

Sealless Centrifugal Pumps for Petroleum, Petrochemical, and Gas Industry Process Service

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

1	Scope	1
2	Normative References	1
3	Terms, Definitions, Acronyms, and Abbreviations	4
3.1	Terms and Definitions	4
3.2	Acronyms and Abbreviations	13
4	General	14
4.1	Unit Responsibility	14
4.2	Nomenclature	14
5	Requirements	15
5.1	Units of Measure	15
5.2	Statutory Requirements	15
5.3	Document Requirements	15
6	Basic Design	15
6.1	General	15
6.2	Pressure Casings	24
6.3	Nozzles and Pressure Casing Connections	26
6.4	External Nozzle Forces and Moments	30
6.5	Rotors	33
6.6	Wear Rings and Running Clearances	33
6.7	Secondary Control/Containment	34
6.8	Dynamics	36
6.9	Process Cooled/Lubricated Bearings and Bearing Housings	41
6.10	Materials	41
6.11	Nameplates and Rotation Arrows	47
7	Accessories	48
7.1	Drivers	48
7.2	Couplings and Guards	49
7.3	Baseplates and Support Frames	49
7.4	Controls and Instrumentation	49
7.5	Piping and Appurtenances	50
7.6	Special Tools	50
8	Inspection, Testing, and Preparation for Shipment	50
8.1	General	50
8.2	Inspection	51
8.3	Testing	54
8.4	Preparation for Shipment	59
9	Specific Pump Sections	60
9.1	Magnetic Drive Pumps	60
9.2	Canned Motor Pumps	73
10	Vendor's Data	75
Annex A	(normative) Specific Speed and Suction-specific Speed	76
Annex B	(normative) Circulation and Cooling Water Piping Schematics	77
Annex C	(informative) Sealless Centrifugal Pump Nomenclature	81
Annex D	(informative) Magnet Materials for Magnetic Couplings	86
Annex E	(informative) Inspector's Checklist	88
Annex F	(normative) Criteria for Piping Design	90
Annex G	(informative) Materials Class Selection Guidance	105

Annex H (normative) Materials and Material Specifications for Pump Parts	107
Annex I (informative) Lateral Analysis	119
Annex J (normative) Determination of Residual Unbalance.....	124
Annex K (normative) Pressure/Temperature Profiles in the Recirculation Circuit.....	130
Annex L (informative) Contract Documents and Engineering Design Data	133
Annex M (informative) Test Data Summary	147
Annex N (informative) Pump Data Sheets and Electronic Data Exchange	152
Annex O (informative) Application Information	167
Annex P (informative) Hazard-based Specification of Control/Containment Guidelines.....	172
Annex Q (informative) Multistage Overhung Sealless Pumps.....	176
Annex R (informative) Instrumentation and Protective Systems	182
Bibliography	187

Figures

1 Machined Face Suitable for Gasket Containment if Using Cylindrical Threads	28
2 Typical Gusset Design.....	29
3 Coordinate System for the Forces and Moments in Table 4A and Table 4B: Vertical Inline Pumps	32
4 Coordinate System for the Forces and Moments in Table 4A and Table 4B: Horizontal Pumps	32
5 Relationship between Flow and Vibration.....	37
6 Locations for Taking Vibration Readings on Horizontal and Vertical Inline Pumps	38
7 Vibration Limits for Pumps Running Above 3600 r/min or Absorbing More Than 300 kW (400 hp).....	39
8 Rotating Component Dimensions to Determine if Single-plane Balancing Is Allowed	40
B.1 Circulation and Cooling Water Piping Schematics	77
B.2 Clean Circulating Fluid Arrangements	78
B.3 Dirty or Special Circulating Fluid Arrangements.....	79
B.4 Cooling Water Piping Arrangements	80
C.1 Typical Nomenclature for Magnetic Drive Pump	82
C.2 Typical Nomenclature for Canned Motor Pump	83
C.3 Magnetic Drive Pump Terms Defined in 3.1	84
C.4 Canned Motor Pump Terms Defined in Section 3	85
I.1 Damping Factor vs. Frequency Ratio	121
I.2 Typical Campbell Diagram	121
J.1 Residual Unbalance Worksheet	126
J.2 Residual Unbalance Worksheet—Polar Chart	127
J.3 Example of Completed Residual Unbalance Worksheet	128
J.4 Example of Completed Residual Unbalance Worksheet—Best-fit Circle for Residual Unbalance	129
K.1 Typical Pressure/Temperature Calculation Points in Magnetic Drive Pump.....	131
K.2 Typical Pressure/Temperature Calculation Points in Canned Motor Pump	131
K.3 Pressure/Temperature Profile Diagram	132
M.1 Test Data Summary Form	147
M.2 Example of Test Curve Format (SI Units)	149
M.3 Test Curve Format (USC Units)	150
M.4 Test Points Shown on Typical Performance Curve.....	151
P.1 Secondary Control/Containment Logic Diagram.....	174
Q.1 M4OH-MAG—Multistage Segmented-ring Magnetic Drive	176
Q.2 M5OH-MAG—Multistage Barrel Magnetic Drive	177
Q.3 M4OH-CAN—Multistage Segmented-ring Canned Motor	177
Q.4 M5OH-CAN—Multistage Barrel Canned Motor	177

