

Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries

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Introduction

It is necessary that users of this standard be aware that further or differing requirements can be needed for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly appropriate where there is innovative or developing technology. Where an alternative is offered, it is necessary that the vendor identify any variations from this standard and provide details.

A bullet (•) at the beginning of a section or subsection indicates that either a decision is required or the purchaser is required to provide further information. It is necessary that this information be indicated on data sheets or stated in the inquiry or purchase order (see examples in Annex N).

This standard shows U.S. customary (USC) units with other units in parentheses for information.

Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries

1 Scope

This standard specifies requirements for centrifugal pumps, including pumps running in reverse as hydraulic power recovery turbines (HPRTs), for use in petroleum, petrochemical, and gas industry process services.

This standard is applicable to overhung pumps, between-bearings pumps, and vertically suspended pumps (see Table 1). Section 9 provides requirements applicable to specific types of pumps. All other sections of this standard are applicable to all pump types. Illustrations are provided of the various specific pump types and the designations assigned to each specific type.

Relevant industry operating experience suggests pumps produced to this standard are suitable for pumping liquids at conditions exceeding any one of the following:

- discharge pressure (gauge): 275 psi; 19.0 bar (1900 kPa);
- suction pressure (gauge): 75 psi; 5.0 bar (500 kPa);
- pumping temperature: 300 °F (150 °C);
- rotational speed: 3600 r/min;
- rated total head: 400 ft (120 m);
- impeller diameter, overhung pumps 13 in. (330 mm).

NOTE For sealless pumps, reference can be made to API 685.

2 Normative References

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

API Standard 5L, *Line Pipe*

API Standard 541, *Form-wound Squirrel Cage Induction Motors—375 kW (500 Horsepower) and Larger*

API Standard 547, *General Purpose Form-wound Squirrel Cage Induction Motors—185 kW (250 hp) through 2240 kW (3000 hp)*

API Standard 611, *General-purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services*

ANSI ¹/API Standard 614, *Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries*

API Standard 670, *Machinery Protection Systems*

API Standard 671, *Special-purpose Couplings for Petroleum, Chemical, and Gas Industry Services*

API Standard 677, *General-purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

¹ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org

API Standard 682, *Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps*

ANSI B11.19-2010, *Performance Criteria for Safeguarding*

ANSI/ABMA 7 ², *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plan*

ANSI/AGMA 9000 ³, *Flexible Couplings—Potential Unbalance Classification*

ANSI/AGMA 9002, *Bores and Keyways for Flexible Couplings (Inch Series)*

ANSI/ASME B1.1 ⁴, *Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)*

ANSI/AWS D1.1, *Structural Welding Code—Steel*

ANSI/HI 14.6 ⁵, *Rotodynamic Pumps for Hydraulic Performance Acceptance Tests*

ASME B1.13M, *Metric Screw Threads: M Profile*

ASME B16.5, *Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard*

ASME B16.11, *Forged Fittings, Socket-Welding and Threaded*

ASME B16.47, *Larger Diameter Steel Flanges NPS 26 Through NPS 60 Metric/Inch Standard*

ASME B18.18.2M, *Inspection and Quality Assurance for High-Volume Machine Assembly Fasteners*

ASME B31.3, *Process Piping*

ASME Boiler and Pressure Vessel Code (BPVC), Section V, *Nondestructive Examination*

ASME Boiler and Pressure Vessel Code (BPVC), Section VIII, *Rules for Construction of Pressure Vessels*

ASME Boiler and Pressure Vessel Code (BPVC), Section IX, *Welding, Brazing and Fusing Qualifications*

DIN 910 ⁶, *Hexagon head screw plugs with collar—Cylindrical thread*

EN 287 ⁷, *Qualification test of welders—Fusion welding—Steels*

EN 953 , *Safety of machinery—Guards—General requirements for the design and construction of fixed and movable guards*

EN 1092-1, *Flanges and their joints—Circular flanges for pipes, valves, fittings and accessories, PN designated—Steel flanges*

EN 13445 (all parts), *Unfired pressure vessels*

EN 13445-4, *Unfired pressure vessels—Fabrication*

² American Bearing Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, VA 22314, www.americanbearings.org.

³ American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, VA 22314-1587, www.agma.org.

⁴ ASM International, 9639 Kinsman Road, Materials Park, Ohio 44073, www.asminternational.org.

⁵ Hydraulic Institute, 6 Campus Drive, First Floor North, Parsippany, New Jersey 07054-4406, www.pumps.org.

⁶ DIN Deutsches Institut für Normung e. V., Saatwinkler Damm 42/43, 13627 Berlin, Germany, www.din.de.

⁷ European Committee for Standardization (CEN-CENELEC), Avenue Marnix 17, B-1000 Brussels, Belgium, www.cen.eu.

EN 13463-1, *Non-electrical equipment for use in potentially explosive atmospheres—Part 1: Basic method and requirements*

IEC 60034-1⁸, *Rotating electrical machines—Part 1: Rating and performance*

IEC 60034-2-1, *Rotating electrical machines—Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*

IEC 60079 (all parts), *Explosive atmospheres*

IEEE 841⁹, *Petroleum and Chemical Industry—Premium-Efficiency, Severe Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)*

ISO 228-1¹⁰, *Pipe threads where pressure-tight joints are not made on the threads—Part 1: Dimensions, tolerances and designation*

ISO 261, *ISO general purpose metric screw threads—General plan*

ISO 262, *ISO general purpose metric screw threads—Selected sizes for screws, bolts and nuts*

ISO 281:2007, *Rolling bearings—Dynamic load ratings and rating life*

ISO 286 (all parts), *System of limits and fits*

ISO 3117, *Tangential keys and keyways*

ISO 3183, *Petroleum and natural gas industries—Steel pipe for pipeline transportation systems*

ISO 4200, *Plain end steel tubes, welded and seamless—General tables of dimensions and masses per unit length*

ISO 5753 (all parts), *Rolling bearings—Internal clearance*

ISO 7005-1, *Pipe flanges—Part 1: Steel flanges for industrial and general service piping systems*

ISO 8501 (all parts), *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness*

ISO 9606 (all parts), *Qualification testing of welders—Fusion welding*

ISO 9906, *Rotodynamic pumps—Hydraulic performance acceptance tests—Grades 1, 2 and 3*

ISO 10441, *Flexible couplings for mechanical power transmission—Special-purpose applications*

ISO 10721-2, *Steel structures—Part 2: Fabrication and erection*

ISO 11342, *Mechanical vibration—Methods and criteria for the mechanical balancing of flexible rotors*

ISO 14120, *Safety of machinery—Guards—General requirements for the design and construction of fixed and movable guards*

⁸ International Electrotechnical Commission, 3 rue de Varembé, 1st Floor, PO Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

⁹ Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, New Jersey 08854, www.ieee.org.

¹⁰ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 14691, *Petroleum, petrochemical and natural gas industries—Flexible couplings for mechanical power transmission—General-purpose applications*

ISO 15607, *Specification and qualification of welding procedures for metallic materials—General rules*
ISO 15609 (all parts), *Specification and qualification of welding procedures for metallic materials—Welding procedure specification*

ISO 15649, *Petroleum and natural gas industries—Piping*

ISO 21940-11, *Mechanical vibration—Procedures and tolerances for rotors with rigid behaviour*

MSS SP-55 ¹¹, *Quality Standard for Steel Castings for Valves, Flanges, Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

NACE MR0103 ¹², *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE MR0175/ISO 15156 (all parts), *Petroleum and Natural Gas Industries—Materials for Use in H₂S-containing Environments in Oil and Gas Production*

SSPC SP 6 ¹³, *Commercial Blast Cleaning*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1

allowable operating region

Portion of a pump's hydraulic coverage over which the pump is allowed to operate, based on vibration within the upper limit of this standard or temperature rise or other limitation, specified by the manufacturer.

3.1.2

axially split

Joint split with the principal face parallel to the shaft centerline.

3.1.3

barrel pump

Horizontal pump of the double-casing type.

3.1.4

barrier fluid

Externally supplied fluid, at a pressure above the pump seal chamber pressure, introduced into an Arrangement 3 seal (pressurized dual mechanical seal) to completely isolate the pump process liquid from the environment.

¹¹ Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, www.mss-hq.com.

¹² NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org.

¹³ The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.

3.1.5 **best efficiency point** **BEP**

Flowrate at which a pump achieves its highest efficiency at rated impeller diameter.

NOTE The BEP flowrate at maximum impeller diameter is used to determine pump specific speed and suction-specific speed. The BEP flowrate at reduced impeller diameters is similarly reduced from the value at maximum impeller diameter.

3.1.6 **buffer fluid**

Externally supplied fluid, at a pressure lower than the pump seal chamber pressure, used as a lubricant and/or to provide a diluent in an Arrangement 2 seal (unpressurized dual mechanical seal).

3.1.7 **cartridge-type element**

Assembly of all the parts of the pump except for the casing.

3.1.8 **classically stiff**

Characterized by the first dry critical speed being above the pump's maximum continuous speed by the following:

- 20 % for rotors designed for wet running only;
- 30 % for rotors designed to be able to run dry.

3.1.9 **critical speed**

Shaft rotational speed at which the rotor-bearing-support system is in a state of resonance.

3.1.10 **datum elevation**

Elevation to which values of net positive suction head (NPSH) are referred (see 6.1.10).

See **net positive suction head** (3.1.33).

3.1.11 **design**

Manufacturer's calculated parameter.

NOTE "Design" is a term that is used by the equipment manufacturer to describe various parameters, such as design power, design pressure, design temperature, or design speed. This term is used only by the equipment manufacturer and not in the purchaser's specifications.

3.1.12 **double casing**

Type of pump construction in which the pressure casing is separate from the pumping elements contained in the casing.

NOTE Examples of pumping elements include diffuser, diaphragms, bowls, and volute inner casings.

3.1.13 **drive-train component**

Item of the equipment used in series to drive the pump.

EXAMPLES Motor, gear, turbine, engine, fluid drive, clutch.

3.1.14**dry critical speed**

Rotor critical speed calculated assuming that there are no liquid effects, that the rotor is supported only at its bearings, and that the bearings are of infinite stiffness.

3.1.15**element
bundle**

Assembly of the rotor plus the internal stationary parts of a centrifugal pump.

3.1.16**hydraulic power recovery turbine****HPRT**

Turbomachine designed to recover power from a fluid stream.

3.1.17**hydrodynamic bearing**

Bearing that uses the principles of hydrodynamic lubrication.

3.1.18**identical pump**

Pump of the same size, hydraulic design, number of stages, rotational speed, clearances, type of shaft seal (axial face or breakdown bushing), type of bearings, coupling mass, coupling overhang, and pumping the same liquid.

3.1.19**informative**

Information only.

3.1.20**maximum allowable temperature**

Maximum continuous temperature for which the manufacturer has designed the pump (or any part to which the term is referred) while pumping the specified liquid at the specified maximum operating pressure (does not include mechanical seal).

See **pressure casing** (3.1.46).

3.1.21**maximum allowable working pressure****MAWP**

Maximum continuous pressure for which the manufacturer has designed the pump (or any part to which the term is referred) while pumping the specified liquid at the specified maximum operating temperature (does not include mechanical seal).

3.1.22**maximum continuous speed**

Highest speed at which the manufacturer's design permits continuous operation.

3.1.23**maximum discharge pressure**

Highest pressure produced by the pump with the furnished impeller(s) at any flow point from zero to maximum flow while operating at any of the continuous speeds that achieve the specified operating cases, with the liquid relative density (specific gravity) pumped and the maximum suction pressure provided for each respective operating case.

