ANSI/HI 6.6-2000

American National Standard for

Reciprocating Pump Tests

ANSI/HI 6.6-2000

Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
07054-4406
www.Pumps.org

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Secretariat
Hydraulic Institute
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Approved February 25, 2000
American National Standards Institute, Inc.

American National Standard

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Contents

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth and well-being of pump manufacturers and 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 purchaser and/or the user and to assist the purchaser 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 directed to the Hydraulic Institute. It will direct all such questions to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute publication or an answer provided by the Institute to a question such as indicated above, the point in question shall be referred to the Executive Committee of the Hydraulic Institute, which then shall act as a Board of Appeals.

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; corresponding US units appear in brackets. Charts, graphs and sample calculations are also shown in both metric and US units.

Since values given in metric units are not exact equivalents to values given in US 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 for this standard was achieved by use of the Canvass Method

The following organizations, recognized as having an interest in the standardization of centrifugal pumps were contacted prior to the approval of this revision of the standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

Bal Seal Engineering
Black & Veatch LLP
Bran & Luebbe
Brown & Caldwell
Camp Dresser & McKee, Inc.
Cheng Fluid Systems, Inc.
David Brown Union Pumps
DeWante & Stowell
Equistar LP
Exeter Energy Limited Partnership
Fluid Sealing Association
Illinois Department of Transportation
Ingersoll-Dresser Pump Company
Krebs Consulting Service
Malcolm Pirnie, Inc.
Marine Machinery Association
McFarland Pump Company
Pacer Pumps
Pinellas County, Gen. Serv. Dept.
The Process Group, LLC
Raytheon Engineers & Constructors
Skidmore
South Florida Water Mgmt. Dist.
Stone & Webster Eng. Corp.
Summers Engineering, Inc.
Systecon, Inc.
Tuthill Pump Group

6.6 Test

6.6.1 Scope

This Standard is for reciprocating power pumps, including controlled volume metering pumps, which are driven by power from an outside source applied to the crankshaft. It includes procedures for testing such pumps.

These standards apply to test of the pump only, unless stated otherwise.

The type of test performed and the auxiliary equipment to be used should be agreed upon by the purchaser and manufacturer prior to the test.

It is not the intent 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 upon by the parties involved without sacrificing the validity of the applicable parts of the standard.

6.6.1.1 Objective

This standard provides uniform procedures for hydrostatic, hydraulic and mechanical pump performance testing and for recording of the test results of reciprocating pumps.

Vibration and acoustical testing methods are not included in this standard. Refer to ANSI/HI 9.1–9.5-2000, Section 9.5 Sound Measurement, for acoustical testing procedures.

6.6.2 Types of tests

This standard contains procedures for the following types of tests:

a) Performance test to demonstrate one of the following:

   1) Mechanical integrity at speed and pressure specified;

   2) Rate of flow and mechanical integrity at speed and pressure specified;

   3) Rate of flow, power and mechanical integrity at speed and pressure specified.

Optional tests as follows when specified:

b) Hydrostatic testing of pressure-retaining components is described in Section 6.6.5;

c) Net positive suction head testing is described in Section 6.6.6.

6.6.2.1 Performance test

Unless otherwise specified, the rate of flow, pressure and efficiency are based on shop tests using water corrected to 20°C (68°F).

If the facility cannot test at rated speed because of limitations in power, electrical frequency, or available speed changers, the pump may be tested at between 50% and 200% of rated speed.

6.6.3 Terminology

The following terms and symbols are used to designate test parameters used in connection with pump tests.

6.6.3.1 Symbols

See Table 6.15 on page 2.

6.6.3.2 Subscripts

See Table 6.16 on page 3.

6.6.3.3 Rated condition point

Rated condition point applies to the rate of flow, discharge pressure, suction pressure, NPSHR, speed and power of the pump as specified by the order.

6.6.3.4 Normal condition point

Normal condition point applies to the point at which the pump will normally operate. It may be the same as the rated condition point.

6.6.3.5 Volume (standard units)

The standard unit of volume shall be as follows:

1) Metric – cubic meter;

2) US units – US gallon or cubic foot.

The specific weight (gamma) of water at a temperature of 20°C (68°F) shall be taken as 396 kN/m^3 (62.3 lb/ft^3). For other temperatures, proper specific weight corrections shall be made, using values from the ASME steam tables.

Table 6.15 — Symbols

Symbol	Term	Metric unit	Abbreviation	US Customary Unit	Abbreviation	Conversion factor[a]
A	Area	square millimeter	mm^2	square inches	in^2	645.2
a	Area of piston rod	square millimeter	mm^2	square inches	in^2	645.2
β (beta)	Meter or orifice ratio	dimensionless	—	dimensionless	—	1
C	Coefficient for acceleration head	dimensionless	—	dimensionless	—	1
D	Displacement	cubic meters per hour	m^3/h	US gallons/minute	gpm	0.2271
d	Diameter	millimeter	mm	inches	in	25.4
Δ (delta)	Difference	dimensionless	—	dimensionless	—	1
η (eta)	Efficiency	percent	%	percent	%	1
g	Gravitational acceleration	meter/second squared	m/s^2	feet/second squared	ft/sec^2	0.3048
γ (gamma)	Specific weight			pounds/cubic foot	lb/ft^3	
h	Head	meter	m	feet	ft	0.3048
L	Stroke length	millimeter	mm	inches	in	25.4
M	Number of pistons	dimensionless	—	dimensionless	—	1
n	Speed	revolutions/minute	rpm	revolutions/minute	rpm	1
NPSHA	Net positive suction head avail.	kilopascal	kPa	pounds/square inch	psi	6.895
NPSHR	Net positive suction head required	kilopascal	kPa	pounds/square inch	psi	6.895
ν (nu)	Kinematic viscosity	millimeter squared/sec	mm^2/s	seconds Saybolt Universal	SSU	0.22
π	pi = 3.1416	dimensionless	—	dimensionless	—	1
p	Pressure	kilopascal	kPa	pounds/square inch	psi	6.895
P	Power	kilowatt	kW	horsepower	hp	0.7457
q	Rate of flow (capacity)	cubic meter/hour	m^3/h	cubic feet/second	ft^3/sec	101.94
Q	Rate of flow (capacity)	cubic meter/hour	m^3/h	US gallons/minute	gpm	0.2271
ρ (rho)	Density	kilogram/cubic meter	kg/m^3	pound mass/cubic foot	lbm/ft^3	16.02
s	Specific gravity	dimensionless	—	dimensionless	—	1
S	Slip	percent	%	percent	%	1
t	Temperature	degrees Celsius	°C	degrees Fahrenheit	°F	(°F–32) × $^5/_9$
τ (tau)	Torque	Newton – meter	N·m	pound-feet	lb-ft	1.356
v	Velocity	meter/second	m/s	feet/second	ft/sec	0.3048
V	Specific volume	cubic meters/kiloNewton	m^3/kN	cubic feet/pound	ft^3/kN	6.365
x	Exponent	none	none	none	none	1
Z	Elevation gauge distance above or below datum	meter	m	feet	ft	0.3048

[a] Conversion factor × US units = metric units.

