± 5% of the stabilized value) for a 5-minute duration.

11.6.8.2.2 Housing vacuum test

The vacuum tightness test is based on air evacuation. The submersible motor assembly's interior cavity is connected with a vacuum line to special test equipment. Air is simultaneously evacuated from the housing cavity and a reference vessel (see Figure 11.6.8.2.2). A vacuum of 55 kPa (8 psi) minimum is required. Leakage is indicated by an excessive air flow rate (leakage) or by a pressure differential between the motor cavity and the reference vessel, as noted on a gauge or instrument located between the housing and the reference vessel.

11.6.8.2.3 Electrical continuity and resistance test

Several components on a typical submersible motor can be tested using resistance measuring instruments. These components include the motor winding electrical resistance, thermal sensors, some moisture sensors, and certain other electronic sensing and control components. The manufacturer's operations and maintenance manual must be consulted to confirm the testing method and desired readings for each test.

The resistance of a submersible motor winding can be measured by connecting the leads of the ohmmeter across a pair of the motor leads (power cable). Each pair will give a measurement for a different winding: T1-T2, T2-T3, and T3-T1. The resistance value is typically very low, and should be compared to the manufacturer's specifications to ensure that they are within acceptable range for operation. An out-of-range value may indicate damaged winding insulation, high level of humidity, or bad connections.

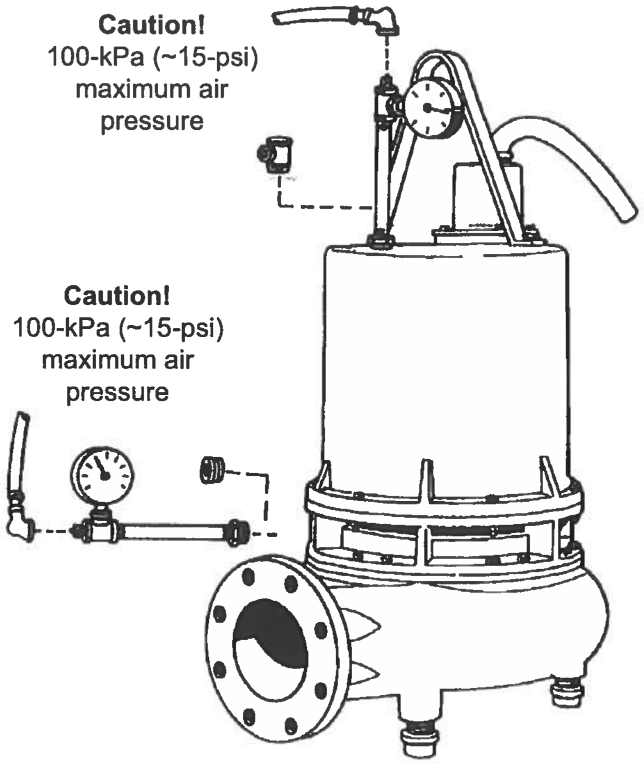


Figure 11.6.8.2.1 — Submersible motor integrity test setup using housing pressure test method

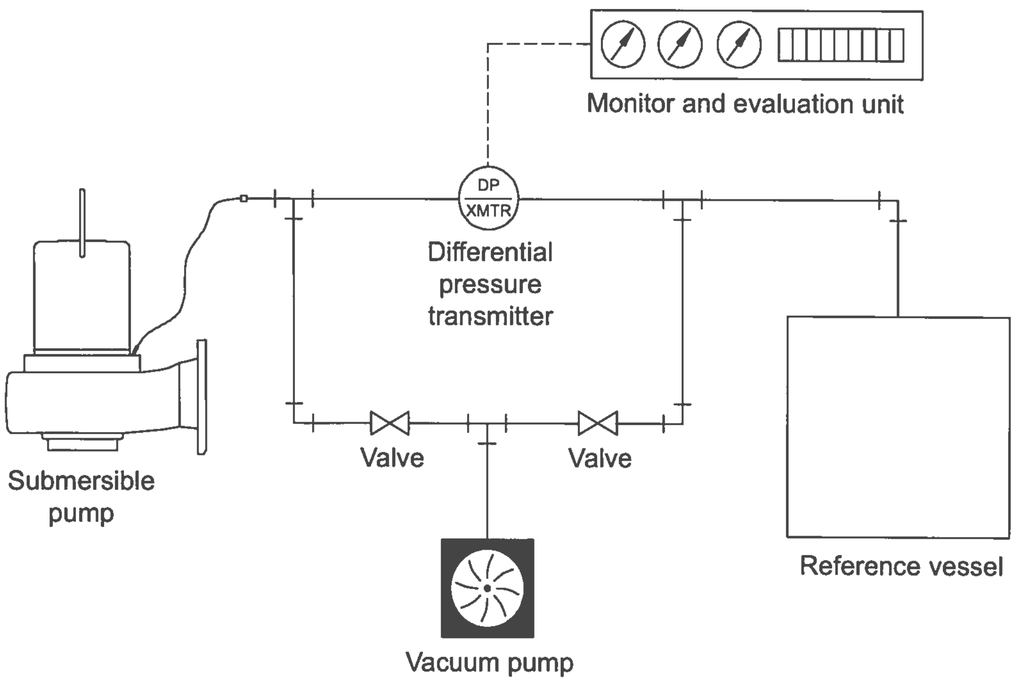


Figure 11.6.8.2.2 — Submersible motor integrity test setup using the housing vacuum test method

The typical submersible motor is equipped with one or more thermal switches (thermostats) embedded in its windings. The switches are typically connected together in series and to two leads that, under normal operating conditions, behave as a closed circuit when measured by an ohmmeter. In the event of a thermostat reaching its switching temperature due to overheating of a winding, the switch will break the loop and the ohmmeter will read an open circuit. The thermal switch leads must be used in the control circuit that operates the pump; it must disconnect power to the motor when an open circuit is detected. It protects the motor from damage due to high temperature, which may be caused by too frequent starts and stops, overload conditions, under voltage, lack of cooling, or other reason. For other types of temperature safety devices, refer to the manufacturer's operation and maintenance manual.

The typical submersible motor moisture sensor can be checked by connecting an ohmmeter across the moisture sensor leads on the control cabling. The resistance reading for a moisture sensor system without a checking resistor should be high or open when the submersible motor housings are free of liquid (moisture). A low resistance or closed reading indicates the housing may contain water and should be disassembled and the integrity of the submersible motor must be checked. On submersible motor units that have a checking resistor in parallel with the moisture sensor probes, the measured resistance at the control cable leads should be nearly equal to the resistance value when the housing(s) are free of moisture. A resistance much lower than the size of the checking resistor indicates the housing may contain water and should be disassembled and the sealing elements checked.

Submersible motors may include other electronic sensors. Using the manufacturer's operations and maintenance manual, checks can be made with an ohmmeter through the submersible motor sensor cabling to check the status and operations of these devices.

11.6.8.2.4 Electrical megohmmeter resistance test

The electrical megohmmeter resistance test is designed to measure the resistance of submersible motor electrical components relative to ground. The test will verify that the insulation of the motor is acceptable and will indicate any moisture intrusion into the submersible motor housing(s). The megohmmeter test shall be performed after the pump has undergone the performance test. The continuity between the ground and the motor frame must be verified. A megohmmeter is then attached between ground and each power cable lead of the submersible motor assembly, and a reading is taken. If a reading is below 2.0 megaohms, then the submersible motor insulation system is failing or moisture is present, and the pump has failed the test.

11.6.8.2.5 Electrical high-potential test

The dielectric high-potential test, known as the *hi-pot test*, shall be run on a completely assembled motor to determine the adequacy of the insulation system.