3.1.24**maximum dynamic sealing pressure**

Highest pressure expected at the seals during any specified operating condition and during start-up and shutdown.

NOTE Both dynamic and static sealing pressures are important to selection of the mechanical seal. They are dependent on the pump suction pressure, operating point, and pump clearances. They are also affected by the pressure of the seal flush. This pressure is specified to the seal vendor. See API 682.

3.1.25**maximum operating temperature**

Highest temperature of the pumped liquid, including upset conditions, to which the pump is exposed.

NOTE This temperature is specified to the seal vendor. See API 682.

3.1.26**maximum static sealing pressure**

Highest pressure, excluding pressures encountered during hydrostatic testing, to which the seals can be subjected while the pump is shut down.

3.1.27**maximum suction pressure**

Highest suction pressure to which the pump is subjected during operation (nontransient; does not include water hammer).

3.1.28**minimum allowable speed**

Lowest speed (revolutions per minute) at which the manufacturer's design will permit continuous operation.

3.1.29**minimum continuous stable flow**

Lowest flow at which the pump can continuously operate without exceeding the vibration limits imposed by this standard.

3.1.30**minimum continuous thermal flow**

Lowest flow at which the pump can continuously operate without its operation being impaired by the temperature rise of the pumped liquid.

3.1.31**minimum design metal temperature**

Lowest mean metal temperature (through the thickness) expected in service, including operation upsets, auto-refrigeration, and temperature of the surrounding environment, for which the equipment is designed.

3.1.32**multistage pump**

Pump with three or more stages.

See 4.2.

3.1.33**net positive suction head****NPSH**

Absolute inlet total head above the head equivalent to the vapor pressure referred to the NPSH datum plane.

NOTE NPSH is expressed in feet (meters) of head of the pumped liquid.

3.1.34**net positive suction head available****NPSHA**

NPSH determined by the purchaser for the pumping system with the liquid at the rated flow and normal pumping temperature.

3.1.35**net positive suction head required****NPSH3**

NPSH that results in a 3 % loss of head (first-stage head in a multistage pump) determined by the vendor by testing with water.

3.1.36**nominal pipe size****NPS**

Designation, usually followed by a size designation number, corresponding approximately to the outside diameter (OD) of the pipe.

NOTE The NPS is expressed in inches.

3.1.37**normal operating point**

Point at which the pump is expected to operate under normal process conditions.

3.1.38**normal-wear part**

Part normally restored or replaced at each pump overhaul.

EXAMPLES Wear rings, inter-stage bushings, balancing device, throat bushing, seal faces, bearings, and gaskets.

3.1.39**normative**

Required.

3.1.40**observed**

Inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed as scheduled even if the purchaser or the purchaser's representative is not present.

3.1.41**oil-mist lubrication**

Lubrication provided by oil mist produced by atomization and transported to the bearing housing, or housings, by compressed air.

3.1.42**operating region**

Portion of a pump's hydraulic coverage over which the pump operates.

3.1.43**overhung pump**

Pump whose impeller is supported by a cantilever shaft from its bearing assembly.

3.1.44**owner**

Final recipient of the equipment who may delegate another agent as the purchaser of the equipment.

3.1.45**positive material identification testing****PMI testing**

Any physical evaluation or test of a material to confirm that the material which has been or will be placed into service is consistent with the selected or specified alloy material designated by the owner. These evaluations or tests may provide either qualitative or quantitative information that is sufficient to verify the nominal alloy composition.

3.1.45**preferred operating region**

Portion of a pump's hydraulic coverage over which the pump's vibration is within the base limit of this standard.

3.1.46**pressure casing**

Composite of all stationary pressure-containing parts of the pump, including all nozzles, seal glands, seal chambers, and auxiliary connections but excluding the stationary and rotating members of mechanical seals.

NOTE The atmospheric side of the seal gland, the seal flush (piping) plan, auxiliary piping, and valves are not part of the pressure casing.

3.1.47**purchaser**

Owner, or owner's agent, who issues the order and specification to the vendor.

3.1.48**pure oil-mist lubrication**

(dry sump)

System in which the mist both lubricates the bearing(s) and purges the housing and there is no oil level in the sump.

3.1.49**purge oil-mist lubrication**

(wet sump)

Systems in which the mist only purges the bearing housing.

3.1.50**radially split**

Split with the principal joint perpendicular to the shaft centerline.

3.1.51**rated operating point**

Point at which the vendor certifies that pump performance is within the tolerances stated in this standard.

NOTE Normally, the rated operating point is the specified operating point with the highest flow.

3.1.52**relative density****specific gravity**

Property of a liquid expressed as the ratio of the liquid's density to that of water at standard temperature.

NOTE Standard temperature is 39.2 °F (4 °C).

3.1.53**rotor**

Assembly of all the rotating parts of a centrifugal pump.

3.1.54**similar pump**

Pump that is accepted, by agreement between purchaser and manufacturer as sufficiently similar to not require a lateral analysis, taking into account the factors listed for an **identical pump** (3.1.18).

3.1.55**spark-resistant material**

Material that is not prone to generate impact sparks under conditions of use.

3.1.56**specific speed**

N_s

Index relating flow, total head, and rotational speed for pumps of similar geometry.

3.1.57**stage**

One impeller and associated diffuser or volute and return channel, if required.

3.1.58**suction-specific speed**

N_{ss} or S

Index relating flow, NPSH₃, and rotational speed for pumps of similar geometry.

3.1.59**throat bushing**

Device that forms a restrictive close clearance around the sleeve (or shaft) between the seal or inner seal of a dual seal cartridge and the impeller.

3.1.60**total indicator reading****total indicated runout****TIR**

Difference between the maximum and minimum readings of a dial indicator or similar device, monitoring a face or cylindrical surface, during one complete revolution of the monitored surface.

NOTE For a perfectly cylindrical surface, the indicator reading implies an eccentricity equal to half the reading. For a perfectly flat face, the indicator reading gives an out-of-perpendicularity equal to the reading. If the diameter in question is not perfectly cylindrical or flat, interpretation of the meaning of TIR is more complex and can represent ovality or lobing.

3.1.61**trip speed**

⟨electric motor driver⟩

Electric motor driver-synchronous speed at maximum supply frequency.

3.1.62**trip speed**

⟨variable-speed driver⟩

Variable-speed driver-speed at which the independent emergency overspeed device operates to shut down the driver.

3.1.63**unit responsibility**

Obligation for coordinating the documentation, delivery, and technical aspects of all the equipment and all auxiliary systems included in the scope of the order.

3.1.64**vendor**

Manufacturer or manufacturer's agent that supplies the equipment and is normally responsible for service support.

3.1.65**vertical in-line pump**

Vertical-axis, single-stage overhung pump whose suction and discharge connections have a common centerline that intersects the shaft axis.

NOTE Types VS6 and VS7 are not considered in-line pumps.

3.1.66**vertically suspended pump**

Vertical-axis pump whose liquid end is suspended from a column and mounting plate.

NOTE The pump's liquid end is usually submerged in the pumped liquid.

3.1.67**wet critical speed**

Rotor critical speed calculated considering the additional support and damping produced by the action of the pumped liquid within internal running clearances at the operating conditions and allowing for stiffness and damping within the bearings.

3.1.68**witnessed**

Inspection or test for which the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or the purchaser's representative is in attendance.

3.2 Acronyms and Abbreviations

AFNOR	Association Française de Normalisation
AISI	American Iron and Steel Institute
ASD	adjustable speed drive
AUS	austenitic stainless steel
AVM	anti-vibration mount
BB	between-bearings
BEP	best efficiency point
CR	chrome
DBSE	distance between shaft ends
DEA	diethylamine
DGS	dry gas seal
DN	diameter nominal
EDE	electronic data exchange

FCC	fluid catalytic cracker
FEA	finite element analysis
FFT	fast Fourier transform
HPRT	hydraulic power recovery turbine
NPSH _i	incipient net positive suction head
LNG	liquefied natural gas
MAWP	maximum allowable working pressure
MEA	monoethylamine
MEK	methylethylketone
MT	magnetic particle inspection
NDT	nondestructive testing
NPS	nominal pipe size
NPSH	net positive suction head
NPSHA	net positive suction head available
NPSH ₃	net positive suction head at 3 % head loss
N_s	specific speed
N_{ss}	suction-specific speed
OD	outside diameter
OH	overhung
PFA/CF	polyfluoroethylene with carbon fiber
PH	precipitation hardened
PMI	positive material identification
PRE	pitting resistance equivalency
PT	liquid penetrant inspection
PTFE	polytetrafluoroethylene
PWHT	postweld heat treatment
RMS	root mean square
RT	radiographic inspection

S	suction-specific speed
SDS	safety data sheet
SFI	shaft flexibility index
SG	specific gravity
SPL	sound pressure level
STL	carbon steel
TEA	triethylamine
TFE	tetrafluoroethylene
TIR	total indicator reading; total indicated runout
UN	Unified constant pitch (a thread form)
UNC	Unified National Coarse (a thread form)
UNS	Unified Numbering System (for metal and alloys)
UT	ultrasonic examination
VDDR	vendor drawing and data requirements
VFD	variable frequency drive
VI	visual inspection
VOC	volatile organic compound
VS	vertically suspended

4 General

4.1 Unit Responsibility

Unless otherwise specified, the pump vendor shall assume unit responsibility and shall assure that all subvendors comply with the requirements of this standard and all reference documents. The technical aspects to be considered by the vendor include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications, and testing of components.

4.2 Classification and Designation

4.2.1 Description of Codes

The pumps described in this standard are classified and designated by type codes, as shown in Table 1.

Table 1—Pump Classification Type Identification

Pump Type ^a			Description		Type Code
Centrifugal pumps	Overhung	Flexibly coupled	Horizontal	Foot-mounted	OH1
				Centerline-supported	OH2
		Rigidly coupled	Vertical in-line with bearing bracket	—	OH3
			Vertical in-line	—	OH4
		Close-coupled	Vertical in-line	—	OH5
			High-speed integrally geared	—	OH6
	Between-bearings	1- and 2-stage	Axially split	Foot-mounted	BB1-A
			Axially split	Near-centerline mounted	BB1-B
			Radially split	Centerline supported	BB2
		Multistage	Axially split	Near-centerline supported	BB3
			Radially split	Single casing	BB4
				Double casing	BB5
	Vertically suspended	Single casing	Discharge through column	—	VS1
				—	VS2
				—	VS3
		Separate discharge pipe		Line shaft	VS4
				Cantilever shaft	VS5
		Double casing	Radially split	—	VS6
				—	VS7

^a Illustrations of the various types of pump are provided in 4.2.2.

4.2.2 Pump Designations and Descriptions

4.2.2.1 General

The figures that follow in this section are generic and informative. They are not meant to show construction details or specific features.

4.2.2.2 Pump Type OH1

Foot-mounted, single-stage overhung pumps shall be designated pump type OH1 (Figure 1). (This type does not meet all the requirements of this standard; see Table 3.)

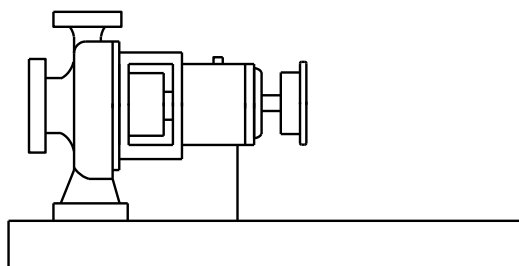


Figure 1—Pump Type OH1

4.2.2.3 Pump Type OH2

Centerline-mounted, single-stage overhung pumps shall be designated pump type OH2 (Figure 2). They have a single bearing housing to absorb all forces imposed upon the pump shaft and maintain rotor position during operation. The pumps are mounted on a baseplate and are flexibly coupled to their drivers.