6.6.3.5.1 Stroke (L)

The traverse of one complete unidirectional motion of the piston or plunger.

6.6.3.5.2 Pump displacement (D)

The volume swept by all pistons or plungers per unit of time. Deduction for piston rod volume is made on double-acting piston type pumps.

For single-acting pumps, plunger or piston:

$$\text{(Metric)} \quad D = \frac{ALnM}{16.7 \times 10^6}$$

$$\text{(US units)} \quad D = \frac{ALnM}{231}$$

For double piston pumps, without tail rods:

$$\text{(Metric)} \quad D = \frac{(2A - a)LnM}{16.7 \times 10^6}$$

$$\text{(US units)} \quad D = \frac{(2A - a)LnM}{231}$$

For double piston pumps with tail rods:

$$\text{(Metric)} \quad D = \frac{2(A - a)LnM}{16.7 \times 10^6}$$

$$\text{(US units)} \quad D = \frac{2(A - a)LnM}{231}$$

Where:

M = number of pistons or plungers

D = pump displacement

A = area of piston/plunger

a = area of piston rod

n = speed in rpm

L = stroke length

6.6.3.5.3 Tail rod

A tail rod is an auxiliary rod attached to the piston on the side opposite the driving piston rod, penetrating

Table 6.16 — Subscripts

Subscript	Term	Subscript	Term
a	Absolute	dvr	Driver input
b	Barometric	p	Pump
c	Piston or plunger	r	Tail rod
g	Gauge	s	Suction
H	Total head	t	Theoretical
i	Inlet	Δ (delta)	Differential
max	Maximum	v	Velocity
min	Minimum	V	Volume
mot	Motor	vp	Vapor pressure
ni	Net Inlet	w	Hydraulic or water
o	Outlet	x	Exponent
oa	Overall	1	Test condition
d	Discharge	2	Specific condition

the end cover through an additional stuffing box. Its function is to provide a hydraulic force balance on the liquid piston by equalizing the net double-acting piston areas.

6.6.3.5.4 Slip (S)

The loss of rate of flow, expressed as a fraction or percent of displacement, due to leaks past the valves (including the back flow) caused by delayed closing and flow past double acting pistons. Slip does not include fluid compressibility or leakage from the liquid end.

6.6.3.5.5 Rate of flow (Q)

The quantity of liquid actually delivered per unit of time at suction conditions. It assumes no entrained gases at the stated operating conditions.

6.6.3.6 Datum

The centerline of the pump inlet from which all elevations and NPSH (NPIP) are measured. The elevation pressure (p_Z) to the datum is positive when the gauge is above datum and negative when the gauge is below datum.

6.6.3.7 Pressure (p)

Pressure is the expression of the energy content of the liquid in units of force per unit area.

6.6.3.7.1 Gauge pressure (p_g)

The pressure energy of the liquid determined by a pressure gauge or other pressure-measuring device, relative to the atmosphere.

6.6.3.7.2 Elevation pressure (p_Z)

The potential energy of the liquid due to elevation of the gauge or liquid surface above or below the datum, expressed as equivalent pressure.

6.6.3.7.3 Elevation head (Z)

The vertical distance from the centerline of a pressure gauge or liquid surface to the datum.

6.6.3.7.4 Velocity pressure (p_v)

The kinetic energy of the liquid flow expressed in equivalent pressure. It is determined as follows:

$$\text{(Metric)} \quad p_v = \frac{v^2/2g}{.102} \times s$$

$$\text{(US units)} \quad p_v = \frac{v^2/2g}{2.31} \times s$$

6.6.3.7.5 Total suction pressure

The total suction pressure is the algebraic sum of the suction gauge pressure, the velocity pressure and the elevation pressure measured on the suction side of the pump:

$$\text{(Metric)} \quad p_s = p_{gs} + \frac{[v_s^2/2g + Z_s]s}{.102} \; kPa$$

$$\text{(US units)} \quad p_s = p_{gs} + \frac{[v_s^2/2g + Z_s]s}{2.31} \; kPa$$

The velocity pressure, $v_s^2/2g$, is computed for the liquid velocity at the point of gauge attachment.

The elevation head, Z, is referred to the datum and is positive when above datum and negative when below datum.

6.6.3.7.6 Total suction lift

When the total suction pressure is negative, it is often called total suction lift.

6.6.3.7.7 Total discharge pressure (p_d)

The total discharge pressure is the algebraic sum of the discharge gauge pressure, the velocity pressure and the elevation pressure measured on the discharge side of the pump:

$$\text{(Metric)} \quad p_d = p_{gd} + \frac{[v_d^2/2g + Z_d]s}{.102} \; kPa$$

$$\text{(US units)} \quad p_d = p_{gd} + \frac{[v_d^2/2g + Z_d]s}{2.31} \; kPa$$

6.6.3.7.8 Total differential pressure (p_H)

The total differential pressure is the measure of the pressure increase imparted to the liquid by the pump and is therefore the difference between the total discharge pressure and the total suction pressure:

$p_H = p_d - p_s$

6.6.3.7.9 Net positive suction head available (NPSHA) (Net positive inlet pressure (NPIPA))

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

$$NPSHA(NPIPA) = p_{sa} - p_{vp}$$

Where:

p_{sa} = total suction pressure + barometric pressure = $p_s + p_b$

or

$$NPSHA\ (NPIPA) = p_s + p_b - p_{vp}$$

6.6.3.7.10 Net positive suction head required (NPSHR) (Net positive inlet pressure required (NPIPR))

Net positive suction head required (NPSHR) is the total suction head in pressure absolute, determined at the suction nozzle and referred to datum, less the absolute vapor pressure of the liquid required to prevent more than 3% loss in rate of flow from the pump at a specific pressure and speed.

6.6.3.8 Power (P)

Power is the work requirement per unit of time to operate the pump, expressed in the following units:

1) Metric – kilowatts;

2) US units – horsepower.

6.6.3.8.1 Pump output power (P_w)

The power imparted to the liquid by the pump. It is also called water horsepower or liquid horsepower.

(Metric) $P_w = Q \times p_H / 3600$

(US units) $P_w = Q \times p_H / 1714$

6.6.3.8.2 Pump input power (P_p)

The power delivered to the pump shaft at the driver to the pump coupling. It is sometimes called brake horsepower.

6.6.3.8.3 Total input power (p_{mot})

The power required by the pump motor or prime mover. It is sometimes called the motor power or driver power.

6.6.3.8.4 Pump efficiency (η_p)

The ratio of the pump output power to the pump input power expressed as a percent:

$$\eta_p = (P_w / P_p) \times 100$$

6.6.3.8.5 Overall efficiency (η_{OA})

The ratio of the pump output power to the total input power expressed as a percent:

$$\eta_{OA} = (P_w / P_{mot}) \times 100$$

6.6.3.8.6 Volumetric efficiency (η_V)

The ratio of the pump rate of flow to its displacement expressed as a percent:

$$\eta_v = \frac{Q}{D} \times 100$$

6.6.4 Performance test

6.6.4.1 Performance test acceptance

The acceptance tolerance applies to the rated condition point only.