Refer to Institute of Electrical and Electronics Engineers (IEEE) standards for specific procedures and cautions regarding the hi-pot test.

Acceptance criteria for this test are based on allowable current leakage to ground, as determined by the manufacturer. For detailed test instructions, refer to the individual manual received with the test equipment, and review IEEE publications relating to high-potential tests.

Hi-pot testing is a destructive test and repeated high-potential testing will degrade the insulation system and is not recommended.

11.6.8.3 Records

These tests are usually of a pass/fail nature with no records required.

11.6.9 Vibration test

11.6.9.1 Objective

A vibration test can be used to verify that a tested pump does not exceed a guaranteed vibration velocity level when tested as a new product with clean, clear water in a factory test facility. This section provides a uniform test procedure and acceptance criteria for OEM factory vibration testing of submersible pumps. This section is intended to define test procedures and acceptance criteria that may be invoked by contractual agreement between a buyer and manufacturer; it is not intended to completely define a manufacturer's standard practice.

11.6.9.2 Test setup

The pump shall be supported during testing in a manner as close as practical to the expected field installation within the limitations of the test facility.

11.6.9.2.1 Pump support

a) For wet-well submersible pumps supported by the discharge connection or piping, the discharge elbow or piping shall be installed on a foundation of adequate mass and rigidity with proper anchoring. No additional support fixtures shall be used unless they are also provided for the final field installation.

b) For dry-pit submersible pumps, the suction and discharge piping shall be connected and anchored so as to avoid excessive strains on the pump nozzles. A foundation of adequate mass and rigidity with proper anchoring shall be provided for pump support.

11.6.9.2.2 Vibration instrumentation

The vibration measurement system shall be calibrated per the manufacturer's recommendations. The vibration accelerometer shall be mounted at the top motor bearing location, radial to the shaft centerline, and at a 45° angle from the pump discharge, as shown in Figure 11.6.9.2.2. Only a single vibration transducer is required.

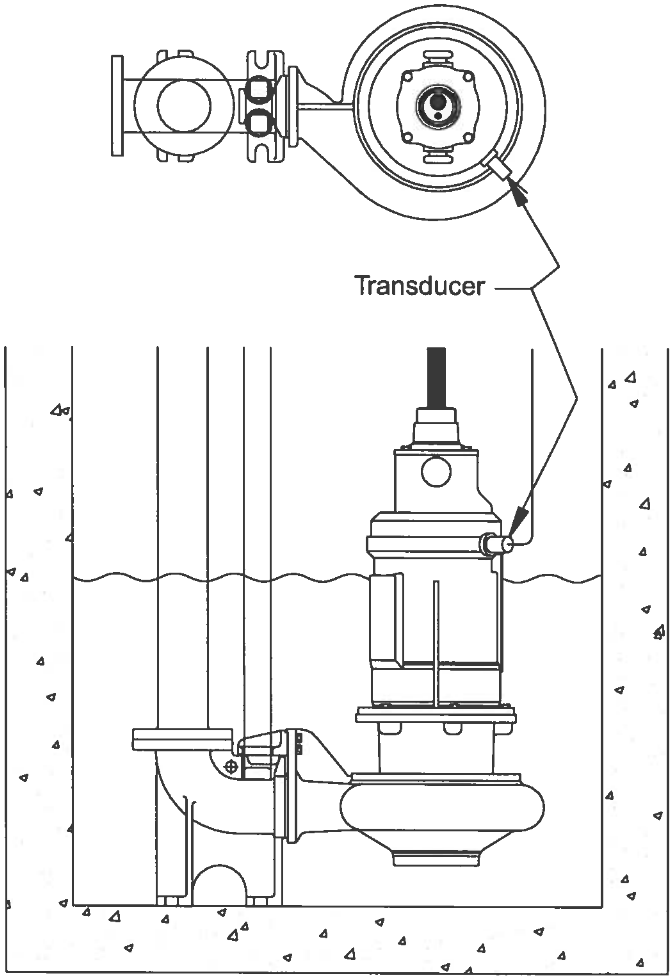


Figure 11.6.9.2.2 — Transducer location

11.6.9.3 Test procedure

The unfiltered root-mean-square (RMS) vibration reading shall be recorded at the top motor bearing location, as shown in Figure 11.6.9.2.2. The following conditions shall be met:

- Operation under steady state conditions while at the specified condition point.
- No entrained air or gas and an adequate NPSHA with suitable margin added. Refer to ANSI/HI 9.6.1 for more information on NPSH margin.
- Wet well shall provide a smooth and stable inlet flow to the pump suction. The inlet flow shall be free of rotation or vortexing.

11.6.9.4 Acceptance criteria

The vibration acceptance limits shown in Figures 11.6.9.4a and 11.6.9.4b are for unfiltered and averaged root-mean-square (RMS) vibration readings. The values shown represent the maximum acceptable vibration level when operating above 80 to 115% of the best efficiency point flow rate. Higher vibration levels can be expected when operating outside of the preferred operating region. For pumps with single-vane impellers, increase all limits shown by 2.5 mm/s (0.1 in/s). Power is understood to be the calculated shaft power for the vibration point tested.

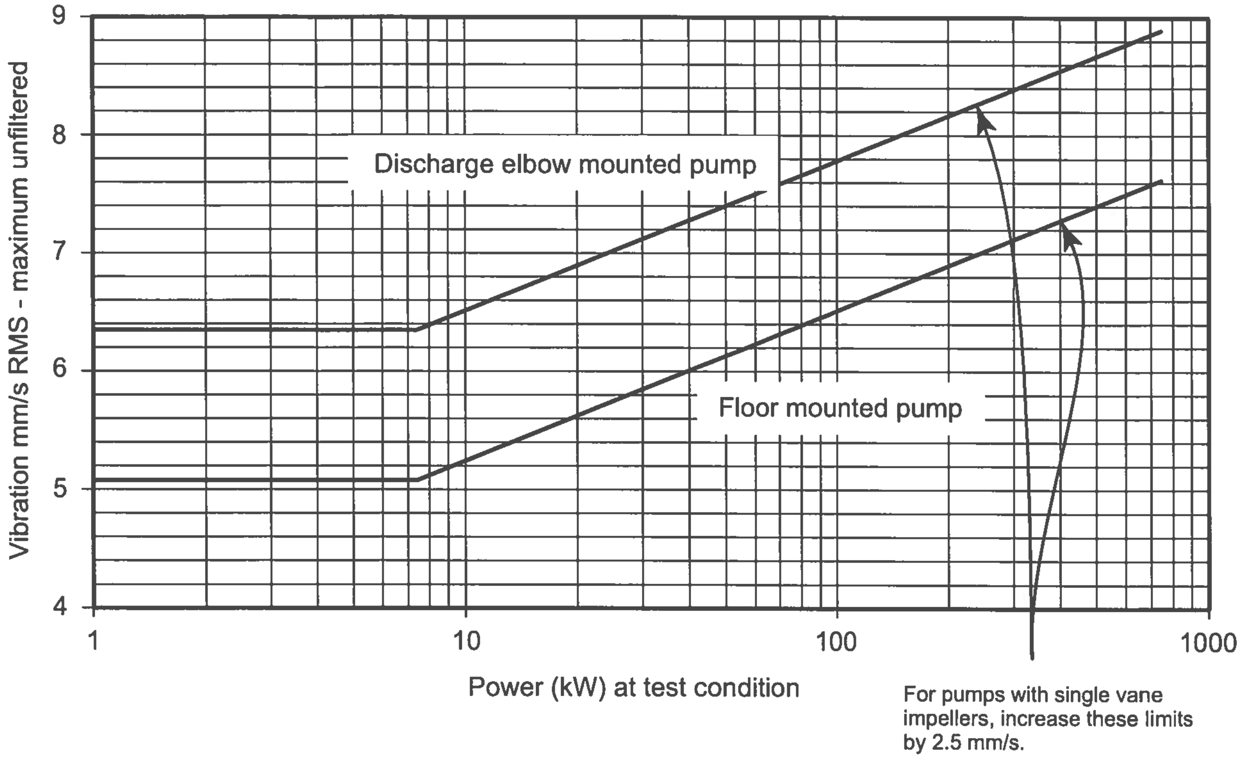


Figure 11.6.9.4a — Vibration limits (metric)