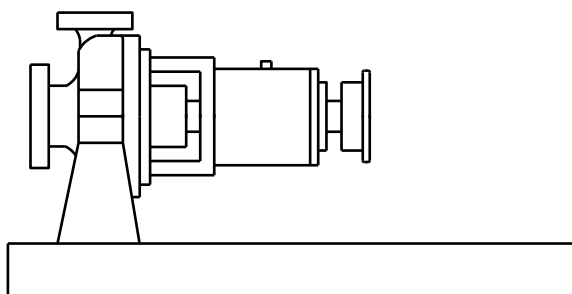


Figure 2—Pump Type OH2

4.2.2.4 Pump Type OH3

Vertical, in-line, single-stage overhung pumps with separate bearing brackets shall be designated pump type OH3 (Figure 3). They have a bearing housing integral with the pump to absorb all pump loads. The driver is usually mounted on a support integral to the pump. The pumps and their drivers are flexibly coupled.

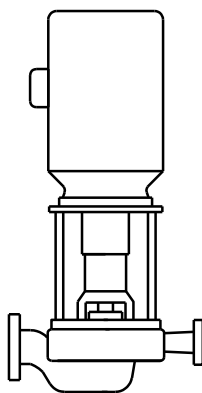


Figure 3—Pump Type OH3

4.2.2.5 Pump Type OH4

Rigidly coupled, vertical, in-line, single-stage overhung pumps shall be designated pump type OH4 (Figure 4). Rigidly coupled pumps have their shaft rigidly coupled to the driver shaft. (This type does not meet all the requirements of this standard; see Table 3.)

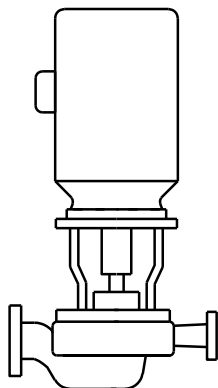


Figure 4—Pump Type OH4

4.2.2.6 Pump Type OH5

Close-coupled, vertical, in-line, single-stage overhung pumps shall be designated pump type OH5 (Figure 5). Close-coupled pumps have their impellers mounted directly on the driver shaft. (This type does not meet all the requirements of this standard; see Table 3.)

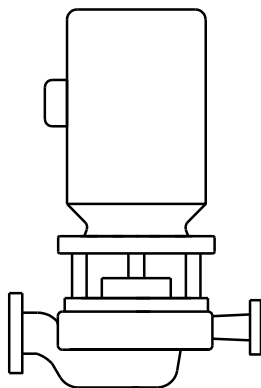


Figure 5—Pump Type OH5

4.2.2.7 Pump Type OH6

High-speed, integral, gear-driven, single-stage overhung pumps shall be designated pump type OH6 (Figure 6). These pumps have a speed-increasing gearbox integral with the pump. The impeller is mounted directly to the gearbox output shaft. There is no coupling between the gearbox and pump; however, the gearbox is flexibly coupled to its driver. The pumps can be oriented vertically or horizontally.

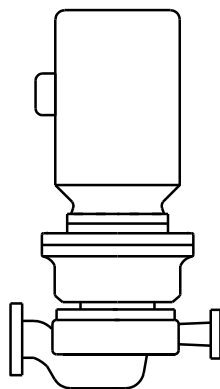
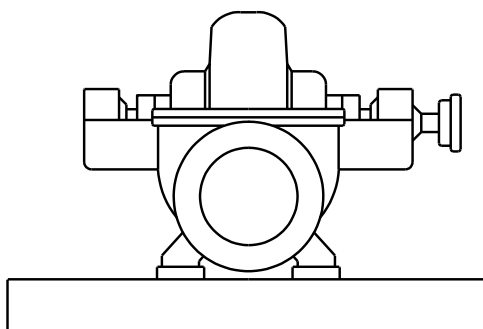


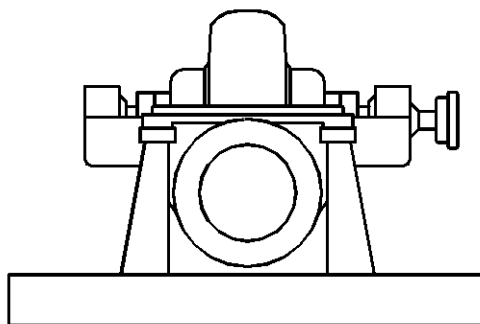
Figure 6—Pump Type OH6

4.2.2.8 Pump Type BB1

Axially split, one- and two-stage, between-bearings pumps shall be designated pump type BB1 (Figure 7).



a) Pump Type BB1-A “Foot Mounted”



b) Pump Type BB1-B “Near-centerline Mounted”

Figure 7—Pump Types BB1-A and BB1-B

4.2.2.9 Pump Type BB2

Radially split, one- and two-stage, between-bearings pumps shall be designated pump type BB2 (Figure 8).

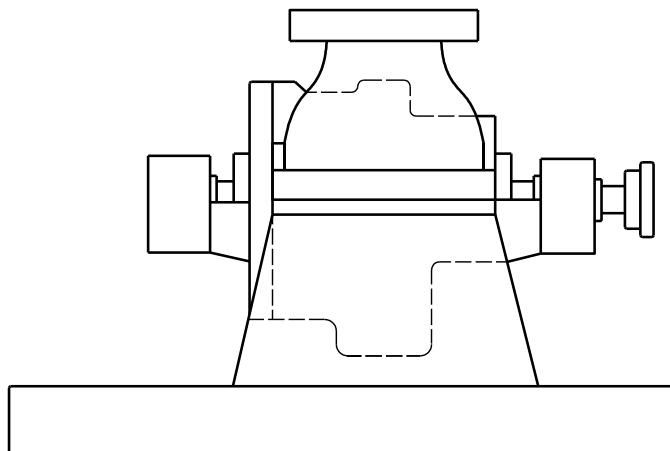


Figure 8—Pump Type BB2

4.2.2.10 Pump Type BB3

Axially split, multistage, between-bearings pumps shall be designated pump type BB3 (Figure 9).

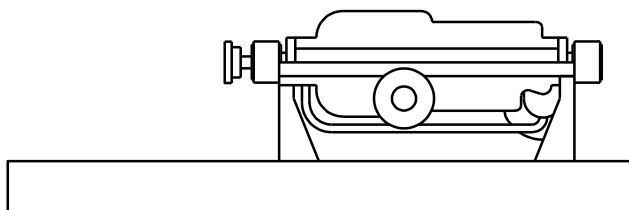


Figure 9—Pump Type BB3

4.2.2.11 Pump Type BB4

Single-casing, radially split, multistage, between-bearings pumps shall be designated pump type BB4 (Figure 10). These pumps are also called ring-section pumps, segmental-ring pumps, or tie-rod pumps. These pumps have a potential leakage path between each segment. (This type does not meet all the requirements of this standard; see Table 3.)

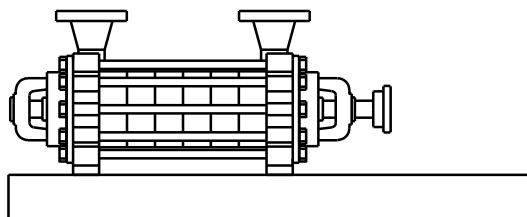


Figure 10—Pump Type BB4

4.2.2.12 Pump Type BB5

Double-casing, radially split, multistage, between-bearings pumps (barrel pumps) shall be designated pump type BB5 (Figure 11).

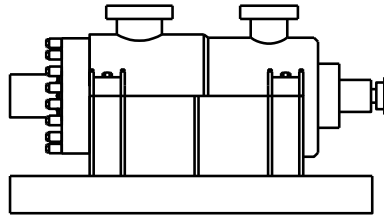


Figure 11—Pump Type BB5

4.2.2.13 Pump Type VS1

Wet pit, vertically suspended, single-casing diffuser pumps with discharge through the column shall be designated pump type VS1 (Figure 12).

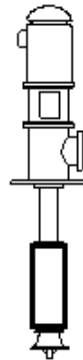


Figure 12—Pump Type VS1

4.2.2.14 Pump Type VS2

Wet pit, vertically suspended, single-casing volute pumps with discharge through the column shall be designated pump type VS2 (Figure 13).

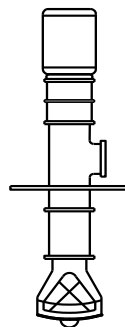


Figure 13—Pump Type VS2

4.2.2.15 Pump Type VS3

Wet pit, vertically suspended, single-casing axial-flow pumps with discharge through the column shall be designated pump type VS3 (Figure 14).

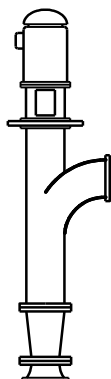


Figure 14—Pump Type VS3

4.2.2.16 Pump Type VS4

Vertically suspended, single-casing, volute, line-shaft-driven sump pumps shall be designated pump type VS4 (Figure 15).

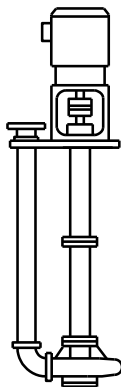


Figure 15—Pump Type VS4

4.2.2.17 Pump Type VS5

Vertically suspended, cantilever sump pumps shall be designated pump type VS5 (Figure 16).

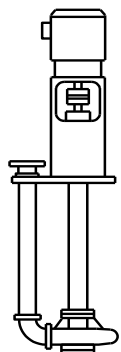


Figure 16—Pump Type VS5

4.2.2.18 Pump Type VS6

Double-casing, diffuser, vertically suspended pumps shall be designated pump type VS6 (Figure 17).

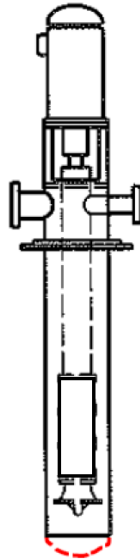


Figure 17—Pump Type VS6

4.2.2.19 Pump Type VS7

Double-casing, volute or volute plus diffuser, vertically suspended pumps shall be designated pump type VS7 (Figure 18).

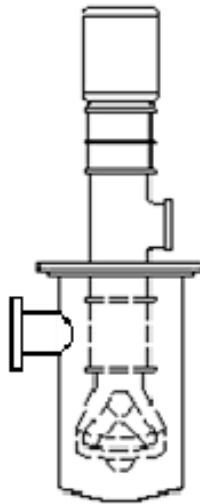


Figure 18—Pump Type VS7

5 Requirements

5.1 Units

- The purchaser shall specify whether data, drawings, and maintenance dimensions of pumps shall be in the U.S. customary (USC) or SI system of measurements. Use of a USC data sheet (see Figure N.1) indicates the USC system of measurements shall be used. Use of an SI data sheet (see Figure N.2) indicates the SI system of measurements shall be used.

5.2 Statutory Requirements

The purchaser and the vendor shall determine the measures to be taken to comply with any governmental codes, regulations, ordinances, or rules that are applicable to the equipment, its packaging and preservation. Equipment installed in the European Economic Area shall comply with all applicable European Union Directives.

NOTE The European Economic Area includes the countries of the European Union plus Norway, Iceland, and Liechtenstein.

5.3 Hierarchy of Requirements

5.3.1 In case of conflict between this standard and the inquiry, the inquiry shall govern. At the time of the order, the purchase order shall govern.

5.3.2 Where requirements specific to a particular pump type in Section 9 conflict with any other section, the requirements of Section 9 shall govern.