Q.5	M4OH-DE-CAN—Multistage Double-extended Canned Motor Spec.....	178
Q.6	M5VS-CAN—Multistage Hybrid-barrel Vertical Canned Motor.....	178
R.1	Magnetic Drive Pump.....	184
R.2	Canned Motor Pump (Horizontal).....	185
R.3	Canned Motor Pump (Vertical)	186

Tables

1	Water Cooling Systems—Conditions on the Water Side	21
2	Common Hazardous Area Electrical Codes	23
3	Casting Factors	25
4A	Nozzle Loading (SI Units).....	30
4B	Nozzle Loading (USC Units).....	31
5	Minimum Internal Running Clearances	35
6	Vibration Limits for Overhung Pumps	39
7	Welding Requirements	45
8	Power Ratings for Motor Drivers.....	48
9	Pressure Casing Material Inspection Requirements.....	52
10	Material Inspection Standards.....	53
11	Performance Acceptance Criteria	54
12	Magnetic Coupling Torque Service Factors.....	63
13	Stiffness Criteria	72
D.1	Properties for Several Commercially Available Grades of Alnico Magnet Material.....	87
E.1	Inspector's Checklist.....	88
F.1	Nozzle Sizes and Location Coordinates for Example 1A.....	94
F.2	Applied Nozzle Loadings for Example 1A	94
F.3	Proposed Applied Nozzle Loadings for Example 2A	97
F.4	Nozzle Sizes and Location Coordinates for Example 1B.....	99
F.5	Applied Nozzle Loadings for Example 1B	99
F.6	Proposed Applied Nozzle Loadings for Example 2B	102
G.1	Material Classes for Sealless Centrifugal Pump Services.....	105
H.1	Material Classes for Pump Parts	108
H.2	Material Specifications for Pump Parts	111
H.3	Nonmetallic Wear Part Materials	118
I.1	Rotor Lateral Analysis Logic Diagram.....	119
L.1	Recommended Spare Parts	135
L.2	VDDR for Sealless Centrifugal Pump Applications (See Tables L.3 and L.4 for Details of the Description)	140
L.3	Details of Table L.2 for Compressor Package	141
L.4	Details of Table L.2 for Motor (MDP Only).....	145
P.1	H Statement Classification Table	173
R.1	Instrumentation and Protective Systems	183

Introduction

Users of this standard should be aware that further or differing requirements may 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 may be particularly appropriate where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this standard and provide details.

Annex A discusses calculations for specific speed and suction-specific speed.

Annex B contains schematic drawings of cooling water and circulation systems.

Annex C illustrates typical nomenclature for sealless pumps.

Annex D provides information on magnetic materials for magnetic couplings.

Annex E provides an inspector's checklist that may be used.

Annex F provides informative criteria for piping design.

Annex G gives guidance on material class selection.

Annex H specifies requirements and gives guidance on materials selection.

Annex I specifies requirements for lateral analysis.

Annex J specifies requirements for determining residual unbalance.

Annex K provides information and examples for pressure temperature profiles in the recirculation circuit.

Annex L contains information and forms that may be used to indicate vendor drawing and data.

Annex M contains forms that may be used to record test data.

Annex N contains a data sheet format that is available for purchasers to use.

Annex O contains application-specific information and cautions.