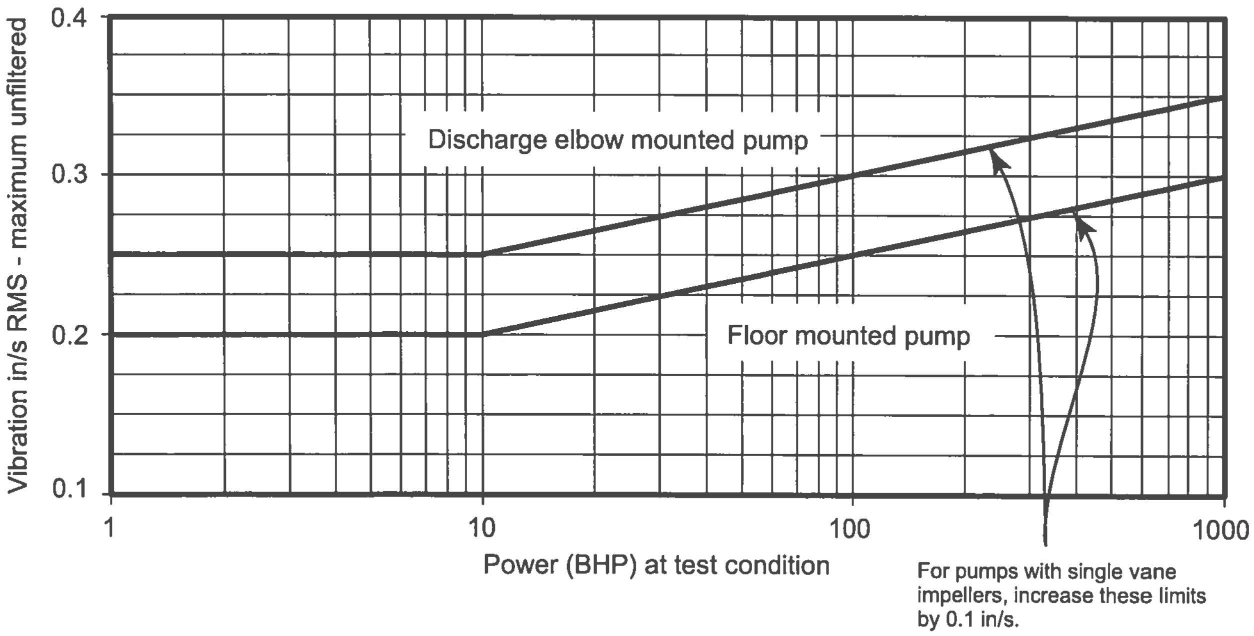


Figure 11.6.9.4b — Vibration limits (US customary units)

11.6.9.5 Records

Complete written or computer records must be kept of all information relevant to the test and kept on file, available to the buyer by the test facility, for five years.

11.6.10 Instrumentation

11.6.10.1 Objective

The purpose of this section is to ensure that the selected test instrumentation is adequate to meet the requirements of this standard.

11.6.10.1.1 Measurement uncertainty

11.6.10.1.2 General

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

11.6.10.1.3 Permissible fluctuations (random fluctuations)

For each quantity to be measured, Table 11.6.10.1.3 gives the permissible amplitude of fluctuations per acceptance grades 1, 2, and 3.

Where the construction 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, their connecting lines, or by electronic data averaging. This can reduce the amplitude of the fluctuations to within the values given in Table 11.6.10.1.3.

Since it is possible that damping will affect the accuracy of the readings, use shall be made of symmetrical and linear damping devices, for example, a capillary tube, which must provide an integration over at least one complete cycle (peak-to-peak) of fluctuations.

Table 11.6.10.1.3 — Permissible amplitude of fluctuation as a percentage of mean value of quantity being measured

Measured quantity	Permissible amplitude of fluctuations per grade		
	Grade 1	Grade 2	Grade 3
Rate of flow	± 2%	± 3%	± 6%
Differential head	± 3%	± 4%	± 10%
Discharge head	± 2%	± 3%	± 6%
Suction 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

11.6.10.1.4 Maximum permissible measurement device uncertainty (systematic)

The uncertainty of a measurement depends on the residual uncertainty of the measurement device and on the method of measurement used. After all known errors have been removed by zero adjustment, calibration, careful measurement of dimensions, proper installation, etc., this remains an uncertainty that never disappears. This uncertainty cannot be reduced by repeating the measurements if the same instrument and the same method of measurement is used.

Table 11.6.10.1.4 shows maximum permissible measurement device uncertainty for the different acceptance grades. It is important to note that these maximum uncertainty values pertain to the measurements at the guarantee point. Many measurement devices have their uncertainty based on their full-scale capability and, when practically applied, the actual measurement uncertainty can be two to four times higher. This means that the measurement device must often have a correspondingly higher accuracy (lower uncertainty).

Section 11.6.10.2 describes different methods of measurement and devices that typically are used to determine rate of flow, pump total head, speed of rotation, and pump power input in the range of accuracy required for tests according to grades 1, 2, and 3.

After having selected an appropriate measurement device and setup, the best assurance of an accurate measurement is obtained by ensuring that a zero adjustment is performed regularly and that device calibration is performed at proper intervals.

Table 11.6.10.1.4 — Maximum permissible measurement device uncertainty at guarantee point

Measured Quantity	Maximum permissible measurement device uncertainty at guarantee point per grade	
	Grade 1	Grade 2 and 3
Rate of flow	± 1.5%	± 2.5%
Differential head	± 1.0%	± 2.5%
Discharge head	± 1.0%	± 2.5%
Suction head	± 1.0%	± 2.5%
Suction head for NPSH testing	± 0.5%	± 1.0%
Driver power input	± 1.0%	± 2.0%
Speed of rotation	± 0.35%	± 1.4%
Torque	± 0.9%	± 2.0%

11.6.10.1.5 Overall measurement uncertainty

The fluctuation 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 fluctuation can be reduced by increasing the number of measurements of the same quantity under the same conditions.

The overall measurement uncertainty is calculated by the square root of the sum of the squares of the systematic and random uncertainties (fluctuations).

11.6.10.1.6 Calibration intervals

Instruments need not be calibrated specifically for each test, but are to be periodically calibrated by the manufacturer or suitable party.

Measuring and testing equipment must be calibrated at periodic intervals as listed in Table 11.6.10.1.6. Intervals may be shortened as required to ensure continued accuracy as evidenced by the results of preceding calibrations. Intervals may be lengthened only when the results of previous calibrations provide definite indications that such action will not adversely affect the accuracy of the system.

11.6.10.2 Measurement of rate of flow

Any accurate flow-measuring system may be used for measuring pump rate of flow. However, it must be installed so that the entire flow passing through the pump also passes through the instrument section.

Introducing a reduced area in the flow stream that results in a reduction in gauge head as the velocity is increased provides flow rate determination by measurement of the differential head. The gauge head differential is measured and used to determine the rate of flow. The meters discussed in Sections 11.6.10.2.1 and 11.6.10.2.2 use this principle.