5.3.3 The hierarchy of documents shall be specified.

NOTE Typical documents include company and industry specifications, meeting notes, and modifications to these documents.

6 Basic Design

6.1 General

6.1.1 Equipment Reliability

- **6.1.1.1** Only equipment that is field proven, as defined by the Purchaser, is acceptable.

NOTE Purchasers can use their engineering judgment in determining what equipment is field proven. API 691 can provide guidance.

- **6.1.1.2** If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

6.1.1.3 In the event no such equipment is available, the vendor shall submit an explanation of how their proposed equipment can be considered field proven.

NOTE A possible explanation can be that all components comprising the assembled machine satisfy the field proven definition.

6.1.2 The vendor shall advise in the proposal any component designed for a finite life.

- **6.1.3** The purchaser shall specify the operating conditions (including any upset, cleaning, seasonal, etc.), the liquid properties, preferred materials, site conditions, and utility conditions, including all data shown on the process data sheet (Annex N). If the application is a HPRT (pump running in reverse or radial inflow liquid

machine), the purchaser shall specify the maximum inlet pressure on the process data sheet (Annex N). HPRTs shall comply with Annex C.

- **6.1.3.1** The purchaser shall specify if equipment will be supplied in accordance with API 691.

NOTE 1 Operating companies can invoke API 691 for certain high-risk applications involving:

- a) special-purpose pumps (refer to Annex O);
- b) critical service pumps and/or;
- c) pumps identified in HAZOP, Process Safety Management (PSM) studies, etc. and internal company risk assessment.

NOTE 2 Both the API 610 data sheets (Annex N) and API 691 data sheets can be issued jointly to define all applicable requirements.

- **6.1.3.2** If API 691 is specified, the vendor shall identify all machinery components that are not "Field Qualified" per API 691 (First Edition), Section 4.3.2 and Table 1.

6.1.4 The equipment shall be capable of operation at the normal and rated operating points and any other anticipated operating conditions specified by the purchaser.

6.1.5 Pumps shall be capable of at least a 5 % head increase at rated flow by replacement of the impeller(s) with one(s) of larger diameter or different hydraulic design, variable-speed capability, or use of a blank stage.

NOTE This requirement is intended to prevent a change in selection caused by refinement of hydraulic requirements after the pump has been purchased. It is not intended to accommodate future unit expansion. If there is a future operating requirement, it is specified separately and considered in selection.

6.1.6 Pumps shall be capable of operating at least up to the maximum continuous speed. The maximum continuous speed shall be

- a) equal to the speed corresponding to the synchronous speed at maximum supply frequency for electrical motors,
- b) at least 105 % of rated speed for variable-speed pumps and any fixed-speed pump sparing or spared by a pump whose driver is capable of exceeding rated speed.

6.1.7 Variable-speed pumps shall be designed for excursions to trip speed without damage.

6.1.8 The conditions in the seal chamber required to maintain a stable fluid film at the seal faces shall be agreed upon by the pump vendor and seal manufacturer, approved by the purchaser, and stated on the pump data sheet. The necessary parameters include temperature, pressure, and flow, as well as provisions for assuring the adequacy of the design for sealing against atmospheric pressure when pumps are idle in vacuum service. During operation, the seal chamber pressure shall be at least a gauge pressure of 5 psi (35 kPa); see API 682.

NOTE Provision for sealing against atmospheric pressure in vacuum service is especially important when handling liquids near their vapor pressure (such as liquefied petroleum gases).

6.1.9 The vendor shall specify the net positive suction head at 3 % head loss (NPSH3) based on water at a temperature of less than 130 °F (55 °C) at the rated flow and rated speed. A reduction or correction factor for liquids other than water (such as hydrocarbons) shall not be applied. The datum elevations for NPSH3 shall be the shaft centerline for horizontal pumps and the impeller suction eye for vertical in-line pumps and vertically suspended pumps.

NOTE 1 NPSH3 means that during operation with NPSH available (NPSHA) equal to NPSH3, the extent of cavitation within the impeller is sufficient to cause a 3 % loss of head. NPSH3 is a performance characteristic of the first-stage impeller.

NOTE 2 The datum elevations defined above for NPSH3 are in accordance with HI 14.6 (ISO 9906). NPSH3 values are provided by the vendor and if specified can be demonstrated by test.

- **6.1.10** The purchaser shall specify the NPSHA based on system conditions at the rated flow. The datum elevations for NPSHA shall be the estimated shaft centerlines for horizontal pumps and the estimated suction-nozzle centerlines for vertical pumps.

NOTE 1 At the beginning of a project, actual elevations of pump shaft and suction nozzle centerlines are estimates based on preliminary information. As the project develops, the final pump geometry is provided by the vendor and the purchaser designs the final pump installation. At that point, the final datum elevations for NPSHA can be determined.

NOTE 2 The purchaser determines the final datum elevation for NPSHA based on the purchased pump and the final installation design. The final NPSHA can then be calculated based on the final datum elevation. The purchaser can record the final NPSHA value.

NOTE 3 The NPSH margin is calculated as the difference of the final NPSHA and the NPSH3 at the common datum defined by HI 14.6 (ISO 9906). The purchaser can record the final NPSH margin value.

NOTE 4 The purchaser considers an appropriate NPSH margin. Acceptable minimum NPSH margins vary by pump type and service. In establishing the NPSH margin, the purchaser and the vendor recognize the relationship between minimum continuous stable flow and the pump's suction-specific speed. In general, minimum continuous stable flow increases as suction-specific speed increases. However, other factors, such as the pump's energy level and hydraulic design, the pumped liquid, and the NPSH margin, also affect the pump's ability to operate satisfactorily over a wide flow range. Pump design that addresses low-flow operation is an evolving technology, and selection of suction-specific speed values and NPSH margins can take into account current industry and vendor experience.

- **6.1.11** The pump suction-specific speed shall be calculated in accordance with Annex A. If the purchaser specifies a suction-specific speed limit, the pump shall have a calculated suction-specific speed not greater than that specified limit.

6.1.12 Pumps that handle liquids more viscous than water shall have their water performance corrected in accordance with HI 9.6.7. Correction factors used for viscous liquid shall be submitted with both sales proposal curves and final test curves.

- **6.1.13** If parallel operation is specified and the pumps are not individually flow controlled, the following is required:
 - a) the pump head curves shall be continuously rising to shutoff;
 - b) the head rise from rated point to shutoff shall be at least 10 %;
 - c) the head values of the pumps at any given flow within the preferred operating range shall be within 3 % of each other for pumps larger than 3 in. (80 mm) discharge.

NOTE The above requirements are not necessary for pumps with individual adjustable speed drives (ASDs) controlled by individual flow measurements.

6.1.14 If a discharge orifice is used as a means of providing a continuously rising head curve, this shall be stated in the proposal.

- **6.1.15** If specified, pump head curves shall be continuously rising from rated point to shutoff.

NOTE Pumps with a continuously rising head curve are preferred for all applications, but this is not possible with all pump types. Head curve shape is dependent on several factors specific to the pumps hydraulic design.

6.1.16 Pumps shall have a preferred operating region of 70 % to 120 % of BEP flowrate of the pump as furnished. Rated flow shall be within the region of 80 % to 110 % of the BEP flowrate of the pump as furnished. The "end of curve flow" is defined as 120 % of the BEP flowrate.

NOTE 1 Setting limits for the preferred operating region and the location of rated flow are not intended to lead to the development of additional small pump sizes or preclude the use of high-specific-speed pumps. Small pumps that are known to operate satisfactorily at flows lower than the 70 % limit specified above and high-specific-speed pumps that can have preferred operating regions narrower than the region specified above can be offered, where appropriate.

NOTE 2 "BEP flowrate of the pump as furnished" refers to the BEP of the pump with the impeller diameter selected to develop rated head at rated flow.

NOTE 3 For allowable operating region, see 3.1.1.

NOTE 4 Generally, pumps with BEP flowrates between the rated and normal points require less energy to operate than pumps with BEP flowrates greater than the specified rated point.

6.1.17 The pump specific speed and the pump suction-specific speed shall be calculated in accordance with Annex A.

6.1.18 For pumps equipped with ASDs, the vendor shall determine the minimum allowable speed of the equipment and record the value.

- **6.1.19** The vendor shall provide maximum expected A-weighted sound pressure level (SPL) for the equipment.

6.1.19.1 Control of the SPL of all equipment furnished shall be a joint effort of the purchaser and the vendor who has unit responsibility.

6.1.19.2 If specified, the equipment furnished by the vendor shall conform to a maximum allowable SPL specified by the purchaser.

NOTE ISO 3740 [7], ISO 3744 [8], and ISO 3746 [9] can be consulted for guidance.

6.1.20 For pumps developing head greater than 650 ft (200 m) per stage and absorbing more than 300 hp (225 kW) per stage, the radial clearance between the diffuser vane or volute tongue (cutwater) and the periphery of the impeller vane shall be at least 3 % of the maximum impeller vane-tip radius for diffuser designs and at least 6 % of the maximum blade-tip radius for volute designs.

NOTE 1 The maximum impeller vane-tip radius is the radius of the largest impeller that can be used within the pump casing (see 6.1.6). The clearance, P , expressed as a percentage, is calculated using Equation (1):

$$P = 100(R_2 - R_1) / R_1 \quad (1)$$

where

R_2 is the radius of volute or diffuser inlet tip;

R_1 is the maximum impeller blade tip radius.

NOTE 2 It is common practice for the impellers of pumps covered by this section to be modified after initial test to correct hydraulic performance by underfilling, overfilling, or "V"-cutting. Any such modifications are documented in accordance with L.3.2.2.

6.1.21 Pumps operating above 3600 r/min and absorbing more than 400 hp (300 kW) per stage can require even larger running clearances and other special construction features. For these pumps, specific requirements shall be agreed upon by the purchaser and the vendor, considering actual operating experience with the specific pump types.

- **6.1.22** The need for bearing housing cooling shall be determined by the vendor, and the method shall be agreed upon by the purchaser. Fan cooling for the bearing housing shall be the first choice. If fan cooling is inadequate, one of the plans in Annex B shall be selected. The cooling system shall be suitable for operation

with the coolant type, pressure and temperature specified by the purchaser. The vendor shall specify the required flow.

NOTE To avoid condensation in the bearing housing, the minimum temperature of the cooling-liquid at the inlet to bearing housing is maintained above the ambient air temperature.

6.1.23 Jackets, if provided, shall have clean-out connections arranged so that the entire passageway can be mechanically cleaned, flushed, and drained.

6.1.24 Jacket systems, if provided, shall be designed to prevent the process stream from leaking into the jacket or the heat transfer medium from leaking into the process. Jacket passages shall not open into casing joints.

6.1.25 Unless otherwise specified, water-cooling systems shall be designed for the conditions on the water side as given in Table 2.

6.1.26 Provisions shall be made for complete venting and draining of cooling-water systems.

6.1.27 The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity over heat exchange surfaces result in a conflict. The criterion for velocity over heat exchange surfaces is intended to minimize water-side fouling; the criterion for minimum temperature rise is intended to minimize the use of cooling water. If such a conflict exists, the purchaser shall approve the final selection.