While pumps must be closely checked for satisfactory mechanical operation during performance testing, the degree and extent of such checking is independent of the level of acceptance tolerances.

6.6.4.2 Witnessing of performance tests

The purchaser or purchaser's designated representative may witness the test when requested by the purchaser in the purchase order.

6.6.4.3 Performance test acceptance values

The following sections describe acceptable variations from rated values for certain test parameters.

6.6.4.3.1 Type I performance test

Type I test is the manufacturer's standard production test for quality assurance and to establish conformance with the manufacturer's commercial mechanical or performance criteria.

6.6.4.3.2 Type II performance test (in addition to Type I)

Speed shall be not less than 50% of rated speed, and discharge pressure shall be between 100% and 105% of rated pressure. Rate of flow shall have no negative tolerance after correction to rated speed from actual test speed.

6.6.4.3.3 Type III performance test (in addition to Type I & II)

Pump mechanical efficiency shall not be less than 99% of rated efficiency. Power shall not be more than 106% of rated power to allow for the tolerance in rate of flow and efficiency.

6.6.4.4 Performance test instrumentation

6.6.4.4.1 Introduction

Performance test instrumentation shall be selected so that it can provide measurements with the accuracy shown in Section 6.6.4.4.2 at rated conditions. Instruments need not be calibrated specifically for each test but are to be periodically calibrated by the instrument manufacturer or other suitable party. Refer to Table 6.20 for suitable period between calibration for performance test instruments.

6.6.4.4.2 Instrument fluctuation[1] and accuracy

Acceptable fluctuation of test readings during test and accuracy of instruments is as shown in the following table:

Actual measurement

	Acceptable fluctuation of test reading ± % of the values	Accuracy of the instrument as a ± % of the values
Rate of flow	5	1.5
Differential pressure	2	1
Discharge pressure	2	1
Suction pressure	2	1
Input power	2	1.5
Pump speed	0.3	0.3

6.6.4.5 Performance test setup

This section contains general guidelines for pump test setup to ensure accurate and repeatable test results (see Figure 6.65). It must be understood that test setups which do not conform with respect to intake structure, piping and measuring equipment may not duplicate test facility results.

The pump test may utilize, but is not limited to, the following:

1) Factory or purchaser furnished driver. Depending on the method used to measure pump input power, driver efficiency data may be required;

2) Factory or purchaser furnished speed reduction unit, if required. To accurately establish pump input power, efficiency data of the speed reducer may be required;

3) A suction pipe or hose from a booster pump, closed tank or open sump, properly sized for the pump being tested. The flow into the pump is to be free from swirl and have symmetrical velocity distribution;

[1] To avoid erroneous results due to inherent pulsing flows, instrumentation with sensitivity to frequency response less than the pumping stroke frequency shall be employed.

4) A compound pressure gauge suitable for measuring the complete range of suction pressures, whether positive or negative;

5) A discharge pipe or hose with a pressure breakdown (throttling) device;

6) A discharge pressure gauge or gauges suitable for measuring the complete range of pressures;

7) Dampening devices may be used for the suction and discharge gauges, such as needle valves or capillary tubes to dampen out the pressure pulsations at the gauges;

8) A means for measuring input power to the pump shall be provided and shall be suitable for measuring the complete range of power;

9) A means for measuring pump speed;

10) Test setups intended for NPSH testing shall be provided with a means for lowering the NPSH to the pump, (such as a suction throttle valve with optional screen or straightening vanes), variable level sump, suction tank vacuum pump or suction tank heater;

11) A means for measuring the temperature of the test liquid;

12) The actual dimensions of the suction and discharge openings where pressure readings are to be taken shall be determined, so that proper velocity pressure calculations can be made.

6.6.4.6 Performance test procedure

The following data, where applicable, shall be obtained prior to the test run (see sample data sheet on page 8):

1) Record of pump type, size and serial number;

2) Verification of liquid properties and temperature shall be taken before and after testing (more often during NPSH tests or with high power pumps);

3) Ambient temperature and barometric pressure;

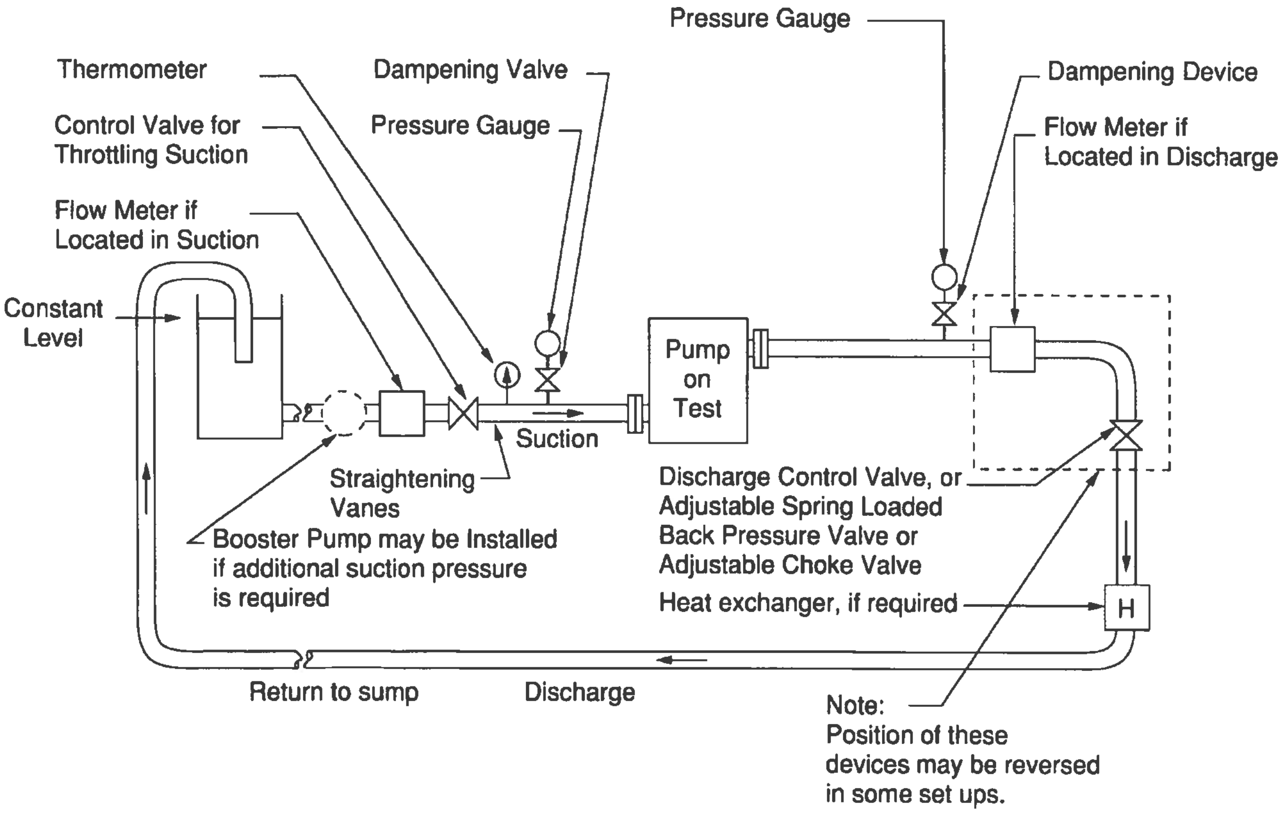

Figure 6.65 — Open or closed tank

Summary of necessary data on pumps to be tested

The following information should be furnished on pumps to be tested:

General:

1. Owner's name ______
2. Plant location ______
3. Elevation above sea level ______
4. Type of service______

Pump:

1. Manufactured by ______
2. Manufacturer's designation ______
3. Manufacturer's serial number______
4. Arrangement: horiz______ vertical______
5. Size suction: nominal ______
   actual ______
6. Size discharge: nominal ______
   actual ______

Intermediate transmission:

1. Manufactured by ______
2. Type______
3. Serial number______
4. Speed ratio______
5. Efficiency ______

Driver:

1. Manufactured by ______
2. Serial number______
3. Type: motor ____ turbine ____other______
4. Rated power ______
5. Rated speed ______
6. Characteristics (voltage, frequency, etc.)______
   ______
7. Calibration data ______
8. Efficiency ______

Specifying rated conditions

The following information is necessary in specifying rated conditions:

1. Liquid pumped (water, oil, etc.) ______
   ______
2. Specific weight______
3. Viscosity at pumping temperature ______
4. Temperature______
5. Vapor pressure______
6. Rate of flow ______
7. Total suction lift ______
8. Total suction pressure ______
9. Net positive suction head required (NPSHR) ______
10. Total discharge pressure ______
11. Total differential pressure ______
12. Output power ______
13. Efficiency (η_p)______
14. Input power ______
15. Speed ______

Test information

Test information should be listed substantially as follows:

General:

1. Where tested ______
2. Date ______
3. Tested by ______
4. Test witnessed by______

Rate of flow:

1. Method of measurement______
   ______
2. Meter—make and serial number ______
   ______
3. Calibration data______
4. Water temperature ______

Pressure:

1. Suction gauge—make and serial number
   ______
2. Calibration data______
   ______
3. Discharge gauge—make and serial number
   ______
4. Calibration data______
   ______

Power:

1. Method of measurement______
   ______
2. Make and serial number of instrument
   ______
3. Calibration data ______
   ______

Speed:

1. Method of measurement______
   ______
2. Make and serial number of instrument
   ______
3. Calibration data______
   ______

4) Records of critical installation dimensions such as tank internal dimensions, pipe internal dimensions and liquid levels relative to datum;

5) Driver data such as type, power, speed range, amperage, voltage and efficiency;

6) Auxiliary equipment data such as speed reduction gears, vibration monitors, pressure monitors, leakage detectors, alarms, etc.;

7) Calibration records and correction factors in accordance with instrumentation section;

8) Identity and authority levels of test personnel;

9) Dimensions of pipes where pressure readings are to be taken, so that proper velocity pressure calculations can be made.

6.6.4.7 Performance test records

Complete written or computer records shall be kept of all information relevant to the test and retained on file, available to the purchaser from the test facility for two years.

6.6.4.8 Performance test calculations

See Table 6.15 for terms and units for the symbols used.

6.6.4.8.1 Calculations of inlet or suction pressure (p_s)

$$\text{(Metric)}\quad p_s = p_{gs} + \frac{s}{.102}\left(\frac{v_s^2}{2g} \pm Z_s\right)$$

$$\text{(US units)}\quad p_s = p_{gs} + \frac{s}{2.31}\left(\frac{v_s^2}{2g} \pm Z_s\right)$$

6.6.4.8.2 Calculation of outlet or discharge pressure (p_d)

$$\text{(Metric)}\quad p_d = p_{ds} + \frac{s}{.102}\left(\frac{v_d^2}{2g} \pm Z_d\right)$$

$$\text{(US units)}\quad p_d = p_{ds} + \frac{s}{2.31}\left(\frac{v_d^2}{2g} \pm Z_d\right)$$

6.6.4.8.3 Calculation of total differential pressure

$$p_H = p_d - p_s$$

6.6.4.8.4 Calculation of input power

The input power, when measured by transmission dynamometer or torque meter is:

$$\text{(Metric)}\quad P_p = \frac{n\tau}{60{,}000}$$

$$\text{(US units)}\quad P_p = \frac{n\tau}{5250}$$

The input power, when measured by a calibrated electric motor is:

$$\text{(Metric)}\quad P_p = P_{mot}\frac{\eta_{mot}}{100} = kW \times \frac{\eta_{mot}}{100}$$

$$\text{(US units)}\quad P_p = P_{mot}\frac{\eta_{mot}}{100} = \frac{kW \times \frac{\eta_{mot}}{100}}{.746}$$

Where:

kW = Kilowatt input to motor;

η_{mot} = Efficiency of motor.

6.6.4.8.5 Calculation of output power (water horsepower)

$$\text{(Metric)}\quad P_w = \frac{Qp_H}{3600}$$

$$\text{(US units)}\quad P_w = \frac{Qp_H}{1714}$$

6.6.4.8.6 Calculation of efficiency

$$\eta = \frac{P_w}{P_p} \times 100$$

6.6.4.8.7 Plotting performance test results

Rate of flow, power and efficiency are usually plotted as ordinates on the same sheet with differential pressure as the abscissa, as shown in Figure 6.66.

6.6.4.8.8 Performance correction to rated speed

When available equipment (e.g., speed reduction gear) prevents operation at the rated speed, the test shall be run at reduced speed and at rated differential pressure. Rate of flow, power and NPSH shall be corrected from test speed to rated speed as follows:

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

$$P_2 = \frac{n_2 P_1}{n_1}$$

$$NPSH_2 = \left[\frac{n_2}{n_1}\right]^2 NPSH_1$$

6.6.4.8.9 Performance correction for viscosity

Viscosity has an effect on volumetric efficiency and input power. Pumps for viscous service which are tested with water may require corrections to approximate the performance with the viscous liquid.

6.6.4.9 Report of performance test

A plot of test results is the normal content of the test report. All parties to the test shall be furnished a copy of this report.