Meters falling within this classification and acceptable for flow rate determination under this standard, when used as described herein, are venturis, nozzles, orifice plates, and Pitot tubes.

A flowmeter should be used on the pump discharge side, and located according to Figure 11.6.5.2a.

Table 11.6.10.1.6 — Instrument recalibration intervals[a]

Equipment	Period (Years)	Equipment	Period (Years)
Rate of Flow		Head	
Pressure differential meters		Bourdon tube (pressure gauge)	0.33
Venturi	NR[b]	Manometers	NR[c]
Nozzle	NR[b]	Dead-weight tester	NR[c]
Orifice plate	NR[b]	Transducers	0.33
Pitot tube	NR[b]	Digital indicator	1
Weir	NR[b]	Input Power	
Rotating meters		kW transducer	3
Turbine	1	Watt-amp-voltmeter, portable	1
Propeller	1	Watt-amp-voltmeter, permanent	1
Noncontact meters		Temperature	
Magnetic flow	1[d]	Electric	2
Ultrasonic	0.5	Mercury	5

[a] Use instrument manufacturer's recommendation if shorter than listed above.

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

[c] Not required unless damage is suspected.

[d] Secondary (electronic processor). The primary section should be recalibrated every five years, unless there is electrical or mechanical failure.

Flowmeters must be installed and used in accordance with the manufacturer's recommendation for straight runs of pipe and flow rate limitations. Flow-straightening devices may be required, depending on test piping. These precautions are stipulated to ensure uniform flow at the meter inlet and stable pressure readings at the pressure taps.

11.6.10.2.1 Rate of flow measurement by pressure differential meter

Pressure differential flowmeters include venturi, nozzle, orifice plate type meters, and Pitot tubes. To ensure accurate results in the measurement of flow rates with meters, certain minimum lengths of straight pipe are required upstream of the meter. Table 11.6.10.2.1a shows these minimum lengths for a venturi meter, expressed in terms of pipe diameters. Tables 11.6.10.2.1b and 11.6.10.2.1c show the length of straight pipe required for a nozzle type meter. A submersible pump shall have at least 10 diameters of pipe between it and the flow-rate meter.

Table 11.6.10.2.1a — Straight pipe required before a venturi meter in diameters of pipe

Meter ratio – (throat to inlet diameter)[a]	0.4	0.5	0.6	0.7	0.8
One standard short-radius elbow	1	2	3	4	6
Two elbows in same plane	2	3	4	6	8
Standard cast-iron flanged reducer	2	5	7.5	10	13
Standard cast-iron flanged increaser	1	2	3	4.5	6
Globe valve with straightening vanes	2	4	6	9	12
Gate valve	2	4	6	9	12

[a] A submersible pump shall have at least 10 diameters of pipe between it and the meter.

Table 11.6.10.2.1b — Straight pipe required before a nozzle or orifice plate in diameters of pipe

Meter ratio β (throat to inlet diameter)[a]	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Tee or wye within line flow	6	6	6.5	7	8.5	10.5	14
One elbow, branch flow through tee or wye, or flow from drum or separator	6	6	6.5	7	9	13	20.5
Globe valve — wide open	9	9	9.5	10.5	13	15	21
Gate valve — wide open	6	6	6	6	7.5	9.5	13.5
Two or more short-radius elbows or bends in same plane	7.5	7.5	8.5	10.5	13.5	18	25

Table 11.6.10.2.1b — Straight pipe required before a nozzle or orifice plate in diameters of pipe (*continued*)

Meter ratio β (throat to inlet diameter)[a]	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Two or more long-radius elbows or bends in same plane	6	6	6.5	8	11	16	23
Two short-radius elbows or bends in different planes	14.5	16	17.5	20.5	24.5	30	40
Two long-radius elbows or bends in different planes	7	8	10	12	16	22	33

[a] A submersible pump shall have at least 10 diameters of pipe between it and the nozzle or orifice.

Table 11.6.10.2.1c — Straight pipe downstream of pressure tap of a nozzle or orifice plate meter in diameters of pipe

Meter ratio β (throat to inlet diameter)	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Gate valve — wide open	0	0	0	0	0	0	0
Wye — within line flow	0	0	0	0	0	0	4
Tee — straight through flow	0	0	0	0	0	3.5	4
Expansion joint	0	0	0	0	0	3.5	4
45° Elbow	0	0	0	0	3.5	3.5	4
Long-radius elbow or bend	2	2.5	2.5	3	3.5	3.5	4
Regulators, control valves, and partly throttled gate valves	6	6	6	6	6	6	6

Whenever possible, the orifice plate should be calibrated in place in the piping system. When this is not possible, a certified curve showing the calibration of the orifice plate must be obtained. This certification must indicate the exact location and size of pressure taps, which are then to be duplicated in the test installation.

To ensure accurate results in the measurement of rates of flow with orifice-type meters, a length of straight pipe is required preceding and following the orifice plate. Tables 11.6.10.2.1b and 11.6.10.2.1c show the length of straight pipe required, expressed in terms of equivalent pipe diameters.

A Pitot tube is a double tube, one within the other. Rate of flow is measured by inserting the tube so that it points into the flow stream. The inner tube measures the velocity head and gauge head of the liquid, and the other tube with a hole in the outer wall measures gauge head only. The head differential is measured and used to determine velocity head that, in turn, determines rate of flow.

11.6.10.2.2 Rate of flow measurement by weirs

This is done in open-channel flow by allowing the liquid to cascade over a dam through a sharp-crested contraction in the dam, which results in an increase in velocity at the contraction. The height in liquid level above the contraction is measured and used to determine rate of flow.

For a detailed discussion of weir construction, installation, and operation, refer to documents dealing directly with open-channel flow measurement.

11.6.10.2.3 Rate of flow measurements from rotating-type flowmeters

Economical devices for measuring flow rate include rotating-type flowmeters, such as turbine, propeller, and paddle-wheel meters. A meter of this type is placed in series with the flow to be measured and calibrated for the pipe size. Electromagnetic counters are used to determine the flow based on the number of rotations per unit time of the rotating element. These devices commonly provide a pulse-type electronic output and give reasonable accuracy.

11.6.10.2.4 Rate of flow measurement from noncontact-type flowmeters

Flow measurement can be made using meters that do not contact the fluid being pumped. The two most common types are magnetic and ultrasonic flow-type meters. These types of meters can be highly accurate provided their placement meets all of the manufacturer's recommendations.

Fluid flowing through the magnetic flowmeter generates a current in the coils within the meter. Because the meter is set for a specific piping diameter, the current created in the coil can be electronically converted to a flow reading through electronic circuitry.

The ultrasonic flowmeter uses a pair of sonic transducers mounted on the exterior of the piping system. A sending sonic transducer initiates a sonic pulse that is received by the receiving sonic transducer. The flow through the piping system changes the timing rate that the receiving transducer receives the signal. Because each unit is calibrated to a specific pipe size and material, this receiving signal rate can be converted to an accurate electronic output. The manufacturer specifies the placement, piping size, and piping materials that can be used by a particular meter.

11.6.10.2.5 Other methods of flow rate measurement

When the methods of rate of flow measurement described above are not applicable, other methods not included in this standard may be used, provided the accuracy of the instrument can be demonstrated, as described in Section 11.6.10.1.1.

11.6.10.3 Head measurement

The units of head and the definition of total head and its component parts are covered in Section 11.6.4.3.8.

11.6.10.3.1 Pressure tap location

The taps must be located in the piping a minimum of two diameters of straight pipe before the suction flange (dry pit) and after the discharge flange. Figure 11.6.10.3.1a shows a single-tap connection. To provide uniform velocity before the suction pressure tap, a straight pipe with unvarying cross section of at least five pipe diameters in length must precede the gauge tap.