Table 2—Water-cooling Systems—Conditions on the Water Side

Parameter	USC and Other Units	SI Units
Velocity over heat exchange surfaces	5 ft/s to 8 ft/s	1.5 m/s to 2.5 m/s
Maximum allowable working pressure (MAWP), gauge shall be as a minimum	100 psi; 7 bar	700 kPa
Test pressure (> 1.5 MAWP), gauge	150 psi; 10.5 bar	1050 kPa
Maximum pressure drop	15 psi, 1 bar	100 kPa
Maximum inlet temperature	90 °F	30 °C
Maximum outlet temperature	120 °F	50 °C
Maximum temperature rise	30 °F	20 °C
Fouling factor on water side	0.002 h-ft ² -°R/Btu	0.35 m ² K/kW
Shell corrosion allowance (not for tubes)	0.125 in.	3.0 mm

6.1.28 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide sufficient clearance between equipment and piping and auxiliaries to allow safe access for operation and maintenance. (For OH2 type pumps, see Figure 40.)

6.1.29 Electrical Classification

6.1.29.1 Locations for installed equipment can be classified as hazardous electrical areas or they can be unclassified. An unclassified area is considered nonhazardous; therefore, motors, electrical instrumentation, equipment, components, and electrical installations for unclassified areas are not governed by hazardous area electrical codes.

6.1.29.2 If an installation location is classified as hazardous, motors, electrical instrumentation, equipment, components, and electrical installations shall be suitable for the hazardous electrical area classification designation as specified.

6.1.29.3 All applicable electrical codes shall be specified. Local electrical codes that apply shall be provided by the purchaser upon request.

6.1.30 Oil reservoirs and housings that enclose moving lubricated parts, such as bearings, shaft seals, highly polished parts, instruments and control elements, shall be designed to minimize contamination by moisture, dust, and other foreign matter during periods of operation and idleness.

6.1.31 All equipment shall be designed to permit rapid and economical maintenance. Major parts, such as casing components and bearing housings, shall be designed and manufactured to ensure accurate alignment on reassembly. This can be accomplished by the use of shouldering, dowels, or keys.

6.1.32 Except for vertically suspended pumps and integrally geared pumps, pumps shall be designed to permit removal of the rotor or inner element without disconnecting the suction or discharge piping or moving the driver.

6.1.33 The pump and its driver shall perform on their test stands and on their permanent foundation within the vibration acceptance criteria specified in 6.9.4. After installation in accordance with the vendor's requirements, the performance of the pump and driver as a combined unit shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

- **6.1.34** Many factors can adversely affect site performance. These factors include such items as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site. If specified, the vendor's representative shall witness:

- a) a check of the piping alignment performed by unfastening the major flanged connections of the equipment;
- b) the initial shaft alignment check at ambient conditions;
- c) shaft alignment at operating temperature, i.e. hot alignment check.

NOTE Refer to API 686 for basic guidelines for conducting piping alignments, shaft cold alignments, and shaft hot alignments.

6.1.35 Spare and all replacement parts for the pump and all furnished auxiliaries shall, as a minimum, meet all the criteria of this standard.

6.1.36 Equipment, including all auxiliaries, shall be designed for outdoor installation and the specified site environmental conditions. The vendor shall advise of any equipment protection required for the jobsite location (i.e. winterization for low ambient temperatures, or protection against unusual humidity, dusty or corrosive conditions, etc.).

6.1.37 Bolting and Threads

6.1.37.1 The details of threading shall conform to ASME B1.1, ASME B1.13M, or ISO 261. The vendor shall advise the type of bolting used on the pump.

6.1.37.2 If ASME B1.1 threads have been specified, the thread series shall be the varying-pitch series UNC for sizes up to 1 in. and 8 UN for sizes greater than 1 in. All threads shall be Class 2 or 3.

NOTE Coatings on pressure casing bolting are sometimes not practical because they can alter the class of the threads. This alteration can affect tightening requirements of the bolting.

6.1.37.3 If ISO 261 and ISO 262 have been specified, the thread series shall be coarse. Threads shall be Class 6g for bolting and studs and Class 6H for nuts.

6.1.37.4 Commercial fasteners shall be manufactured in accordance with the requirements of ASME B18.18.2M or shall be procured from distributors having quality plans in accordance with ASME B18.18.2M.

6.1.38 Adequate clearance shall be provided at all bolting locations to permit the use of socket or box wrenches.

6.1.39 Unless otherwise specified or agreed, studs shall be supplied on all main casing joints, and all other joints and connections shall be supplied with external hexagon-head bolting.

6.1.40 Fasteners (excluding washers and headless set-screws) shall have the material grade and manufacturer's identification symbols applied to one end of studs $\frac{3}{8}$ in. (10 mm) in diameter and larger and to the heads of bolts $\frac{1}{4}$ in. (6 mm) in diameter and larger. If the available area is inadequate, the grade symbol may be marked on one end and the manufacturer's identification symbol marked on the other end. Studs shall be marked on the exposed end.

NOTE A set-screw is a headless screw with a hexagonal socket in one end.

6.1.41 Pressure casing fasteners shall be not less than 0.5 in. (12 mm) diameter.

6.2 Pump Types

- **6.2.1** The pump types listed in Table 3 have special design features that prevent them from fully complying with this standard. These pumps shall be offered only if specified by the purchaser and if the manufacturer has proven experience for the specific application. Table 3 lists the features requiring special consideration for these pump types and gives in parentheses the relevant subsection(s) of this standard.

Table 3—Special Design Features of Particular Pump Types

Pump Type	Features Requiring Special Consideration
Horizontal foot-mounted overhung, OH1	a) Pressure rating (6.3.6) b) Casing support (6.3.14)
Rigidly coupled vertical in-line, OH4	a) Motor construction (7.1.8, 7.1.9) b) Rotor stiffness (6.9.1.3) c) Product-lubricated guide bearing (6.10.1.1) d) Shaft runout at seal (6.6.9, 6.8.5)
Close-coupled (impeller mounted on motor shaft), OH5	a) Motor construction (7.1.8, 7.1.9) b) Motor bearing and winding temperature at high pumping temperatures c) Seal removal (6.8.2)
Two-stage overhung	a) Rotor stiffness (6.9.1.3)
Double-suction overhung	a) Rotor stiffness (6.9.1.3)
Ring-section casing (multistage), BB4	a) Pressure containment (6.3.3, 6.3.13) b) Dismantling (6.1.31)
Built-in mechanical seal (no separable seal gland)	a) Seal removal (6.8.2)

- **6.2.2** If the pump is deemed by the purchaser to be a special-purpose pump, refer to Annex O for guidance.

6.3 Pressure Casings

6.3.1 The maximum discharge pressure shall be the highest of the maximum discharge pressures as calculated for all of the operating cases. The calculations shall be based on the maximum differential pressure that the pump is able to develop when operating with the furnished impeller(s) at the continuous speed and

when pumping the relative density (specific gravity) from respective operating cases, plus the maximum suction pressure for respective operating cases. The pump vendor shall calculate the maximum discharge pressure for the pump and shall record that value.

- **6.3.2** If specified, the maximum discharge pressure shall be increased by the additional differential pressure developed during one or more of the following operating circumstances:

- a) operation with temporary liquid of relative density higher than those specified in the liquid characteristics section of the pump data sheet (e.g. post-construction pipe cleaning liquid);
- b) installation of an impeller of the maximum diameter and/or number of stages that the pump can accommodate;
- c) operation to trip or maximum speed of the driver.

NOTE The purchaser will assess the likelihood of the occurrence of Items a), b), and/or c) before specifying any of them. Momentary differential pressure excursions are sometimes considered covered by the hydrostatic test margin (see 8.3.2.2).

6.3.3 The pressure casing shall be designed to

- a) operate without leakage or internal contact between rotating and stationary components while subject simultaneously to the MAWP (and maximum operating temperature) and the worst-case combination of twice the allowable nozzle loads of Table 5 applied through each nozzle;
- b) withstand the hydrostatic test (see 8.3.2).

NOTE The twice-nozzle-load requirement is a pressure casing design criterion. Allowable nozzle loads for piping designers are the values given in Table 5, which, in addition to pressure casing design, include other factors that affect allowable nozzle loads, such as casing support and baseplate stiffness.

6.3.4 For pressure casing components, the tensile stress used in the design shall not exceed 0.25 times the minimum ultimate tensile strength or 0.67 times the minimum yield strength for that material, whichever is lower, with MAWP across the full range of specified operating temperatures. For castings, the minimum ultimate tensile strength and minimum yield strength for that material shall be multiplied by the appropriate casting factor, as shown in Table 4.

Table 4—Casting Factors

Type of Nondestructive Examination	Casting Factor
Visual, magnetic particle, and/or liquid penetrant	0.8
Spot radiography	0.9
Ultrasonic	0.9
Full radiography	1.0

6.3.5 The vendor's proposal shall state the source of the material properties from those listed in Table H.2 (i.e. ASTM, ISO, UNS, EN, JIS), as well as the casting factors applied. National material standards other than those listed in Table H.2 may be used with specific purchaser approval.

NOTE 1 In general, the criteria in 6.3.3 result in deflection (strain) being the determining consideration in the design of pump casings with respect to pressure retention and nozzle loads. Ultimate tensile or yield strength is seldom the limiting factor.

NOTE 2 For bolting, the allowable tensile stress is used to determine the total bolting area based on hydrostatic load or gasket preload. It is recognized that to provide the initial load required to obtain a reliable bolted joint under cyclic loading, it is necessary that the bolting be tightened to produce a tensile stress higher than the design tensile stress. Usual values are in the range of 0.7 to 0.9 times yield.

6.3.6 Except as noted in 6.3.8, the MAWP shall be at least the maximum discharge pressure (see 6.3.1 and 6.3.2) plus 10 % of the maximum differential pressure and shall not be less than:

- a) for pump types BB1, VS1, VS2, VS3, VS4, VS5, VS6, and VS7: a pressure rating equal to that of an ASME B16.5, Class 150 steel flange of material grade corresponding to that of the pressure casing;

NOTE For the purpose of this provision, ISO 7005-1 PN20 and EN 1759-1, Class 150 are equivalent to ASME B16.5, Class 150.

- b) for all other pump types: a gauge pressure rating equal to at least 600 psi (4 MPa; 40 bar) at 100 °F (38 °C).

6.3.7 The pump-seal chamber and seal gland shall have a pressure-temperature rating at least equal to the MAWP and temperature of the pump casing to which it is attached, in accordance with API 682, Fourth Edition, Section 3.1.52.

- **6.3.8** If specified, pump types VS6, VS7, OH6, BB3, BB4, and BB5 may be designed for dual pressure ratings. The purchaser should consider installation of relief valves on the suction side of such installations. If specified, suction regions shall be designed for the same MAWP as the discharge section.
- **6.3.9** Unless otherwise specified, MAWP of pressure casings for HPRTs shall be at least equal to the maximum inlet pressure or the minimum MAWP values specified by 6.3.6, whichever is greater. If a relief valve is provided on the downstream piping before the first block valve, the MAWP of the low-pressure region of the casing shall be at least equal to the specified relief valve set point.
- **6.3.10** The pressure casing shall be designed with a corrosion allowance to meet the requirements of 6.1.1. Unless otherwise specified, the minimum corrosion allowance shall be 0.12 in. (3 mm).

NOTE The vendor is encouraged to propose alternative corrosion allowances for consideration if materials of construction with superior corrosion resistance are employed without affecting safety and reliability.

6.3.11 The inner casing of double-casing pumps shall be designed to withstand the maximum differential pressure or 50 psi (350 kPa, 3.5 bar), whichever is greater.

6.3.12 Unless otherwise specified, pumps with radially split casings are required in services for any of the following operating conditions:

- a) pumping temperature of 400 °F (200 °C) or higher;
- b) liquids with a relative density of less than 0.7 at the specified pumping temperature;
- c) liquids at a rated discharge gauge pressure above 1450 psi (10 MPa, 100 bar);
- d) liquid temperature transients greater than 100 °F (55 °C);
- e) liquid temperature transients that cause casing metal temperature change rates greater than 5 °F (3 °C) per minute.