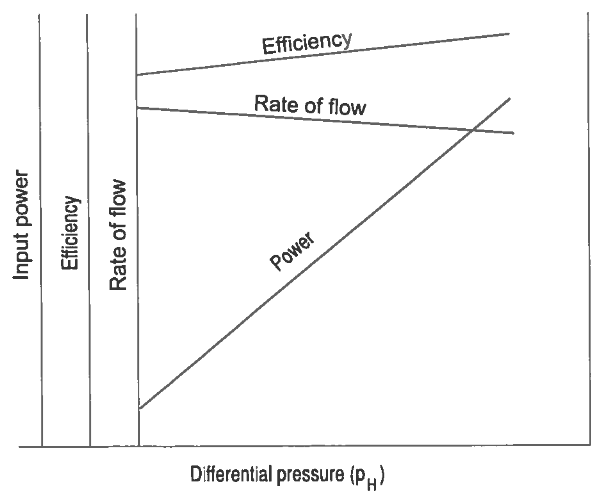

Figure 6.66 — Plotting test results

6.6.5 Hydrostatic test of pressure-retaining components

6.6.5.1 Hydrostatic test objective

To demonstrate that the pump when subjected to liquid pressure will not leak or fail structurally.

For the purpose of this requirement, "will not leak" means only prevention of escape of liquid through the external surfaces of the pump, normally to atmosphere.

6.6.5.2 Hydrostatic test parameters

Each part of the pump that contains liquid under pressure shall be capable of withstanding a hydrostatic test at not less than 150% of the pressure that would occur in that part when the pump is operating at rated conditions for the given application of the pump.

Components or assembled pumps — The test shall be conducted on either the liquid-containing components or the assembled pump.

Components — The test shall be conducted on the liquid-containing components such as pump cylinders. Care must be taken not to impose pressure in excess of 150% of design on areas designed for lower pressure operation.

Assembled pump — The test shall be conducted on the entire liquid-containing area of the pump, but care must be taken not to impose pressure in excess of 150% of design on areas such as inlet manifolds.

Test duration — Test pressure shall be maintained for a sufficient period of time to permit complete examination of the parts under pressure. The hydrostatic test shall be considered satisfactory when no leaks or structural failures are observed for a minimum of 3 minutes for pumps 75 kW (100 horsepower) and below, 10 minutes above 75 kW (100 horsepower).

Test liquid — Test liquid shall be water or oil having a maximum viscosity of 32 centistokes (150 SSU) at test temperature.

Temperature — If the part tested is to operate at a temperature at which the strength of material is below the strength of the material at room temperature, the hydrostatic test pressure should be multiplied by a factor obtained by dividing the allowable working stress for the material at room temperature by that at operating temperature. The pressure thus obtained will then be the minimum pressure at which hydrostatic pressure should be performed. The data sheet should list the actual hydrostatic test pressure.

6.6.5.3 Hydrostatic test procedure

Components to be tested shall have all the openings adequately sealed. Provisions must be made to vent all the air at the highest point on the component. The item shall be filled with the test liquid, pressurized, and the test pressure shall be maintained for the duration of the test. No leakage through the component tested shall be visible; however, leakage through the stuffing box packing or between valves and seat shall be permitted.

6.6.5.4 Hydrostatic test records

Complete written or computer records shall be kept of all pertinent information and retained on file, available to the user by the test facility for two years. This information should include:

1) Identification by models, sizes, serial number;

2) Test liquid;

3) Maximum allowable pressures and temperature;

4) Hydrostatic test pressure and test durations.

6.6.6 Net positive suction head required (NPSHR) test

6.6.6.1 NPSHR test objective

To determine the net positive suction head required NPSHR (NPIPR) required by the pump.

6.6.6.2 NPSHR test equipment (test circuit)

Three typical arrangements are shown for determining the cavitation characteristics of pumps.

In the first arrangement, Figure 6.65, the pump is supplied from a constant level supply through a throttle valve, which is followed by a section of pipe containing straightening vanes or seven diameters of straight pipe to straighten the flow. This arrangement dissipates the turbulence produced by the throttle valve and makes possible an accurate reading of suction pressure at the pump inlet.

This simple arrangement usually is satisfactory for NPSHR greater than 35 kPa (5 psi), 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 6.67, the pump is supplied from a sump in which the liquid level can be varied to establish the desired NPSH. This arrangement provides an actual suction lift and hence more nearly duplicates operating conditions of pumps on water service. Care should be taken to prevent vortexing as the liquid level is varied.

In the third arrangement, Figure 6.68, the pump is supplied from a closed tank in which the level is held constant and the NPSH is adjusted by varying the air or gas pressure over the liquid, 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. This arrangement more nearly duplicates service conditions where a pump takes its supply from a closed vessel with the liquid at or near its vapor pressure. It is also acceptable to test with a closed loop without the closed tank on the suction side.

6.6.6.3 NPSHR test liquid

Water shall be used.

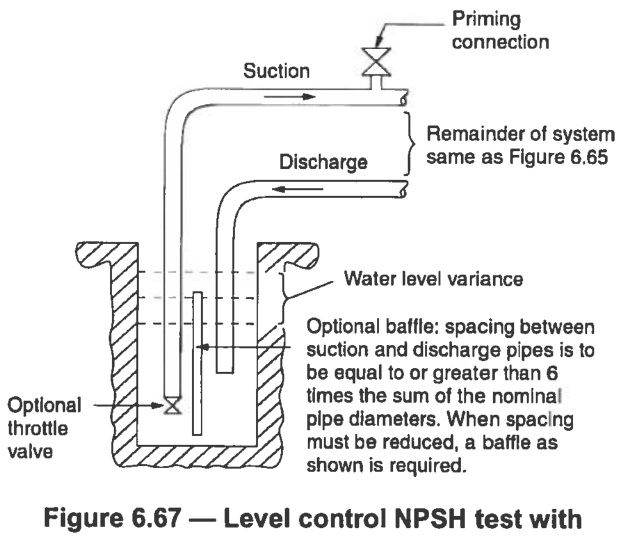

Figure 6.67 — Level control NPSH test with deep sump supply

6.6.6.4 NPSHR test aeration of water

Water aeration shall be minimized by taking the following precautions:

- Submerged return lines;
- Reservoir sized to allow air removal achieving required pressures, positive or negative;
- Inlet line properly located to prevent vortexing;
- Reservoir baffles to isolate inlet from return line;
- Pipe joints and stuffing boxes tightened to guard against air leakage into the system;
- Use of suction stabilizer with air collection space located as close as possible to the pump suction connection.

6.6.6.5 NPSHR test procedure

The NPSH test should be performed at constant differential pressure (specified pressure unless limited by available power) and speed while measuring rate of flow at different values of NPSH available. The NPSH should be incrementally reduced until rate of flow loss reaches 3%.