Pipe friction losses between the pump and the pressure tap are taken into account at the manufacturer's discretion. The friction factor used for the friction loss calculation must be based on the appropriate roughness factors for the actual pipe section.

The following precautions must be taken in forming openings for pressure-measuring instruments and for making connection:

a) The opening in the pipe must be flush with and normal to the pipe inside surface.

b) The pipe inside surface must be smooth and of unvarying cross section. For a distance of at least 300 mm (12 in) preceding the opening, all tubercles and roughness must be removed with a file or emery cloth, if necessary.

c) The opening must be 3 to 6 mm (1/8 to 1/4 in) in diameter and length must be equal to twice the diameter.

d) The edges of the opening must be provided with a suitable radius tangential to the wall of the water passage and must be free of burrs or irregularities. Figure 11.6.10.3.1a shows suggested arrangements of taps or orifices in conformity with the above.

e) When multiple openings (see Figure 11.6.10.3.1b) are agreed on as an alternative, they must not be connected to a head-measuring instrument unless there will be no more than 1% pressure variance between pressures at each opening. If pressure variance exceeds 1%, they must be measured separately and averaged.

f) All connections or leads from the opening tap must be free of liquid leakage. These leads must be as short and direct as possible. For the dry-tube type of leads, suitable drain pots must be provided and a loop must be formed of sufficient height to keep the pumped liquid from entering the leads. For the wet-tube type of leads, vent cocks for flushing must be provided at any high point or loop crest to ensure that they are properly bled of any air.

g) Suitable dampening devices may be used in the leads.

11.6.10.3.2 Measurement of head by means of gauges

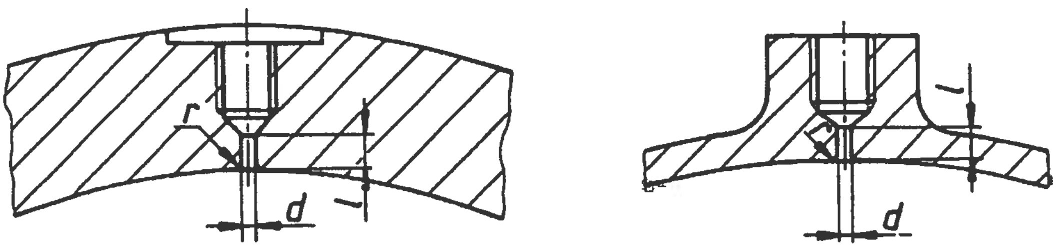
The quantities (Z_d) and (Z_s) are negative if the corresponding values are below the datum elevation.

It is recommended that the suction gauge location be as close to the centerline of the suction pipe as possible (see Figure 11.6.10.3.2). Accuracy may decrease the farther the gauge is placed from the centerline of the suction pipe due to accumulation of air.

Manometers, pressure transducers, and other pressure devices can be used in place of pressure gauges. However, the basic expression for total head and the placement of the instruments is the same.

11.6.10.4 Pump input power measurement

The electric power input to the submersible pump motor shall be measured by either the two-wattmeter or the three-wattmeter method. This allows using either single-phase wattmeters, a wattmeter measuring two or three phases simultaneously, or integrating watt-hour meters. Electrical power measurements shall conform to IEEE 112 section 4.1.6.



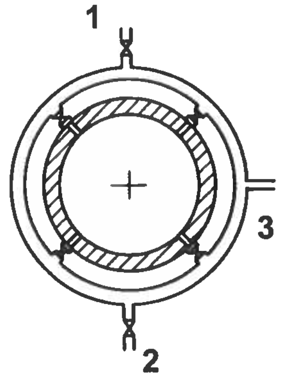
Thick wall

Thin wall

$l \geq 2.5\ d$, where d = 3 to 6 mm or 1/10 pipe diameter, whichever value is smaller

$r \leq d/10$

Figure 11.6.10.3.1a — Requirements for static pressure tappings



NOTE: 1 is a vent, 2 is a drain, and 3 is a connection to the pressure-measuring instrument.

Figure 11.6.10.3.1b — Four pressure tappings connected by a ring manifold (grade 1)

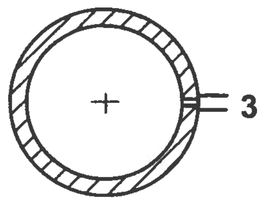


Figure 11.6.10.3.1c — One pressure tapping (general for grade 2 and 3)

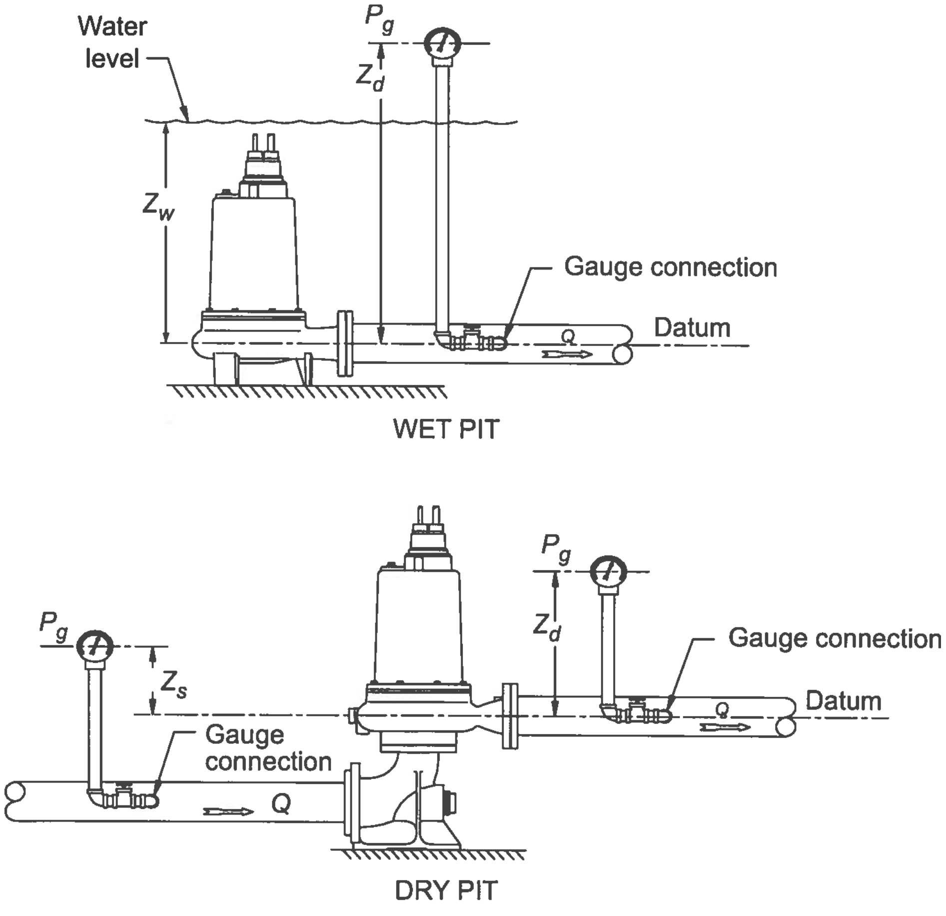


Figure 11.6.10.3.2 — Gauge connectors

11.6.10.5 Methods of rotary speed measurement

Speed measurement is not typically required for the testing of a submersible pump. Determination of speed is mandatory only when:

a) The manufacturer has elected to test at a speed different than the specified contract speed.

b) Variable speed performance or NPSH tests are required.

c) Model pump is being tested to demonstrate acceptance of the contract pump.

The various methods and instrumentation are discussed in detail in ASME performance test code *Measurement of Rotary Speed*, PTC 19.13.