NOTE 1 Axially split casings have been used successfully beyond the limits given above, particularly for pipeline applications at higher pressure and with lower relative density (specific gravity). The success of such applications depends on the margin between design pressure and rated pressure, the manufacturer's experience with similar applications, the design and manufacture of the split joint, and the user's ability to correctly remake the split joint in the field. The purchaser usually considers these factors before specifying an axially split casing for conditions beyond the above limits.

NOTE 2 Items d) and e) are for operating cases where a pump can be "shocked" if pumping liquids with different temperatures. These temperature transients tend to occur during start-up for a pump that is not warmed-up or cooled down ahead of the introduction of process liquid. Item d) is addressing step-changes in pumped liquid temperature, and Item e) addresses a slower rate of change in temperature but still exceeds the casing material temperature change rate.

- **6.3.13** Radially split casings shall have metal-to-metal fits, with confined controlled-compression gaskets, such as an O-ring or a spiral-wound type. Gaskets other than spiral-wound may be proposed and furnished if proven suitable for service and approved by the purchaser. Radially split pressure casing joints and bolting shall be designed to seat a spiral-wound gasket (see 9.3.2.3 for VS type pumps).

NOTE Table H.1 shows only spiral-wound gaskets for casing joints. Spiral-wound gaskets are generally preferred because they are perceived by users to have had better availability, are more conducive to material identification, have a broader chemical compatibility and temperature range, contact a wider sealing surface (are less susceptible to leakage because of sealing surface irregularities), and are easier to handle and store than O-rings. API 682 specifically requires O-ring gaskets on low-temperature [$< 350^{\circ}\text{F}$ (175°C)] pressure-seal gland plates.

6.3.14 Centerline-supported pump casings shall be used for all horizontal pumps except as allowed in 9.2.1.2.

6.3.15 O-ring sealing surfaces, including all grooves and bores, shall have a maximum surface roughness average value, R_a , of $63\text{ }\mu\text{in.}$ ($1.6\text{ }\mu\text{m}$) for static O-rings and $32\text{ }\mu\text{in.}$ ($0.8\text{ }\mu\text{m}$) for the surface against which dynamic O-rings slide. Bores shall have a minimum 0.12 in. (3 mm) radius or a minimum 0.06 in. (1.5 mm) chamfered lead-in for static O-rings and a minimum 0.08 in. (2 mm) chamfered lead-in for dynamic O-rings. Chamfers shall have a maximum angle of 30° .

6.3.16 Spiral-wound gasket sealing surfaces shall have a maximum surface roughness average value, R_a , of $250\text{ }\mu\text{in}$ ($6.4\text{ }\mu\text{m}$) and minimum surface roughness average value of $125\text{ }\mu\text{in}$ ($3.2\text{ }\mu\text{m}$).

6.3.17 Jackscrews shall be provided to facilitate disassembly of the casing. One of the contacting faces shall be relieved (counter-bored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

6.3.18 The use of threaded holes in pressure parts shall be minimized. To prevent leakage in pressure sections of casings, metal, equal in thickness to at least half the nominal bolt or stud diameter, plus the allowance for corrosion, shall be left around and below the bottom of drilled and threaded holes.

6.3.19 Internal bolting shall be of a material fully resistant to corrosive attack by the pumped liquid.

6.3.20 If the manufacture of cast pressure casing parts requires the use of openings for core support, core removal, or waterway inspection and cleaning, these openings shall be designed so they can be closed by welding, using an appropriate, qualified weld procedure, during the completion of casting manufacture.

- **6.3.21** If specified, the main casing joint studs and nuts shall be designed for the use of hydraulic bolt tensioning. Procedures and extent of special tooling provided by the vendor shall be agreed.

NOTE Hydraulic bolt tensioning of casing bolt studs and nuts is generally applicable to specific pump types such as BB3 and BB5.

6.4 Nozzles and Pressure Casing Connections

6.4.1 Casing Opening Sizes

6.4.1.1 Openings for nozzles and other pressure casing connections shall be standard pipe sizes. Openings of nominal pipe size (NPS) $1\frac{1}{4}$, NPS $2\frac{1}{2}$, NPS $3\frac{1}{2}$, NPS 5, NPS 7, and NPS 9 [diameter nominal (DN) 32, DN 65, DN 90, DN 125, DN 175, and DN 225] shall not be used.

6.4.1.2 Casing connections other than suction and discharge nozzles shall be at least NPS $\frac{1}{2}$ (DN 15) for pumps with discharge nozzle openings NPS 2 (DN 50) and smaller. Connections shall be at least NPS $\frac{3}{4}$ (DN 20) for pumps with discharge nozzle openings NPS 3 (DN 80) and larger, except that connections for seal flush piping and gauges may be NPS $\frac{1}{2}$ (DN 15) regardless of pump size.

6.4.2 Casing Nozzle Connections

6.4.2.1 All casing connection nozzles shall be flanged, except for the seal gland connection, or those on pumps with forged casings, which shall be flanged or machined and studded. One- and two-stage pumps shall have suction and discharge flanges of equal rating. If the pump is supplied with machined and studded connections, the pump vendor shall provide drawings showing the dimensions of break-out spool pieces to allow the pump to be conveniently removed from the piping. Spool pieces shall be provided by the purchaser.

NOTE Break-out spool pieces eliminate the requirement to remove large sections of piping in order to take the pump casing out during major overhauls.

6.4.2.2 All nozzle flanges shall conform to the pressure ratings and dimensional requirements of ASME B16.5 and ASME B16.47 Series B, except as noted in 6.4.2.2.1, 6.4.2.2.2, 6.4.2.3, and 6.4.2.4.

NOTE For the purpose of this standard, ISO 7005-1 and EN 1759.1 are equivalent to ASME B16.5 and ASME B16.47.

6.4.2.2.1 For ASME B16.5 flange sizes from 1/2 NPS (12 mm) to 10 NPS (250 mm), the actual outside diameters (ODs) of the flanges shall be not less than their nominal OD minus 0.16 in. (4 mm). For ASME B16.5 flange sizes from 12 NPS (300 mm) to 24 NPS (600 mm), the actual ODs of the flanges shall be not less than their nominal OD minus 0.21 in. (5 mm).

NOTE These tolerances are consistent with the negative tolerances stated on EN 1092-1, Table 22.

6.4.2.2.2 For ASME B16.47 flanges, the actual ODs of the flanges shall be not less than their nominal OD minus 0.25 in. (6 mm).

6.4.2.3 Flanges in all materials that are thicker or have a larger OD than required by the relevant ISO or ASME standards in this standard are acceptable. Nonstandard (oversized) flanges shall be completely dimensioned on the arrangement drawing. If nonstandard flanges require studs or bolts of nonstandard length, this requirement shall be identified on the arrangement drawing.

6.4.2.4 Flanges shall be full faced or spot faced on the back and shall be designed for through bolting, except for jacketed casings. If nonstandard stud lengths are required for extra-thick flanges, the vendor shall provide studs of the appropriate length.

6.4.2.5 To minimize nozzle loading and facilitate installation of piping, machined faces of pump flanges shall be parallel to the plane of the flange as shown on the general arrangement drawing within 0.5°. Bolt holes or studs shall straddle centerlines parallel to the main axes of the pump.

6.4.2.6 Connections, including gusseting, welded to the casing (up to the first flange) shall meet or exceed the material and the pressure-temperature requirements of the casing, including impact values, rather than the requirements of the connected piping. For C6 construction, 316L piping and fittings are required for process temperatures up to and including 500 °F (260 °C), above which UNS N06625 materials shall be used. Gussets shall be a minimum of 316L in either case.

6.4.2.7 All connection welding shall be completed before the casing is hydrostatically tested (see 8.3.2).

6.4.2.8 All connections shall be suitable for the hydrostatic test pressure of the region of the casing to which they are attached.

6.4.2.9 All of the purchaser's connections shall be accessible for disassembly without requiring the pump, or any major part of the pump, to be moved.

6.4.3 Auxiliary Connections

6.4.3.1 Auxiliary connections shall be integrally flanged, socket welded, or butt welded as specified by the purchaser. Seal welding of threaded connections is not permitted.

- **6.4.3.2** If specified, for pumps in pipeline service with a maximum operating temperature of 130 °F (55 °C) or less, auxiliary connections may be threaded. Threaded openings shall be tapered threads in accordance with ASME B1.20.1 or ISO 7-1 or alternatively cylindrical threads in accordance with ISO 228-1. Cylindrical threads shall be sealed with a contained face gasket of suitable material sealing to a machined face (see Figure 19). The chosen method and details of threaded connection shall be approved by the purchaser. Where possible, threaded connections shall be brought to a remote flange that can be disassembled for maintenance so as to require the least amount of assembly/disassembly of the threaded connection.

NOTE 1 Threaded connections on pressure-containing parts are prone to leakage.

NOTE 2 Tapered threads create a seal by deformation of threads or use of a suitable thread sealant. They are prone to leakage if under-torqued and prone to thread damage if overtorqued.

NOTE 3 Cylindrical threads with a face gasket require suitable gasket material and are prone to leakage due to under-torque (inadequate gasket compression) or overtorque (extruding of the gasket). Surface finish and condition of the gasket mating faces are critical for proper sealing.

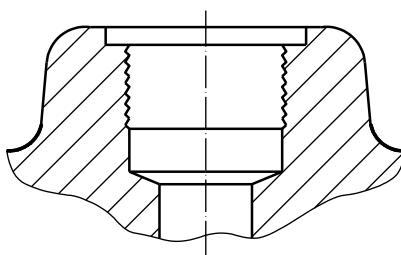


Figure 19—Machined Face Suitable for Gasket Containment if Using Cylindrical Threads

- **6.4.3.3** If specified, special threaded fittings for transitioning from the casing to tubing for seal flush piping may be used provided that a secondary sealing feature, such as O-rings, are used and that the joint does not depend on the thread contact alone to seal the fluid. The connection boss shall have a machined face suitable for sealing contact.

6.4.3.4 The first segment of piping connected to the casing shall not be more than 6 in. (150 mm) long and shall be a minimum of schedule 160 seamless for pipe sizes NPS 1 (DN 25) and smaller and a minimum of schedule 80 for pipe sizes NPS 1½ (DN 40) and larger. The first segment of piping (nipple) shall be straight, if practical, to allow connections such as drains to be cleaned. The first segment can attach axially to avoid increasing centerline height (see 7.4.5). On small pumps, if this causes interference with the suction nozzle, for example, this requirement is considered impractical.

6.4.3.5 Threaded openings, which are allowed in seal glands and in pump casings for some pipeline services (if specified in 6.4.3.2), shall be plugged. Plugs for tapered threads shall be long-shank solid round-head, or long-shank hexagon-head, bar stock plugs in accordance with ASME B16.11. Plugs for cylindrical threads shall be solid hexagon-head plugs in accordance with DIN 910. These plugs shall meet the material requirements of the casing. A lubricant/sealant that is suitable for high-temperature duty shall be used to ensure that the threads are vapor-tight. Plastic plugs are not permitted.

- **6.4.3.6** If specified, auxiliary connections to the pressure casing shall be machined and studded. These connections shall conform to the facing and drilling requirements of 6.4.2.2. Studs and nuts shall be furnished installed. If the stud engagement does not control the depth of the threads in the mating hole, the first 1.5 threads at both ends of the stud shall be removed.