Annex P contains hazard-based criteria for secondary containment/control specification.

Annex Q provides considerations for application for multistage sealless pumps.

Annex R defines options for instrumentation and protective systems.

This standard requires the purchaser to specify certain details and features.

A bullet (●) at the beginning of a section or paragraph indicates that either a decision by, or further information from, the purchaser is required. Further information should be shown on the data sheets or stated in the quotation request and purchase order.

In this standard, US customary units are included in parentheses for information.

API does not give guidelines on when a sealless pump should be considered. Sealless technology is well suited for the following applications:

- lethal;
- toxic;
- flammable fluids;
- expensive fluids;

- fluids with dissolved solids (i.e. caustic);
- carcinogenic;
- heat transfer fluids (hot and cold);
- emissions are regulated;
- clean fluids (typically);
- low specific gravity;
- fluids that are difficult to seal.

Increasingly stringent environmental requirements surrounding volatile organic compounds have led to the increased use of sealless technology. A thorough, unbiased evaluation and application of the appropriate sealless technology results from carefully evaluating both technologies (canned motor pump and magnetic drive pump). There are many refinery applications ideally suited to sealless technology. The following are a few examples of where sealless technology is being applied in refineries currently:

- hydrofluoric acid (HF acid);
- anhydrous hydrofluoric acid;
- naphtha;
- sulfuric acid;
- butane;
- isobutane;
- methanol;
- caustic;
- propylene;
- alkylate;
- methyl mercaptan;
- aromatics (benzene, xylene, toluene);
- sour water (water containing H_2S);
- olefins.

Process units that would pump the above fluids (pure or as a mixture) are varied and could include:

- alkylation (HF acid or sulfuric acid);
- sulfur plant;
- aromatics recovery unit;
- hydrotreaters;
- boiler house;
- hydrocracker;
- fluidized catalytic cracker;
- reformer;
- crude.

Sealless Centrifugal Pumps for Petroleum, Petrochemical, and Gas Industry Process Service

1 Scope

1.1 This standard covers the minimum requirements for sealless centrifugal pumps for use in petroleum, heavy-duty petrochemical, and gas industry services. Refer to Annex O for application information. Notes following a clause are informative.

1.2 This standard is applicable to single-stage overhung pumps of two classifications, magnetic drive pumps (MDPs) and canned motor pumps (CMPs). Sections 2 through 8 and Section 10 cover requirements applicable to both classifications. Section 9 is divided into two subsections and covers requirements unique to each classification.

NOTE Extension of applicability to other designs such as multistage will need additional input and agreement between the purchaser and the supplier. Considerations for multistage sealless pumps are given in Annex Q.

1.3 If application of sealless pumps is indicated, relevant industry operating experience suggests that sealless pumps produced to this standard should be considered for pumping liquids at conditions exceeding any of the following:

— discharge pressure	1900 kPa	(275 psig);
— suction pressure	500 kPa	(75 psig);
— pumping temperature	150 °C	(300 °F);
— rated total head	120 m	(400 ft).

NOTE For sealed pumps, refer to API 610.

2 Normative References

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

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

API Standard 610, *Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries*

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

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

API Standard 670, *Machinery Protection Systems*

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

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

API Recommended Practice 686, *Recommended Practice for Machinery Installation and Installation Design*

API Recommended Practice 691, *Risk-based Machinery Management*

ANSI ¹/ABMA 7 ², *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plan*

ABMA 9 (R2015), *Load Ratings and Fatigue Life for Ball Bearings*

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

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

ANSI/AWS D1.1/D1.1M ⁴, *Structural Welding Code—Steel*

ANSI B11.19, *Performance Requirements for Risk Reduction Measures: Safeguarding and Other Means of Reducing Risk*

ANSI/ASME B1.1 ⁵, *Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)*

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

ASME B1.20.1, *Pipe Threads, General Purpose (Inch)*

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 B17.1, *Keys and Keyseats*

ASME B18.18, *Inspection and Quality Assurance for High-Volume Machine Assembly Fasteners*

ASME B31.3, *Process Piping*

ASME Boiler and Pressure Vessel Code, Section V—*Nondestructive Examination*

ASME Boiler and Pressure Vessel Code, Section VIII—*Rules for Construction of Pressure Vessels*

ASME Boiler and Pressure Vessel Code, Section IX—*Welding and Brazing Qualifications*

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

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

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

EN 80079-36, *Non-electrical equipment for potentially explosive atmospheres—Basic method and requirements*

ANSI/HI 14.6 ⁷, *Rotodynamic Pumps for Hydraulic Performance Acceptance Tests*

¹ American National Standards Institute, 1899 L Street, NW, Washington, DC 20036, <https://ansi.org>.