Test speeds for submersible pumps may range from a few hundred to thousands of revolutions per minute. Because the pump test data will be taken under steady state conditions, the maximum permissible short-term speed fluctuations and uncertainties must meet the limits of Tables 11.6.10.1.3 and 11.6.10.1.4, respectively.

Frequency-responsive devices have the advantage of not requiring direct contact with the motor or pump shaft, hence impose no additional load on the motor. The vibrating reed type is useful only when the shaft is completely inaccessible. Electronic units may be converted to read rpm directly using a shaft-mounted gear and a noncontacting magnetic pickup. Because the line frequency (which determines the timing interval) is typically 60 Hz ± 0.1%, the method is accurate to the nearest rpm, as read on a digital readout. The timing interval may be set as short as 0.1 second, thus making any speed fluctuations readily discernible.

11.6.10.6 Temperature measurement and instruments

Temperature may be measured using etched-stem thermometers, liquid-in-glass thermometers, thermocouples, or resistance thermometers providing an accuracy of ± 1 °C (2 °F) or better. The temperature-measuring device must have no effect on the measurements of pressure and flow rate.

11.6.11 Model tests

In many installations involving units of large size or prototype design, model tests are of great utility. Even when it might be feasible to test the large unit in the factory, a model may often be tested with greater accuracy and thoroughness. By adopting a standard size of model for various pumps, comparable performances can be obtained. Model test results are valid only when dimensional scaling techniques between the prototype and the model follow consistent rules for hydraulic similitude.

Testing models in advance of final design and installation of a large unit not only provides advance assurance of performance, but makes alterations possible in time for use in the prototype unit. See ANSI/HI 14.6 *Rotodynamic Pumps for Hydraulic Performance Acceptance Tests* for details on criteria of a pump model.

Appendix A

Wire-to-water pump efficiency (informative)

Wire-to-water efficiency versus pump efficiency

This submersible pump test standard revision represents a major departure from earlier pump test standards in that *the submersible pump is guaranteed and tested as a complete unit*, i.e., the wire-to-water efficiency, or electric input power, may be guaranteed in addition to flow and head. This standard does not differentiate between the various sources of losses within the boundary of the submersible pump unit. The formulas contained in the appendices are provided to estimate an individual element of the pump unit's overall efficiency, such as motor efficiency or pump efficiency. Other possible pump component efficiencies, such as cooling system efficiency, mechanical seal efficiency, bearing efficiency, etc. are typically more difficult to obtain. They have traditionally been included in either the pump efficiency or the motor efficiency, artificially lowering that particular value. It is meaningless to compare pump test results from a submersible pump test made to this standard with data for a nonsubmersible pump.

A.1 Pump efficiency

Measurements of head, flow, and power are needed to generate a pump efficiency curve. With this information the pump efficiency can be calculated. The efficiency shown on a submersible pump curve is typically calculated using the input power to the pump shaft. The shown efficiency is therefore the water 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 shaft power is by direct measurement of the shaft torque and rpm. This is typically done using a torque transducer and a tachometer to measure torque and shaft speed. These values can then be multiplied to calculate the shaft power. Because a submersible pump is supplied as an integral unit, shaft power (measuring shaft torque and speed) is not feasible on a production pump submitted for acceptance testing.

A less accurate method, but one that is often specified, is to do a test using the complete pump (job motor). The accuracy of this test will be lower than when the pump is tested by itself. In this instance the power measured by a wattmeter is the input power to the motor, not to the pump shaft. The input power to the shaft is then calculated by taking into account the published motor efficiency data. Because the motor's published efficiency has its own tolerances, the calculated value for the pump input power is significantly less accurate than when the shaft torque and rpm are directly measured.

A.2 Wire-to-water efficiency

In the case of a close-coupled submersible pump unit, there are several loss sources in addition to the motor losses and the pump's hydraulic losses that may be present depending on the design of the unit. Examples include mechanical seal losses, motor cooling system losses, bearing friction losses, and power cable losses.

The efficiency (and power consumption) information provided by the pump manufacturer's typical book curve therefore only provides the end user the required power at the pump input shaft. Because there is no general convention in place, a manufacturer may produce its performance curves with pumps that are sealed loosely with packing. This allows fairly consistent results to be produced. However, it is often required that pumps be performance-tested with mechanical seals rather than with packing. This will always produce higher power requirements and hence lower efficiencies. (The additional power consumed can be very significant when calculating efficiency, particularly when the seals are large, when dual seals are used, or when input power is relatively low, such as for small pumps.)

From an energy consumption standpoint, pump efficiency alone 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 input power consumption data. Wire-to-water efficiency does provide the user with the true cost to operate that pump. Wire-to-water performance curves can be easily provided by the pump manufacturer by simply placing a wattmeter at the input to the motor and using this as the source of power consumption. No motor or drive efficiency calculations are needed. Wire-to-water efficiency data will allow the end user to know the true power consumption of the submersible pump.

A.3 Pump power and efficiency definitions and calculations

A.3.1 Pump shaft power (P_p)

The net power delivered to the pump shaft by the submersible motor (the term *brake horsepower* is used in US customary units).

The power absorbed by shaft mechanical sealing devices are excluded when calculating P_p (seal losses are usually included as part of the submersible motor losses). Special tests and testing equipment are required to determine P_p empirically. These tests are beyond the scope of this standard. The value P_p is normally a calculated value based on manufacturer dynamometer testing of similar units. (Refer to IEEE 112, *Standard Test Procedure for Polyphase Induction Motors and Generators.*)

A.3.2 Submersible motor efficiency (η_{mot})

Motor efficiency (η_{mot}) is a measure of how effectively a motor converts electrical power into mechanical power.

$$\eta_{mot} = \frac{P_w \times 100}{P_{mot}}\text{, expressed as percent}$$

Power to drive all shaft seals and any internal motor viscous losses are included as a motor loss. Losses attributed to electric cabling, variable-speed drives, nonsinusoidal power supplies, externally powered cooling devices, and bearing losses due to pump thrust-generated loads are to be excluded when calculating η_{mot}. Motor efficiency varies depending on the load, voltage, and supplied frequency to the motor.

A.3.3 Pump efficiency (η_p)

The pump efficiency (η_p) is a ratio of water horsepower (P_w) to the brake horsepower (P_p), usually expressed as a percentage.

$$\eta_p = \frac{P_w \times 100}{P_p}\text{, expressed as percent}$$

All losses internal to the pump wet end, bearing losses due to pump thrust-generated loads, losses caused by using the pumped liquid to cool the electrical driver, and any power required to drive pump-out vanes (or similar devices) slightly reduce the calculated pump efficiency and must be included when calculating brake horsepower P_p.

Appendix B

Sample problems and formulas (informative)

This appendix includes sample problems demonstrating the application of testing tolerances and formulas outlined in this standard. Following is a list of the sample problems and formulas included.

List of affinity rules.

Calculation of head, flow, NPSHR, and horsepower based on a change in pump speed (frequency).

Calculation of head, flow, and horsepower based on a change in pump impeller diameter.

Calculation of NPSHA on a wet-pit pump.

Calculation of NPSHA on a dry-pit pump.

Calculation of pump performance ranges based on corresponding tolerance bands.