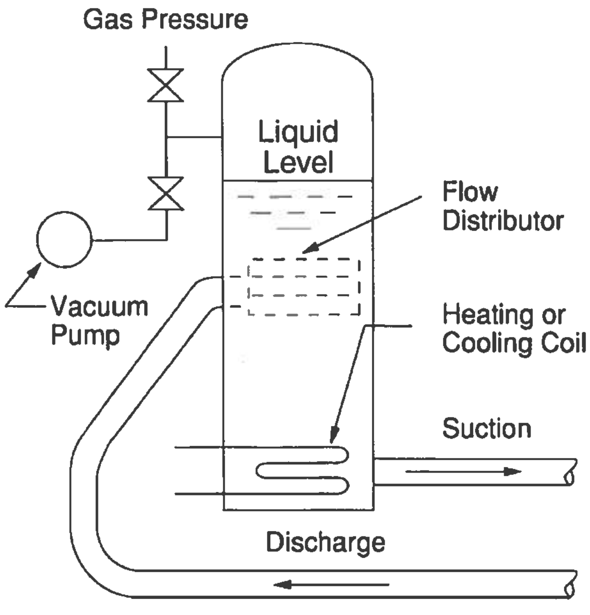

Figure 6.68 — Vacuum and/or heat control NPSH test with closed loop

When in service, the pump must be operated above the NPSHR if pitting, noise, vibration unstable operation and even mechanical failure are to be avoided. The margin of operating NPSHA above NPSHR depends upon the particular pump, liquid and installation.

During test, caution must be taken to avoid operation in deep cavitation. If that should occur with suction valve throttling, the discharge valve should be opened to release the pump load simultaneously with the opening of the suction throttle valve.

6.6.6.5.1 NPSHR correction to rated speed

$$NPSHR_2 = \left[\frac{n_2}{n_1}\right]^2 NPSHR_1$$

Where:

n_1 = test speed in rpm;

n_2 = rated speed in rpm.

If it can be demonstrated that with a particular pump under specific operating conditions and exponent different from that of the square of the speed exists, such an exponent may be recognized and used.

6.6.6.5.2 Tolerance of NPSHR test parameters

Test parameters shall be maintained within the limits shown.

Test parameter	Maintain within % of required
Speed	± 7%[a]
Pressure	± 2%
Temperature	± 3%

[a] Subject to available gear ratios and A.C. frequency. Agreement by parties to the test must be obtained if greater variation is necessary.

6.6.6.5.3 NPSHR test data presentation

The results (when sensed by rate of flow reduction) shall be plotted on graph paper. The abscissa indicates NPSHA (NPIPA) of water and the ordinate indicates rate of flow. The NPSHR (NPIPR) for the pump shall be marked on the curve (see Figure 6.69).

When required, additional curves may be generated by varying pump speed or the liquid viscosity, therefore producing a family of curves illustrating the effect of those parameters.

6.6.7 Measurement of rate of flow

Any technically sound flow-measuring system can be used for measuring pump rate of flow. However, it must be installed so that the entire pump flow is passing through the instrument section.

Rate of flow instruments are classified into two functional groups. One group primarily measures batch quantity, and the other primarily measures rate of flow.

6.6.7.1 Rate of flow measurement by weight

Measurement of rate of flow by weight depends upon the accuracy of the scales used and the accuracy of the measurement of time. A certification of scales shall become part of the test record, or, in the absence of certification, the scales shall be calibrated with standard weights before or after test. Time intervals for the collection period must be measured to an accuracy of one-quarter of one percent.

6.6.7.2 Rate of flow measurement by volume

This is done by measuring the change in volume of a tank or reservoir during a measured period of time.

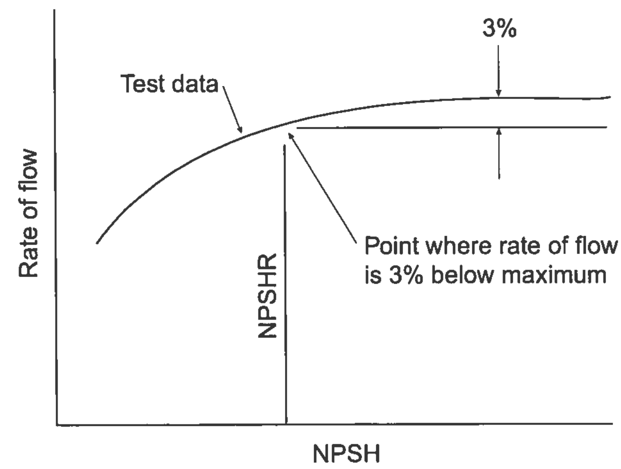

Figure 6.69 — NPSHR test results

The tank or reservoir can be located on the inlet or discharge side of the pump, and all flow into or out of the tank or reservoir must pass through the pump.

In establishing reservoir volume by linear measurements, consideration must be given to the geometric regularity (flatness, parallelism, roundness, etc.) of the reservoir surfaces as well as dimensional changes due to thermal expansion or contraction or distortion resulting from hydrostatic pressure of the liquid.

Liquid levels shall be measured by means such as hook gauges, floats and vertical or inclined gauge glasses.

In some locations and under some circumstances, evaporation and loss of liquid by spray may be significant and may be greater than the effects of thermal expansion or contraction. Allowance for such loss shall be made, or the loss shall be prevented.

6.6.7.3 Rate of flow measurement by displacement type meters

Meters responsive to displacement include piston meters, wobble plate meters, rotary vane meters and the like.

For such meters to comply with this standard, they must be certified to be insensitive to the effects of pulsating flow, be calibrated at the pulsation rate with liquid of similar viscosity and density, or be isolated from pulsation by the use of effective pulsation stabilizers or dampeners.

6.6.7.4 Rate of flow measurements by head type rate meters

This is done by introducing a reduced area in the flow stream which results in a reduction in gauge head as the velocity is increased. The gauge head differential is measured and used to determine the rate of flow. The meters discussed in Sections 6.6.7.4.1, 6.6.7.4.2 and 6.6.7.4.3 use this principle.

Meters falling within this classification, and acceptable for rate of flow determination under this standard, when used as prescribed herein, are venturi meters, nozzles and orifice plates.

For any such meter, compliance with the standard requires that a certified curve showing the calibration of the meter be obtained from the calibrating agency. This certification must state the method used in calibration and whether the meter itself was calibrated, or whether calibration was obtained on an exact duplicate.

When a flow meter is used on the discharge, it is preferable to install it in the high-pressure section between the pump and the pressure breakdown valve. If the working pressure of the meter is lower than the maximum pump discharge pressure, it may be installed downstream of the pressure breakdown valve, with a back pressure valve located downstream of the flow meter to ensure that the pressure will stay above vapor pressure during operation.

These precautions are stipulated to assure uniform flow velocity within ± 20% at the meter inlet and stable flow at the downstream pressure taps. If there is a question as to whether or not uniform flow has been obtained, it shall be checked by a velocity head traverse of the pipe immediately preceding the meter to assure symmetrical velocity distribution within the pipe.

The pipe for one diameter preceding the upstream pressure taps shall be free from tubercles or other surface imperfections which would establish a local disturbance in line with these openings. Pressure tap openings shall be flush with the interior of the pipe or meter element, as appropriate, and shall be free of burrs (see Figures 6.70 and 6.71).

Suction stabilizers or discharge dampeners may be required to provide sufficiently smooth flow to the meter.