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

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

⁴ American Welding Society, 8669 NW 36 Street, # 130, Miami, Florida 33166, www.aws.org.

⁵ American Society of Mechanical Engineers, Two Park Avenue, New York, New York 10016, www.asme.org.

⁶ Deutsches Institut für Normung e. V., Am DIN-Platz, Burggrafenstraße 6, 10787 Berlin, Germany, www.din.de/en.

⁷ Hydraulic Institute, 300 Interpace Parkway, Parsippany, New Jersey 07054, www.pumps.org.

ANSI/HI 9.6.7, *Rotodynamic Pumps—Guideline for Effects of Liquid Viscosity on Performance*

IEC 60079 (all parts) ⁸, *Explosive Atmospheres*

IEEE 252, *IEEE Standard Test Procedure for Polyphase Induction Motors Having Liquid in the Magnetic Gap*

IEEE 841 ⁹, *Standard for Petroleum and Chemical Industry—Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)*

ISO 7-1 ¹⁰, *Pipe threads where pressure—Tight joints are made on the threads, Part 1—Dimensions, tolerances and designation*

ISO 228-1, *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, *Rolling bearings—Dynamic load ratings and rating life*

ISO 724, *ISO general-purpose metric screw threads—Basic dimensions*

ISO 898, *Mechanical properties of fasteners made of carbon steel and alloy steel*

ISO 965 (all parts), *ISO general-purpose metric screw threads—Tolerances*

ISO 3117, *Tangential keys and keyways*

ISO 3506, *Fasteners—Mechanical properties of corrosion-resistant stainless steel fasteners*

ISO 3740, *Acoustics—Determination of sound power levels of noise sources—Guidelines for the use of basic standards*

ISO 3744, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Engineering methods for an essentially free field over a reflecting plane*

ISO 3746, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Survey method using an enveloping measurement surface over a reflecting plane*

ISO 6708, *Pipework components—Definition and selection of DN (nominal size)*

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 test of welders—Fusion welding*

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

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

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

⁸ International Electrotechnical Commission, 3 rue de Varembe, CH-1211, Geneva 20, Switzerland, www.iec.ch.

⁹ Institute of Electrical and Electronics Engineers, 3 Park Avenue, 17th Floor, New York, New York, 10016, www.ieee.org.

¹⁰ International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 – 1214 Vernier, Geneva, Switzerland, www.iso.org.

ISO 15156 (all parts), *Petroleum and natural gas industries—Materials for use in H₂S-containing environments in oil and gas production*

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

ISO 17945, *Petroleum, petrochemical and natural gas industries—Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments*

ISO TR 17766:2005, *Centrifugal pumps handling viscous liquids—Performance corrections*

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

MSS SP-55¹¹, *Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

NACE MR0103¹²/ISO 17945, *Petroleum, petrochemical and natural gas industries—Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments*

NACE MR0175/ISO 15156, *Petroleum and natural gas industries—Materials for use in H₂S-containing environments in oil and gas production*

NFPA 70¹³, *National Electrical Code*

NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*

SSPC SP 6¹⁴, *Commercial Blast Cleaning*

United Nations ST/SG/AC.10/30/Rev 2¹⁵, *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)*

2.2 The applicability of changes in standards, codes, and specifications that occur after the publication of this standard shall be agreed between the purchaser and the vendor.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

air gap

Radial distance between the inside of the outer magnet ring and the containment shell or the total radial dimension between the stator inside bore and the outside diameter of the basic rotor core (armature) prior to installation of stator liner and rotor liner.

¹¹ Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park St. NE, Vienna, Virginia 22180, <http://msshq.org>.

¹² NACE International (now Association for Materials Protection and Performance), 15835 Park Ten Place, Houston, Texas 77084, <https://ampp.org>.

¹³ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

¹⁴ Society for Protective Coatings (now Association for Materials Protection and Performance), 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, <https://ampp.org>.