6.4.3.7 All pumps shall be provided with vent and drain connections, except that vent connections may be omitted if the pump is made self-venting by the arrangement of the nozzles. Pumps that are not self-venting shall be provided with vent connections in the pressure casing, as required (see 6.8.10). If the pump cannot be completely drained for geometrical reasons, this shall be stated in the proposal. The operating manual shall include a drawing indicating the quantity and location(s) of the liquid remaining in the pump.

NOTE As a guide, a pump is considered functionally self-venting if the nozzle arrangement and the casing configuration permit sufficient venting of gases from the first-stage impeller and volute area to prevent loss of prime during the starting sequence.

6.4.3.8 A process compatible thread lubricant of proper temperature specification shall be used on all threaded connections. Thread tape shall not be used.

6.4.3.9 For socket-welded construction, there shall be a $\frac{1}{16}$ in. (1.5 mm) gap between the pipe end and bottom of the socket before welding.

6.4.3.10 Piping NPS 1 and smaller shall be gusseted in two orthogonal planes to increase the rigidity of the piped connection, in accordance with the following stipulations, except connections for seal flush piping and gauges.

- a) Gussets shall be of a material compatible with the pressure casing and the piping and shall be made of either flat bar with a minimum cross section of 1 in. by 0.12 in. (25 mm by 3 mm) or round bar with a minimum diameter of 0.38 in. (9 mm).
- b) Gusset design shall be typically as shown in Figure 20.

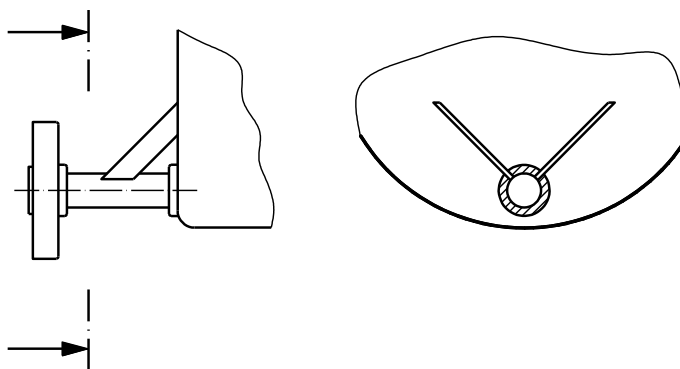


Figure 20—Typical Gusset Design

- c) Gussets shall be located at or near the connection end of the piping and fitted to the closest convenient location on the casing to provide maximum rigidity. The long width of gussets made with bar shall be perpendicular to the pipe and shall be located to avoid interference with the flange bolting or any maintenance areas on the pump.
- d) Gusset welding shall meet the fabrication requirements (see 6.12.3), including postweld heat treatment (PWHT) when required, and the inspection requirements (see 8.2.2) of this standard.
- e) Gussets may also be bolted to the casing if drilling and tapping is done prior to hydrostatic test. Proposals to use clamped or bolted gusset designs shall be submitted to the purchaser for approval.

6.5 External Nozzle Forces and Moments

6.5.1 Steel and alloy-steel horizontal pumps and their baseplates, vertical in-line pumps with supports anchored to the foundation, and vertically suspended pumps shall be designed for satisfactory performance if subjected to the forces and moments in Table 5 applied simultaneously to both suction and discharge nozzles in the worst-case combination for the pump in question. For horizontal pumps, two effects of nozzle loads are considered: distortion of the pump casing (see 6.3.3 and 6.3.4) and misalignment of the pump and driver shafts (see 7.4.23).

6.5.2 Allowable forces and moments for vertical in-line pumps with supports not anchored to the foundation may be twice the values in Table 5 for side nozzles.

6.5.3 For pump casings constructed of materials other than steel or alloy steel or for pumps with nozzles larger than NPS 16 (DN 400), the vendor shall submit allowable nozzle loads corresponding to the format in Table 5.

6.5.4 The coordinate system(s) shown in Figure 21, Figure 22, Figure 23, Figure 24, and Figure 25 shall be used to apply the forces and moments in Table 5.

- **6.5.5** Annex F gives methods of qualifying nozzle loads in excess of those in Table 5. The purchaser should be aware that the use of the methods in Annex F can result in a misalignment up to 50 % greater than that based on the loads given in Table 5 and can impact equipment installation criteria. The use of the methods in Annex F requires approval by the purchaser and specific direction to the piping designers with regard to how to apply the equations in the Annex to the system design.

Table 5—Nozzle Loadings

Location/Orientation	Nozzle-loading Force as a Function of Flange Size—USC Units lbf								
	Nominal Size of Flange (NPS)								
	≤ 2	3	4	6	8	10	12	14	16
Each top nozzle									
F_X	160	240	320	560	850	1200	1500	1600	1900
F_Y	130	200	260	460	700	1000	1200	1300	1500
F_Z	200	300	400	700	1100	1500	1800	2000	2300
F_R	290	430	570	1010	1560	2200	2600	2900	3300
Each side nozzle									
F_X	160	240	320	560	850	1200	1500	1600	1900
F_Y	200	300	400	700	1100	1500	1800	2000	2300
F_Z	130	200	260	460	700	1000	1200	1300	1500
F_R	290	430	570	1010	1560	2200	2600	2900	3300
Each end nozzle									
F_X	200	300	400	700	1100	1500	1800	2000	2300
F_Y	160	240	320	560	850	1200	1500	1600	1900
F_Z	130	200	260	460	700	1000	1200	1300	1500
F_R	290	430	570	1010	1560	2200	2600	2900	3300
Moment ft·lbf									
Each nozzle									
M_X	340	700	980	1700	2600	3700	4500	4700	5400
M_Y	170	350	500	870	1300	1800	2200	2300	2700
M_Z	260	530	740	1300	1900	2800	3400	3500	4000
M_R	460	950	1330	2310	3500	5000	6100	6300	7200
NOTE 1 See Figure 21 through Figure 25 for orientation of nozzle loads (X, Y, and Z).									
NOTE 2 Each value shown above indicates range from minus that value to plus that value; e.g. 160 indicates a range from -160 to +160.									

Table 5—Nozzle Loadings (Continued)

Location/Orientation	Nozzle-loading Force as a Function of Flange Size—SI Units								
	N								
	Nominal Size of Flange (DN)								
	≤ 50	80	100	150	200	250	300	350	400
Each top nozzle									
F_X	710	1070	1420	2490	3780	5340	6670	7120	8450
F_Y	580	890	1160	2050	3110	4450	5340	5780	6670
F_Z	890	1330	1780	3110	4890	6670	8000	8900	10,230
F_R	1280	1930	2560	4480	6920	9630	11,700	12,780	14,850
Each side nozzle									
F_X	710	1070	1420	2490	3780	5340	6670	7120	8450
F_Y	890	1330	1780	3110	4890	6670	8000	8900	10,230
F_Z	580	890	1160	2050	3110	4450	5340	5780	6670
F_R	1280	1930	2560	4480	6920	9630	11,700	12,780	14,850
Each end nozzle									
F_X	890	1330	1780	3110	4890	6670	8000	8900	10,230
F_Y	710	1070	1420	2490	3780	5340	6670	7120	8450
F_Z	580	890	1160	2050	3110	4450	5340	5780	6670
F_R	1280	1930	2560	4480	6920	9630	11,700	12,780	14,850
Moment N·m									
Each nozzle									
M_X	460	950	1330	2300	3530	5020	6100	6370	7320
M_Y	230	470	680	1180	1760	2440	2980	3120	3660
M_Z	350	720	1000	1760	2580	3800	4610	4750	5420
M_R	620	1280	1800	3130	4710	6750	8210	8540	9820

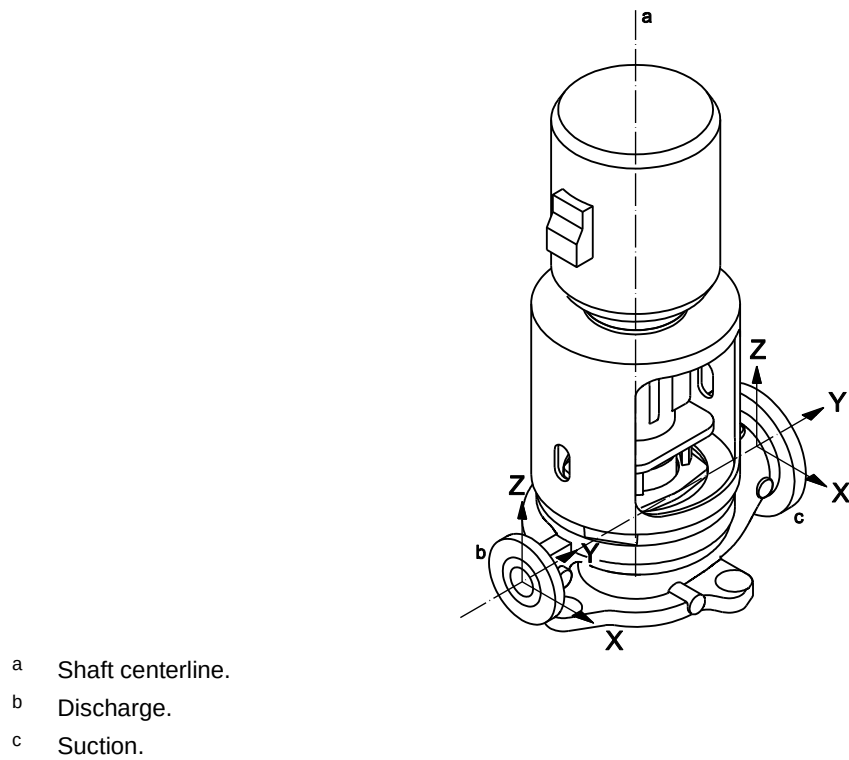
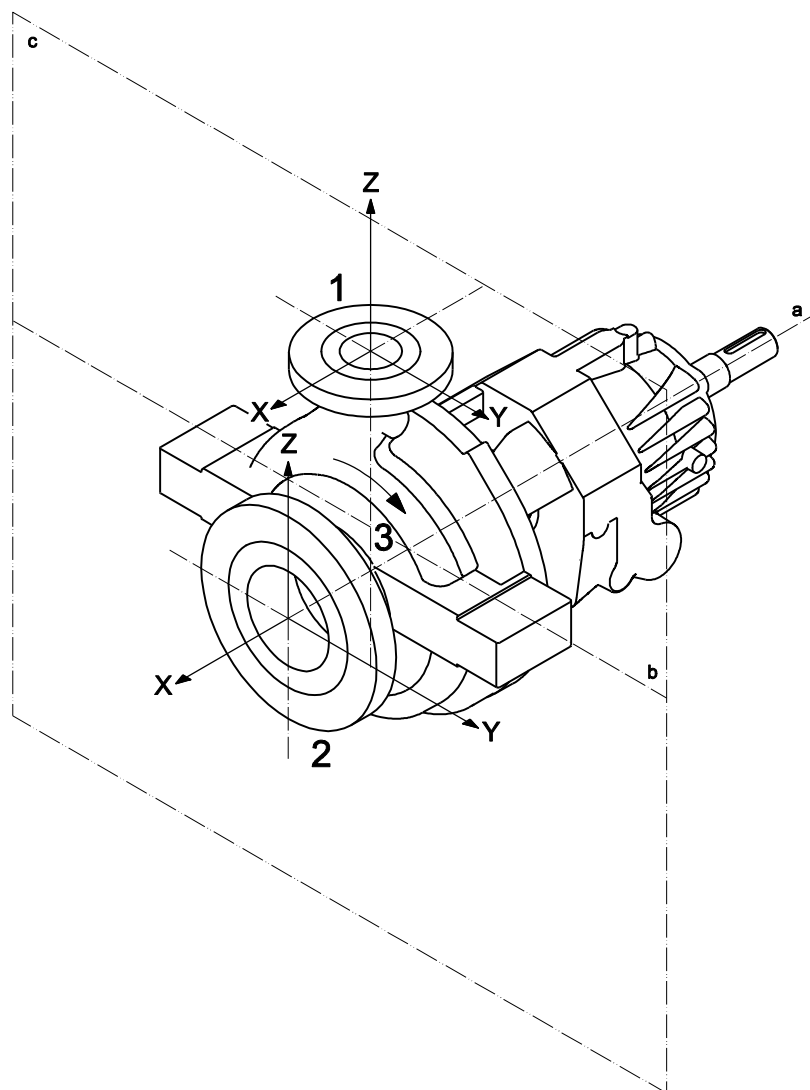
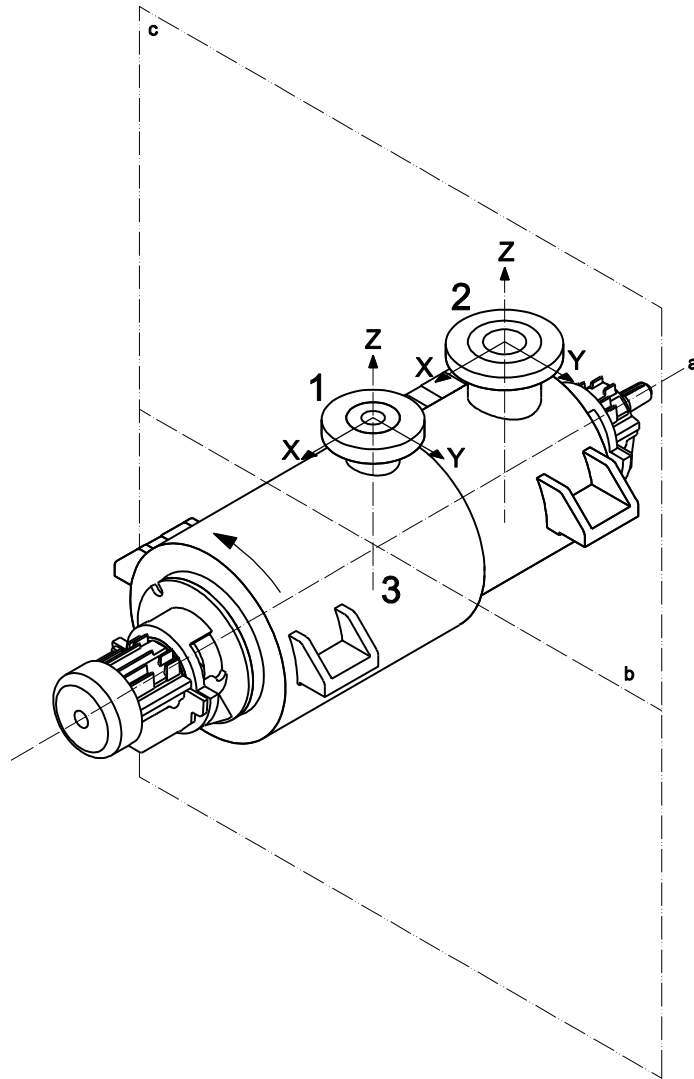