A reciprocating pump should not pump directly into a head type meter.

6.6.7.4.1 Rate of flow measurement by venturi meter

All provisions of Section 6.6.7.4 covering head type rate meters are applicable to rate of flow measurement by venturi meter.

To ensure accurate results in the measurement of rates of flow with venturi meters, certain minimum lengths of straight pipe are required upstream of the meter. Table 6.19 shows these minimum lengths expressed in terms of equivalent diameters.

6.6.7.4.2 Rate of flow measurement by nozzles

All provisions of Section 6.6.7.4 covering head type rate meters are applicable to rate of flow measurement by nozzles.

To ensure accurate results in the measurement of rates of flow with nozzle type meters, a sufficient length of straight pipe is required preceding and following the nozzle inlet. Table 6.17 shows the length of straight pipe required, expressed in terms of equivalent diameters.

6.6.7.4.3 Rate of flow measurement by thin square-edged orifice plate

All provisions of Section 6.6.7.4 covering head type rate meters are applicable to rate of flow measurement by thin square-edged orifice plate.

Whenever possible, the orifice plate should be calibrated in place in the piping system by weight or volume. When this is not possible, a certified curve showing the calibration of the orifice plate shall be

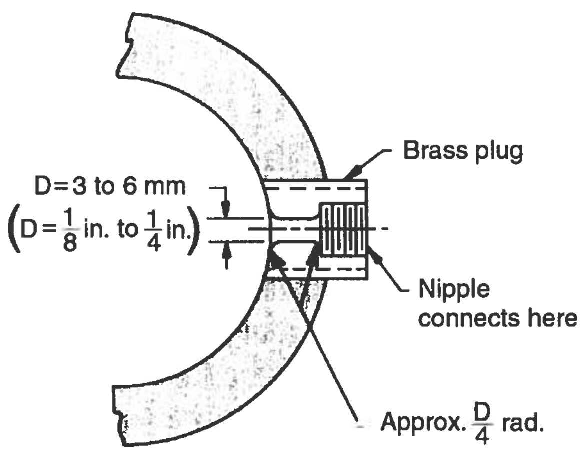

Figure 6.70 — Pressure tap opening

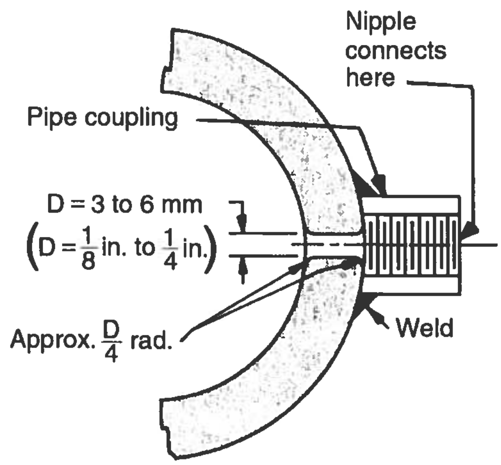

Figure 6.71 — Welded-on pressure tap opening

obtained. This certification shall conform to requirements given under the section on head type rate meters and shall, in addition, 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 sufficient length of straight pipe is required preceding and following the orifice plate. Tables 6.18 and 6.19 show the length of straight pipe required between fittings and the meter. Suction stabilizers or discharge dampeners are usually required to reduce flow pulsations to below the threshold of meter sensitivity.

6.6.7.5 Rate of flow measurement by pitot tubes

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

Where it is impossible to employ one of the methods described above, the pitot tube may be used. When the flow conditions are steady during the time required to make a traverse that is with variations less than ± 0.5%, and when used by a qualified person, the flow may be determined with a fair degree of accuracy.

The procedure set forth in the ANSI/ASME PTC 18-1992, *Hydraulic Turbines*, is recommended.

6.6.7.6 Rate of flow measurement by other methods

When the methods of rate of flow measurement described above are not applicable, there are other methods not included in this standard which may be utilized, provided the accuracy of the instrument described in Section 6.6.4.5 can be demonstrated.

6.6.8 Pressure measurement

The units of pressure and the definition of total differential pressure and its component parts are covered in Section 6.6.3.7.

6.6.8.1 Pressure tap location

A minimum of two diameters of straight pipe of unvarying cross section before the suction stabilizer and after the discharge dampener following an elbow, valve or other obstruction is necessary to ensure representative flow conditions. If a stabilizer and/or a dampener is not employed, the gauge must be dampened sufficiently to prevent pulsations from affecting the gauge readings.

The opening in the pipe shall be flush with and normal to wall of the water passage.

The wall of the water passage shall be smooth and of unvarying cross section. For a distance of at least 300 mm (12 inches) preceding the opening, all tubercles and roughness shall be removed with a file or emery cloth, if necessary.

The opening shall be of a diameter from 3 to 6 mm (1/8 to 1/4 inch) and a length equal to twice the diameter.

The edge of the opening shall be provided with a suitable radius tangential to the wall of the water passage, and shall be free from burrs or irregularities. Figures

Table 6.17 — Straight pipe required preceding and following any fitting before nozzle in diameters of pipe

Meter ratio β (throat to inlet diameter)	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
Two elbows in planes at 90 degrees and with straightening vanes	2	3	4	5	7
Standard C.I. flanged reducer	2	5	7.5	10	13
Standard C.I. flanged increaser	1	2	3	4.5	6
Globe valve — and with straightening vanes	2	4	6	9	12
Gate valve — 0.2 open	2	4	6	9	12
Gate valve — 0.5 open	2	3	4	6	8
Gate valve — full open	0	0.5	1	2	3

6.70 and 6.71 show suggested arrangements of taps or orifices in conformity with the above.

Where more than one tap or orifice is required at a given measuring section, a separate connection, properly valved, shall be made. As an alternative, separate instruments shall be provided.

Multiple pressure taps shall not be connected to a head-measuring instrument unless there will be not more than 1% pressure variation between pressures at each opening.

6.6.8.2 Measurement of pressure by means of gauges

The terminology in Section 6.6.3 applies to Figure 6.72 where temperature effects are negligible.

Table 6.18 — Straight pipe required following any fitting before orifice 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
Tee or wye with in-line flow	6	6	6.5	7	8.5	10.5	14
One elbow, branch flow through tee to 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 the same plane	7.5	7.5	8.5	10.5	13.5	18	25
Two or more long radius elbows or bends in the 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

Table 6.19 — Straight pipe required after downstream pressure tap of a nozzle or orifice plate before any fitting 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
Tee or wye with in-line flow	0	0	0	0	0	3.5	4
Expansion joint	0	0	0	0	0	3.5	4
45-degree 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

The quantities (Z_d and Z_s) are negative if the gauge center is below the datum elevation.

6.6.8.3 Measurement of pressure by means of calibrated gauges

Some applicable types of pressure indicators are:

- Pressure transducers-strain gauge and magnetic type;
- Diaphragm-activated magnetic linkage type;
- Bellows-activated torque to transfer type;
- Bourdon tube-actuated gear type.