B.1 Affinity rules (rotodynamic pumps)

$$\frac{n_1}{n_2} = \frac{Q_1}{Q_2} \quad \text{or} \quad Q_2 = Q_1\left(\frac{n_2}{n_1}\right)$$

$$\left(\frac{n_1}{n_2}\right)^2 = \frac{H_1}{H_2} \quad \text{or} \quad H_2 = H_1\left(\frac{n_2}{n_1}\right)^2$$

$$\left(\frac{n_1}{n_2}\right)^3 = \frac{P_1}{P_2} \quad \text{or} \quad P_2 = P_1\left(\frac{n_2}{n_1}\right)^3$$

$$\left(\frac{n_1}{n_2}\right)^2 = \frac{NPSH_1}{NPSH_2} \quad \text{or} \quad NPSH_2 = NPSH_1\left(\frac{n_2}{n_1}\right)^2$$

$$\frac{d_1}{d_2} = \frac{Q_1}{Q_2} \quad \text{or} \quad Q_2 = Q_1\left(\frac{d_2}{d_1}\right)$$

$$\left(\frac{d_1}{d_2}\right)^2 = \frac{H_1}{H_2} \quad \text{or} \quad H_2 = H_1\left(\frac{d_2}{d_1}\right)^2$$

$$\left(\frac{d_1}{d_2}\right)^3 = \frac{P_1}{P_2} \quad \text{or} \quad P_2 = P_1\left(\frac{d_2}{d_1}\right)^3$$

Where:

n_1 = speed of rotation 1

n_2 = speed of rotation 2

Q_1 = rate of flow 1

Q_2 = rate of flow 2

H_1 = total head 1

H_2 = total head 2

P_1 = power 1

P_2 = power 2

$NPSH_1$ = net positive suction head 1

$NPSH_2$ = net positive suction head 2

d_1 = impeller diameter 1

d_2 = impeller diameter 2

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.

The affinity rules define the manner in which head, flow rate, horsepower, and NPSH vary in a centrifugal pump with respect to speed (frequency) or impeller diameter changes. (NOTE: The affinity rules for changes in diameter are applicable to small changes in diameter only.) If the pump operates near its cavitation limit, other factors may have an effect on the performance. Such factors include the thermodynamic effect on the vapor pressure of the fluid, change in surface tension, and test differences due to the relative air content on the liquid.

If the manufacturer can demonstrate that, with a given pump under particular conditions, the relationship varies from the formulas shown above, then the modified relationship may be used accordingly.

B.2 Calculated performance based on change in pump speed (metric)

Assume a pump is operating at 30 L/s, 20 m of head, is drawing 8.0 kW, and requires 4.0 m of NPSH to operate properly when running at 1150 rpm. What would the anticipated performance be if the pump speed was increased to 1750 rpm?

Change in rate of flow:

$$\frac{n_1}{n_2} = \frac{Q_1}{Q_2}$$

$$\frac{1150 \text{ rpm}}{1750 \text{ rpm}} = \frac{(30 \text{ L/s})}{Q_2}$$

$$0.657 = \frac{(30 \text{ L/s})}{Q_2}$$

$$Q_2 = \frac{(30 \text{ L/s})}{0.657}$$

$$Q_2 = 45.7 \text{ L/s}$$

Change in total head:

$$H_2 = H_1\left(\frac{n_2}{n_1}\right)^2$$

$$H_2 = 20\ \text{m}\left(\frac{1750\ \text{rpm}}{1150\ \text{rpm}}\right)^2 = 20\ \text{m}(1.522)^2$$

$$H_2 = 46.3\ \text{m}$$

Change in power:

$$\left(\frac{n_1}{n_2}\right)^3 = \frac{P_1}{P_2}$$

$$\left(\frac{1150\ \text{rpm}}{1750\ \text{rpm}}\right)^3 = \frac{8.0\ \text{kW}}{P_2}$$

$$0.284 = \frac{8.0\ \text{kW}}{P_2}$$

$$P_2 = \frac{8.0\ \text{kW}}{0.284}$$

$$P_2 = 28.2\ \text{kW}$$

Change in NPSHR:

$$NPSHR_2 = NPSHR_1\left(\frac{n_2}{n_1}\right)^2$$

$$NPSHR_2 = 4.0\ \text{m}\left(\frac{1750\ \text{rpm}}{1150\ \text{rpm}}\right)^2 = 4.0\ \text{m}(1.522)^2$$

$$NPSHR_2 = 9.3\ \text{m}$$

B.3 Calculated performance based on change in pump impeller diameter (US customary units)

Assume a pump is operating at 500 gpm, 95.0 ft of head, and is drawing 16.0 hp with a 9.50-in diameter impeller. What would the anticipated performance be if the pump impeller diameter was decreased to 9.00 in?

The affinity rules for changes in diameter are applicable to small changes in diameter only.

Change in rate of flow:

$$Q_2 = Q_1\left(\frac{d_2}{d_1}\right) = 500\left(\frac{9.00}{9.50}\right)$$

$$Q_2 = 474\ \text{gpm}$$

Change in total head:

$$\left(\frac{d_1}{d_2}\right)^2 = \frac{H_1}{H_2}$$

$$\left(\frac{9.50\text{ in}}{9.00\text{ in}}\right)^2 = \frac{95.0\text{ ft}}{H_2}$$

$$1.114 = \frac{95.0\text{ ft}}{H_2}$$

$$H_2 = \frac{95.0\text{ ft}}{1.114}$$

$$H_2 = 85.3\text{ ft}$$

Change in power:

$$P_2 = P_1\left(\frac{d_2}{d_1}\right)^3$$

$$P_2 = 16.0\text{ hp}\left(\frac{9.00}{9.50}\right)^3 = 16.0\text{ hp}(0.947)^3$$

$$P_2 = 13.6\text{ hp}$$

B.4 Calculation of NPSHA on a wet-pit pump (metric)

Assume a submersible pump is installed near sea level in wet-pit service. It is installed in a wet well open to the atmosphere, with a water level that corresponds to a submergence of 2.0 m over the impeller datum (see Figure 11.6.4.3.7b). What is the NPSHA? (Assume the barometric pressure P_{atm} = 101.4 kPa at sea level and a maximum liquid temperature of 20 °C.)

$$NPSHA = h_{sa} - h_{vp}$$

$$h_{sa} = h_{atm} + Z_s + h_{vs} - h_f$$

$$h_{atm} = \frac{(P_{atm} \times 0.102)}{s} = \frac{(101.4 \times 0.102)}{1.0} = 10.34\text{ m}$$

$$Z_s = 2.00\text{ m}$$

$$h_{vs} = 0\text{ m}$$

$$h_f = 0\text{ m}$$

$$\therefore h_{sa} = 10.34\text{ m} + 2\text{ m} + 0\text{ m} - 0\text{ m} = 12.34\text{ m}$$

From the standard steam tables, at 20 °C, P_{vp} = 2.34 kPa absolute

$$h_{vp} = \frac{(P_{vp} \times 0.102)}{s} = \frac{(2.34 \times 0.102)}{1.0} = 0.24 \text{ m}$$

$$\therefore NPSHA = 12.34 \text{ m} - 0.24 \text{ m} = 12.10 \text{ m}$$

B.5 Calculation of NPSHA on a dry-pit pump (US customary units)

Assume a submersible pump is installed in a dry-pit service at an elevation of 5500 ft above sea level. It pumps ambient wastewater from a wet-well tank that has a level corresponding to 4.0 ft of positive suction head over the impeller datum. The suction pipe layout consists of a 6-in bell mouth inlet, a 6-in long radius flanged 90° elbow, 25.0 ft of 6-in cast iron pipe, a 6-in flanged gate valve, and a 6-in flanged pump inlet 90° elbow (standard). What is the NPSHA when the pump is operating at the design flow of 300 gpm? (Assume that the barometric pressure P_{atm} = 12.1 psia at 5500 ft based on an atmospheric chart and a maximum liquid temperature of 68 °F.)

$$NPSHA = h_{sa} - h_{vp}$$

$$h_{sa} = h_{atm} + Z_s + h_{vs} - h_f$$

$$h_{at} = \frac{P_{atm} \times 2.31}{s} = \frac{12.1 \times 2.31}{1.0} = 28.0 \text{ ft}$$

$$Z_s = 4.0 \text{ ft}$$

$$h_{vs} = 0 \text{ ft}$$

$$h_f = h_{f\,pipe} + h_{f\,fittings}$$

The frictional losses in the suction piping are obtained from pipe friction loss tables for 6-in cast iron pipe and the resistance coefficients for the valve and fittings. (See Hydraulic Institute *Engineering Data Book.*)

A 6-in bell mouth inlet has a loss coefficient, K, of 0.05.