Figure 21—Coordinate System for the Forces and Moments in Table 5, Vertical In-line Pumps

**Key**

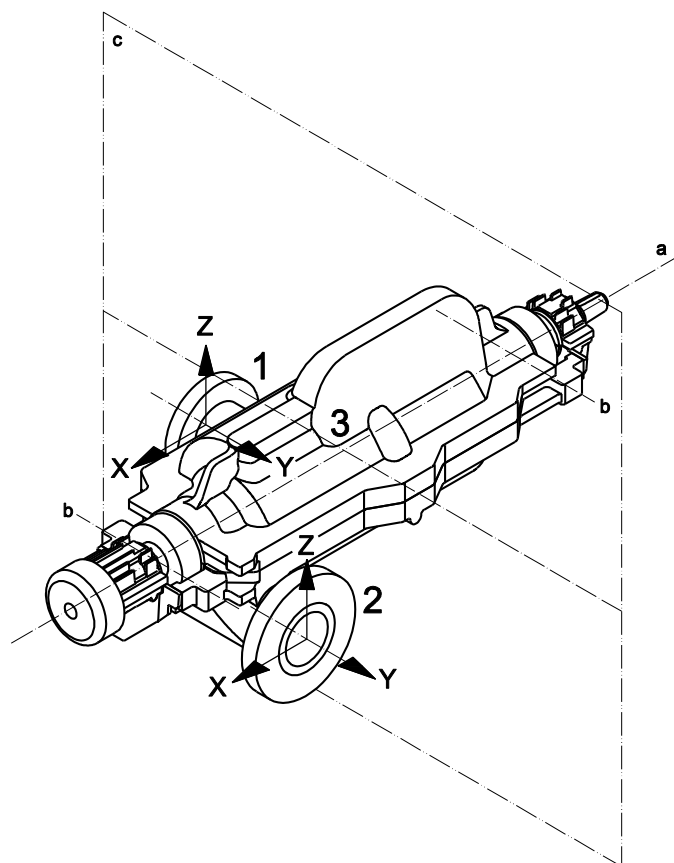
- 1 discharge nozzle
- 2 suction nozzle
- 3 center of pump
- a Shaft centerline.
- b Pedestal centerline.
- c Vertical plane.

Figure 22—Coordinate System for the Forces and Moments in Table 5, Horizontal Pumps with End Suction and Top Discharge Nozzles

**Key**

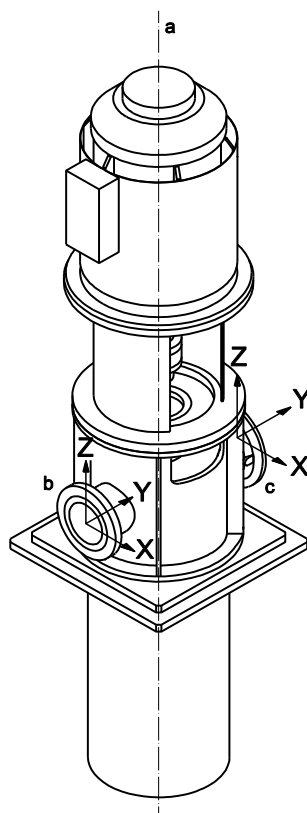
- 1 discharge nozzle
- 2 suction nozzle
- 3 center of pump
- a Shaft centerline.
- b Pedestal centerline.
- c Vertical plane.

Figure 23—Coordinate System for the Forces and Moments in Table 5, Horizontal Pumps with Top Nozzles

**Key**

- 1 discharge nozzle
- 2 suction nozzle
- 3 center of pump
- a Shaft centerline.
- b Pedestal centerline.
- c Vertical plane.

**Figure 24—Coordinate System for the Forces and Moments in
Table 5, Horizontal Pumps with Side Suction and Side Discharge Nozzles**



- a Shaft centerline.
- b Discharge.
- c Suction.

Figure 25—Coordinate System for the Forces and Moments in Table 5, Vertically Suspended, Double-casing Pumps

6.6 Rotors

6.6.1 Impellers shall be of the fully enclosed, semi-open or open type.

NOTE Enclosed (closed) impellers are less sensitive to axial position and, therefore, preferable for long shaft assemblies where axial displacement due to thermal expansion/contraction or to thrust can be substantial. Semi-open impellers can offer a higher efficiency, due to the elimination of disc friction from one shroud. The running clearances for semi-open impellers in vertical pumps can be adjusted from the coupling or top of the motor, thus possibly restoring efficiency and pump output without disassembly of pump parts. The open impeller is typically of an axial-flow propeller type designed for large capacities at low heads; the open impeller is also used for volute sump pumps with a separate discharge.

6.6.2 Impellers shall be single-piece castings, forgings, or fabrications.

NOTE Impellers made as forgings or fabrications have machined waterways, which can offer improved performance for low-specific-speed designs.

6.6.3 Impellers shall be keyed to the shaft. Pinning of impellers to the shaft is not acceptable. With the purchaser's approval, collets may be used in vertically suspended pumps. Overhung impellers shall be secured to the shaft by a cap screw or cap nut that does not expose shaft threads. The securing device shall be threaded to tighten by liquid drag on the impeller during normal rotation, and a positive mechanical locking method (e.g. a staked and corrosion-resistant set-screw or a tongue-type washer) is required. Cap screws shall have fillets and a reduced-diameter shank to reduce stress concentrations.

6.6.4 All shaft keyways shall have fillet radii in accordance with ASME B17.1 or ISO 3117.

6.6.5 Impellers shall have solid hubs. Impellers may have cored hubs if the core is completely filled with a suitable metal that has a melting point of not less than 1000 °F (540 °C).

NOTE The requirement to fill cored impeller hubs is intended to minimize the danger to personnel if and when impellers are removed by heating.

6.6.6 For shafts that require sleeve gaskets to pass over threads, at least 0.06 in. (1.5 mm) radial clearance shall be provided between the threads and the internal diameter of the gasket, and the diameter transition shall be chamfered in accordance with 6.3.15.

6.6.7 The shaft-to-seal sleeve fit(s) shall be F7/h6 in accordance with ISO 286 (all parts).

6.6.8 Areas of shafts that can be damaged by set-screws shall be relieved to facilitate the removal of sleeves or other components.

6.6.9 Shafts shall be single-piece construction, machined, and finished throughout their length so that the total indicated runout (TIR) is not more than 0.001 in. (25 µm). Shafts constructed of multiple pieces assembled together, such as stub shaft extensions to drive lube oil pumps, shall require purchaser's approval.

6.6.10 If noncontacting shaft vibration probes are furnished in accordance with 7.5.2.2, the shaft sensing areas (both radial vibration and axial position) for observation by radial vibration probes shall:

- a) be concentric with the bearing journals;
- b) be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway, for a minimum distance of one probe tip diameter on each side of the probe;
- c) not be metallized, sleeved, or plated on rotors made of materials that exhibit consistent electrical properties;
- d) have a final surface finish of 32 µin. (0.8 µm) Ra or smoother, preferably obtained by honing or burnishing;
- e) be properly demagnetized to the levels specified in API 670, or otherwise treated so that the combined total electrical and mechanical runout does not exceed the following:
 - 1) for areas observed by radial vibration probes, 25 % of the allowed peak-to-peak vibration amplitude or 0.25 mil (6 µm), whichever is greater;
 - 2) for areas to be observed by axial position probes, 0.5 mil (13 µm).

6.6.11 If the shaft is made of material that exhibits inconsistent electrical properties, the shaft-sensing areas may be produced by shrink-fitting sleeves or target rings on the shaft. Target rings shall be finished in accordance with 6.6.10 and shall be identified in the technical documentation. Materials known to exhibit inconsistent electrical properties are high-chromium alloys such as 17-4 PH, duplex stainless steel, and many austenitic stainless steels.

6.6.12 If provisions for mounting noncontacting shaft vibration probes are specified (7.5.2.2), the shaft shall be prepared in accordance with the requirements of 6.6.10 and API 670.

6.6.13 If noncontacting shaft vibration probes are furnished, accurate records of electrical and mechanical runout for the full 360° at each probe location shall be included in the mechanical test report. Electrical and mechanical runout records shall be phase referenced to a permanent location on the shaft such as a key slot.

6.7 Wear Rings and Running Clearances

6.7.1 Radial running clearances shall be used to limit internal leakage and, where necessary, balance axial thrust. Impeller pump-out vanes or close axial clearances shall not be used to balance axial thrust. Renewable