¹⁵ United Nations Economic Commission for Europe, Palais des Nations, CH - 1211 Geneva 10, Switzerland, <https://unece.org>.

3.1.2**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.

3.1.3**axial thrust**

Net axial load on the pump shaft caused by hydraulic forces acting on the impeller shrouds and rotor or inner magnet ring.

3.1.4**axially split**

Split with the principal joint parallel to the shaft centerline.

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

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

NOTE The best efficiency point (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**canned motor pump****CMP**

Type of sealless pump that has a common shaft to link pump and motor in a single sealed unit. The pumped liquid, or a flush fluid, is circulated through the motor rotor chamber, but is isolated from the motor electrical components by a thin corrosion-resistant nonmagnetic stator liner (see Figure C.2).

3.1.7**containment shell**

Pressure-containing boundary located within the drive end that separates the inner and outer magnet rings of an MDP (see Figure C.1 and Figure C.3).

3.1.8**coupling (magnetic)**

Attraction of the magnets of the inner magnet ring and outer magnet ring allowing both to rotate synchronously or asynchronously in the case of a torque ring drive.

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 6.1.12).
cf. "net positive suction head" (3.1.37).

3.1.11**decouple**

To break the magnetic linkage between inner and outer magnet rings of a synchronous coupling resulting in a failure of the magnet assemblies to rotate synchronously.

3.1.12**demagnetization**

Loss of magnetic attraction due to such causes as mechanical damage or elevated temperature.

3.1.13 design

Manufacturer's calculated parameter.

NOTE A term used by the equipment manufacturer to describe various parameters such as, design power, design pressure, design temperature, or design speed. It is not intended for the purchaser to use this term.

3.1.14 drive train component

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

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

3.1.15 eddy current losses

Losses from random electrical currents generated in a conductive material when a magnetic field is rotated around it. These losses are normally dissipated as heat due to the electrical resistance of the material.

3.1.16 electrical feed-through barrier

Static seal in a CMP through which electrical lines feed the motor stator (see Figure C.4).

3.1.17 hydraulic thrust balance

Axial thrust equalization achieved by means of an impeller design, by impeller balance holes or by thrust balancing through variable orifices in the drive end.

3.1.18 hydrodynamic bearing

Bearings that incorporate a fluid film to form an oil wedge, or wedges, that support the load without shaft-to-bearing contact.

NOTE The bearing surfaces are oriented so that relative motion forms a fluid wedge, or wedges, to support the load without journal-to-bearing contact.

3.1.19 informative

For more enlightened understanding only.
cf. "normative" (3.1.42).

3.1.20 inner magnet ring

Cylindrical band of magnets operating within the containment shell of an MDP, driven by the outer magnet ring. The inner magnet ring contains the same number of magnetic poles as the outer magnet ring and is mounted on the same shaft as the pump impeller (see Figure C.3).

3.1.21 inner magnet sheathing

Protective covering of the inner magnet ring in an MDP (see Figure C.3).

3.1.22 journal sleeve

Renewable component of the journal.

3.1.23 liquid end

End of the pump that converts mechanical energy to kinetic energy in the pumped fluid.

3.1.24**liquid gap**

Radial distance between the containment shell inside surface and the outside surface of the inner magnet sheathing or the radial distance between the stator liner inside surface and the rotor liner outside surface.

3.1.25**locked rotor amps**

Maximum amps that a motor will draw at zero rotation with rated voltage applied at rated frequency.

3.1.26**locked rotor torque**

Maximum torque that a motor will produce at zero rotation with rated voltage applied at rated frequency.

3.1.27**magnetic drive pump****magdrive pump****MDP**

Type of sealless pump that utilizes magnets to drive an internal rotating assembly consisting of an impeller, shaft, and inner drive member (torque ring or inner magnet ring) through a thin, corrosion-resistant containment shell (see Figure C.1).

3.1.28**maximum allowable temperature**

Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) if pumping the specified liquid at the specified maximum operating pressure.

3.1.29**maximum allowable working pressure****MAWP**

Maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) if pumping the specified liquid at the specified maximum operating temperature.

3.1.30**maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the manufacturer's design permits continuous operation.

3.1.31**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.