A 6-in long radius flanged 90° elbow has a loss coefficient, K, of 0.18.

A 6-in flanged gate valve has a loss coefficient, K, of 0.11.

A 6-in regular flanged 90° elbow has a loss coefficient, K, of 0.29.

6-in cast iron pipe has a friction loss of 0.745 ft per 100 ft of length and the pipe velocity (V) is 3.40 ft per second at 300 gpm.

Adding all the loss coefficients for the fittings

(0.05 + 0.18 + 0.11 + 0.29) = 0.63

The friction loss for the fittings is

$$h_{f\,fittings} = K\frac{V^2}{2g}$$

$$h_{f\ fittings} = 0.63\ \frac{3.40^2}{2 \times 32.17} = 0.1\ \text{ft}$$

The friction loss for the 25 ft of 6-in pipe is

$$h_{f\ pipe} = 0.745 \times \frac{25}{100} = 0.2\ \text{ft}$$

$$\therefore h_f = 0.3\ \text{ft}$$

$$h_{sa} = 28.0\ \text{ft} + 4.0\ \text{ft} - 0.3\ \text{ft} = 31.7\ \text{ft}$$

From the standard steam tables, at 68 °F, P_{vp} = 0.34 psia

$$h_{vp} = \frac{P_{vp} \times 2.31}{s} = \frac{0.34 \times 2.31}{1.0} = 0.8\ \text{ft}$$

$$\therefore NPSHA = 31.7\ \text{ft} - 0.8\ \text{ft} = 30.9\ \text{ft}$$

B.6 Sample calculation of performance tolerance bands for pump acceptance according to grade 1E and 2B (US customary units)

Assume that a user is considering asking for a pump guarantee according to grade 1E or grade 2B, including a pump efficiency guarantee. The guarantee point for the proposed pump is 1200 gpm at 100 ft of head and 70% overall efficiency. Based on this information, what are acceptable performance limits based on grade 1E and grade 2B acceptance tolerances?

At rated flow (1200 gpm), the head may vary by ± 3% for a grade 1E test and ± 5% for a grade 2B test.

Grade 1E head	Grade 2B head
Max. = 100 ft × 1.03	Max. = 100 ft × 1.05
Max. = 103 ft	**Max. = 105 ft**
Min. = 100 ft × 0.97	Min. = 100 ft × 0.95
Min. = 97 ft	**Min. = 95 ft**

At the rated head (100 ft), the flow may vary ± 5% for a grade 1E test and ± 8% for a grade 2B test.

Grade 1E flow	Grade 2B flow
Max. = 1200 gpm × 1.05	Max. = 1200 gpm × 1.08
Max. = 1260 gpm	**Max. = 1296 gpm**
Min. = 1200 gpm × 0.95	Min. = 1200 gpm × 0.92
Min. = 1140 gpm	**Min. = 1104 gpm**

The efficiency tolerances are as follows:

Grade 1E efficiency	Grade 2B efficiency
$\eta_{min} = \eta_P$	$\eta_{min} = \eta_P \times 0.95$
η_{min} = 70%	η_{min} = 66.5%

Based on the maximum and minimum acceptance values of the test tolerances on head, flow rate, and efficiency, the input power required may vary as follows:

$$P_{max} = Q \times H \times \frac{s}{(3960 \times \eta_{min})}$$

Maximum acceptance level 1E power range

$$P_{max} = 1260 \times 100 \times \frac{1.0}{(3960 \times 0.70)}$$

$$P_{max} = 45.5 \text{ hp}$$

or

$$P_{max} = 1200 \times 103 \times \frac{1.0}{(3960 \times 0.70)}$$

$$P_{max} = 44.6 \text{ hp}$$

$$P_{max} = Q \times H \times \frac{s}{(3960 \times \eta_{min})}$$

Maximum acceptance level 2B power range

$$P_{max} = 1296 \times 100 \times \frac{1.0}{(3960 \times 0.665)}$$

$$P_{max} = 49.2 \text{ hp}$$

or

$$P_{max} = 1200 \times 105 \times \frac{1.0}{(3960 \times 0.665)}$$

$$P_{max} = 47.8 \text{ hp}$$

Appendix C

Standards-setting organizations (informative)

Standards-setting organizations

Listed below are the major standards-setting organizations whose work relates to submersible pumps and their components. For additional information on applicable standards, contact these organizations directly.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)
11 W. 42nd Street, 13th Floor
New York, NY 10036-9002
Phone: 212/642-4900
FAX: 212/398-0023
Web site: www.ansi.org

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)
100 Barr Harbor Drive
Conshocken, PA 19428
Phone: 610/832-9500
FAX: 610/832-9555
Web site: www.astm.org
Order/Customer Service Department:
Phone: 215/299-5585
FAX: 215/977-9679
Web site: www.astm.org

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)
3 Park Ave.
New York, NY 10016
Phone: 212/591-7722
FAX: 212/591-7739
Web site: www.asme.org

AMERICAN WATER WORKS ASSOCIATION (AWWA)
6666 W. Quincy Ave.
Denver, CO 80235
Phone: 303/794-7711
FAX: 303/794-7310
Web site: www.awwa.org

CANADIAN STANDARDS ASSOCIATION (CSA)
178 Rexdale Boulevard
Rexdale, Ontario, Canada M9W IR3
Phone: 416/747-4000
FAX: 416/747-4149
Web site: www.csa.org

FACTORY MUTUAL RESEARCH CORPORATION
1151 Boston-Providence Turnpike
P. 0. Box 9102
Norwood, MA 02062
Phone: 781/762-4300
FAX: 781/762-9375
Web site: www.factorymutual.com

HYDRAULIC INSTITUTE (HI)
6 Campus Drive
Parsippany, NJ 07054-4406
Phone: 973/267-9700
FAX: 973/267-9055
Web site: www.Pumps.org

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)
1, rue de Varembe
1211 Geneva 20, Switzerland
Web site: www.iso.ch

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)
345 East 47th Street
New York, NY 10017-2394
Phone: 212/705-7900
FAX: 212/752-4929
Web site: www.ieee.org

NATIONAL ELECTRICAL CODE (NEC)
See National Fire Protection Association

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)
2101 L Street, NW
Washington, DC 20037
Phone: 202/457-8400
FAX: 202/457-8411
Web site: www.nema.org

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)
P. 0. Box 9101
1 Batterymarch Park
Quincy, MA 02269-9101
Phone: 617/770-3000
FAX: 800/770-0700
Subscription Department:
Phone: 800/344-3555
FAX: 800/593-6372
508/895-8301
Web site: www.nfpa.org

NSF INTERNATIONAL
P. 0. Box 130140
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NSF Building
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FAX: 734/769-0109
Web site: www.nsf.org

UNDERWRITERS LABORATORIES
333 Pfingsten Road
Northbrook, IL 60062
Phone: 847/272-8800
FAX: 847/272-8129
Web site: www.ul.com

Appendix D

Index

This appendix is not part of this standard, but is presented to help the user with factors referenced in the standard.

Note: an f. indicates a figure, and a t. indicates a table.