All gauges shall be calibrated before and after each series of tests.

6.6.8.4 Measurement of pressure by other methods

When the methods of quantity measurement described above are not applicable, there are other methods not included in this standard which may be utilized, provided the accuracy of the instrument can be demonstrated.

6.6.9 Power measurements

Pump input power may be determined by transmission dynamometers, torsion dynamometers, strain gauge type torque-measuring devices, calibrated motors or other sufficiently accurate measuring devices.

When applicable, readings of power shall be taken at the same time that rate of flow is measured.

Methods of measurement of power input to the pump fall into two general categories:

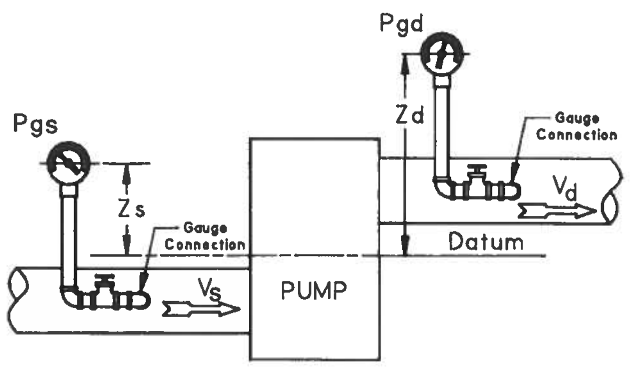

Figure 6.72 — Gauge connections

- Those which determine the actual power or torque delivered to the pump and are made during the test by some form of dynamometer or torque meter;
- Those which determine the power input to the driving element, taking into account the driver efficiency when operating under specific conditions.

When pump input power is determined by transmission dynamometers, the unloaded dynamometer shall be statically checked prior to the test by measuring the load reading deflection for a given torque; and by taking the tare reading on the dynamometer scale at rated speed with the pump disconnected. After the test, the dynamometer shall be rechecked to assure that no change has taken place. In the event of a change of ± 0.5% of the power at BEP, the test shall be rerun. An accurate measurement of speed within ± 0.3% is essential.

The use of calibrated dynamometers or motors is an acceptable method for measurement of input power to the pump.

Calibration of the torsion dynamometer shall be conducted with the torsion-indicating means in place. The indicator should be observed with a series of increasing loadings and then with a series of decreasing loadings. During the taking of readings with increasing loadings, the loading is at no time to be decreased; similarly, during the decreasing loadings, the loading should be based on the average of the increasing and decreasing loadings as determined by the calibration. If the difference in readings between increasing and decreasing loadings exceeds 1%, the torsion dynamometer shall be deemed unsatisfactory.

Dynamometers shall not be employed for testing pumps with a maximum torque below one-quarter of the rated dynamometer torque.

When strain gauge type torque measuring devices are used to measure pump input horsepower, they shall be calibrated, with their accompanying instrumentation, at regular intervals. After the test, the readout instrumentation balance shall be rechecked to assure that no appreciable change has taken place. In the event of a change of ± 0.5% of the power at BEP, the test shall be rerun.

Calibrated electric motors are satisfactory to determine the power input to the pump shaft. The electrical input to the motor is observed, and the observations are multiplied by the motor efficiency to determine the power input to the pump shaft.

Calibrated laboratory type electric meters and transformers shall be used to measure power input to all motors.

6.6.10 Speed measurement

Test speeds for pumps may be in the range of tens to thousands of revolutions per minute. Since the pump test data are taken under steady state conditions, the maximum permissible short term speed fluctuation shall be no more than 0.3%. The instruments should also be capable of measuring speed with an accuracy of ± 0.3%. The speed measuring methods described, therefore, are those which, at moderate speeds, give a measure of the average speed over an interval of from less than one second up to one to two minutes, depending on the type of instrumentation.

The revolution counter and timer method, as its name implies, involves the counting of the number of revolutions or strokes over an interval of time. A major source of error is inexact synchronization of counter and timer. If synchronization is automatic (e.g., digital tachometers), accuracy is achieved over a time interval of a few seconds. If a handheld counter and stopwatch are used, the timing interval should be about two minutes. During this time, the speed must, of course, be constant, and stoppage of the counter on the shaft must be avoided. The stopwatch should be periodically checked against a standard timer.

Tachometers provide a direct reading of speed averaged over a fixed time interval. Some types automatically repeat the reading process. Hand-held units must be reset manually. The above comments regarding uniform speed and slippage pertain here also. A tachometer should be checked periodically against a counter and stopwatch.

Frequency-responsive devices have the advantage of not requiring direct contact with the motor or pump shaft and hence impose no additional load on the motor. The vibration reed type is of use only when the shaft is completely inaccessible.

Electronic units may be converted to read RPM directly using a shaft-mounted gear and a non-contacting magnetic pickup. This 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.

Most stroboscopes are limited in accuracy due to uncertainty in the precision of the strobe frequency. The only approach suitable for pump test purposes is to use the strobe to determine motor slip under load relative to synchronous speed, using a stopwatch to time the slippage while driving the strobe at line frequency (which is known to the accuracy given above and can be determined with even greater precision for the time and location of the test).

6.6.11 Temperature measurement

Temperature should be measured as close to the pump inlet as possible The temperature measuring device shall have no effect on the measurements of pressure and rate of flow.

6.6.12 Instrument calibration interval

Table 6.20 shows the recommended instrument calibration interval for the variety of instruments used in this standard.

Table 6.20 — Recommended instrument calibration interval[a]

Rate of Flow	
Quantity meter	
Weighing tanks	1 yr
Volumetric tank	10 yr
Rate meters	
Venturi	[c]
Nozzle	[c]
Orifice plate	[c]
Weir	[c]
Turbine	1 yr
Magnetic flow	1 yr
Rotameter	5 yr
Propeller	1 yr
Ultra-sonic	5 yr
Pressure	
Bourdon tube (pressure gauge)	4 mo
Manometers	Not req'd
Dead weight tester	1 yr
Transducers	4 mo
Digital indicator	1 yr
Power	
Dynamometer w/scale	6 yr
Dynamometer w/load scale	6 mo
Power (*continued*)	
Torque bar	1 yr
Calibrated motor	Not req'd[b]
KW Transducer	3 yr
Watt-amp-volt, portable	1 yr
Watt-amp-volt, permanent	1 yr
Strain gauges	6 mo
Transmission gears to 500 HP	10 yr
Transmission gears above 500 HP	20 yr
Speed	
Tachometers	3 yr
Eddy current drag	10 yr
Electronic	Not req'd [b)]
Frequency-responsive devices	
Vibrating reed	10 yr
Electronic	10 yr
Photocell	10 yr
Stroboscopes	5 yr
Torque meter (speed)	1 yr
Temperature	
Electric	2 yr
Mercury	5 yr

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

[b] Unless electrical or mechanical failure.

[c] Calibration is not required unless it is suspected there are critical dimensional changes.

Appendix A

Index

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

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

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