3.1.32**maximum operating temperature**

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

3.1.33**maximum suction pressure**

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

3.1.34**minimum continuous stable flow**

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

3.1.35**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.

3.1.36**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.

3.1.37**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 meters (feet) of head of the pumped liquid.

3.1.38**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.

3.1.39**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.

3.1.40**normal operating point**

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

3.1.41**normal wear part**

Part normally restored or replaced at each pump overhaul.

EXAMPLE Wear rings, throat bushing, bearings, and gaskets.

3.1.42**normative**

Required.

cf. "informative" (3.1.19).

3.1.43**observed inspection****observed test**

Classification of inspection or test where the purchaser is notified of the schedule and the inspection or test is performed, even if the purchaser or their representative is not present.

3.1.44**oil mist lubrication**

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

3.1.45**operating region**

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

3.1.46**outer magnet ring**

Band of permanent magnets securely fixed to a cylindrical frame and evenly spaced to provide a uniform magnetic field. The outer magnet ring rotates about the containment shell, driving the inner magnet ring or torque ring.

3.1.47**overhung pump**

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

NOTE Overhung pumps can be horizontal or vertical.

3.1.48**owner**

Final recipient of the equipment who sometimes delegates another agent as the purchaser of the equipment.

3.1.49**pole**

Region of a magnet where flux density is concentrated.

3.1.50**positive material identification testing****PMI**

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

3.1.51**power end**

End of the pump that provides the mechanical energy necessary for the operation of the liquid end.

3.1.52**preferred operating region**

Portion of a pump's hydraulic coverage over which the pump's vibration is within the base limit of this standard (see 6.1.17).

3.1.53**pressure casing**

Composite of all stationary pressure-containing parts of the unit, including all nozzles and other attached parts.

3.1.54**primary pressure casing**

Composite of all stationary pressure-containing parts of the unit that normally are exposed to pumped liquids, including the stator liner or containment shell (see Figure C.1 and Figure C.2).

3.1.55**product-lubricated bearing**

Bearing bushing and journal that operate in a pumped liquid-lubricated environment to support the shaft of the inner magnet ring of an MDP or the rotor assembly of a CMP.

3.1.56**purchaser**

Agency that issues the order and specification to the vendor.

NOTE The purchaser can be the owner of the plant in which the equipment is to be installed or the owner's appointed agent.

3.1.57**pure oil mist lubrication (dry sump)**

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

3.1.58**purge oil mist lubrication (wet sump)**

System in which the mist only purges the bearing housing.

NOTE Bearing lubrication is by conventional oil bath, flinger, or oil ring.

3.1.59 **R_a**

Arithmetic average of the absolute value of the profile height deviations recorded within the evaluation length and measured from the mean line.

NOTE It is the average height of the entire surface, within the sampling length, from the mean line.

3.1.60**radial load**

Side load perpendicular to the pump shaft and drive shaft due to unbalanced hydraulic loading on the impeller, mechanical and magnetic rotor unbalance, rotor assembly weight, and forces of the fluid circulating through the rotor chamber.

3.1.61**radially split**

Split with the principal joint perpendicular to the shaft centerline.

3.1.62**rated operating point**

Point at which the vendor certifies that pump performance is within the tolerances stated in this standard (see 8.3.3.3.2).

3.1.63**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 15 °C (59 °F).

3.1.64**restrictive device**

Secondary control feature on an MDP that forms a restrictive close clearance around the shaft (or sleeve) of the outer magnet ring.

3.1.65**rotor**

Assembly of all the rotating parts of a centrifugal pump.

3.1.66**rotor chamber**

Liquid filled cavity bounded by the inside diameter of the stator liner and the bearing housings in a CMP or

the liquid filled cavity in an MDP internal to the containment shell that contains the inner magnet ring, shaft, and bearings (see Figure C.3 and Figure C.4).

3.1.67

rotor chamber temperature rise

Temperature increase of the fluid circulated through the rotor chamber; it is the difference between the temperature of the fluid leaving the rotor chamber and that entering.

3.1.68

rotor liner

Outer sheathing of the rotor assembly in a CMP (see Figure C.4).

3.1.69

sealless pump

Pump design that does not require an external dynamic shaft seal. Static seals are the primary method of containing the fluid.

3.1.70

secondary containment

Confinement of the pumped liquid within a secondary pressure casing in the event of failure of the primary containment shell or stator liner.

3.1.71

secondary containment system

Combination of devices (possibly including a mechanical seal) that, in the event of leakage from the primary containment shell or stator liner, confines the pumped liquid within a secondary pressure casing that includes provisions to indicate a failure of the primary containment shell or stator liner and effect shutdown.

3.1.72

secondary control

Minimization of release of pumped liquid in the event of failure of the containment shell or stator liner.

3.1.73

secondary control system

Combination of devices (including a secondary pressure casing) that, in the event of leakage from the containment shell or stator liner, minimizes and safely directs the release of pumped liquid. It includes provision(s) to indicate a failure of the containment shell or liner.

3.1.74

secondary pressure casing

Composite of all pressure-containing parts of the unit that are exposed to pressure resulting from failure of a containment shell or stator liner.

3.1.75

sleeve bearing

Bearing consisting of a rotating member (journal) and a stationary member (bearing bushing).

3.1.76

slip

Speed differential between the torque ring and outer magnet ring in a torque ring drive pump.

3.1.77

spark-resistant material

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

**3.1.78
specific speed** N_s

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

**3.1.79
stator housing**

Housing in which a stator assembly is mounted in a CMP (see Figure C.2).

**3.1.80
stator liner**

Member that separates the liquid in the rotor chamber from the stator assembly in a CMP (see Figure C.4).

**3.1.81
suction pressure**

Liquid pressure at the suction flange of the pump.

**3.1.82
suction-specific speed** N_{ss} or S

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

**3.1.83
throat bushing**

Device that forms a restrictive close clearance around the sleeve (or shaft) between the rotor chamber and the impeller.

**3.1.84
tolerance ring**

Component that acts as an elastic shim to frictionally position mating cylindrical parts.

**3.1.85
torque ring drive**

Magnetic coupling consisting of a permanent outer magnet ring and an inner torque ring containing a network of copper rods supported on a mild steel core. The rotating outer magnet ring generates eddy currents in the copper rods, which converts the core to an electromagnet. The electromagnet follows the rotating outer magnet ring, but at a slightly slower speed due to slip.

**3.1.86
total indicator reading****total indicator 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-squareness equal to the reading. If the diameter in question is not designed perfectly cylindrical or flat, interpretation of the meaning of TIR is more complex and can represent ovality or lobing.

**3.1.87
trip speed**

Speed (in revolutions per minute) at which the independent emergency overspeed device operates to shut down a driver. Also electric motor driver synchronous speed at maximum supply frequency.

3.1.88**unit responsibility**

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

3.1.89**vendor
supplier**

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

3.1.90**vertical inline pump**

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

3.1.91**volatile hazardous air pollutant****VHAP**

Any compound as defined by Title 1, Part A, Section 112 of the US National Emission Standards for Hazardous Air Pollutants (NESHAP) (Clean Air Act Amendment).

3.1.92**witnessed**

Classification of inspection or test for which the purchaser is notified of schedule 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

ASD	adjustable speed drive
BEP	best efficiency point
BPVC	<i>Boiler and Pressure Vessel Code</i>
CMP	canned motor pump
DBSE	distance between shaft ends
DN	nominal diameter
EDE	electronic data exchange
FFT	fast Fourier transform
HAZOP	hazard and operability study
ID	inside diameter
MAWP	maximum allowable working pressure
MCS	maximum continuous speed
MDP	magnetic drive pump
MT	magnetic particle inspection

NDT	nondestructive testing
NPS	nominal pipe size
NPSH	net positive suction head
NPSH3	net positive suction head (3 % head loss)
NPSHA	net positive suction head available
N_s	specific speed
N_{ss}	suction-specific speed
OD	outside diameter
OH2	overhung horizontal pump type 2 (with centerline support)
PMI	positive material identification
PT	liquid penetrant inspection
PWHT	post-weld heat treatment
R_a	arithmetic average if the absolute value
RMS	root mean square
RT	radiographic inspection
SI	International System of Units
SPL	sound pressure level
USC	United States customary
UT	ultrasonic test
VDDR	vendor drawing and data requirements

4 General

4.1 Unit Responsibility

The pump vendor shall have unit responsibility. The pump vendor shall ensure 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, containment design, couplings, dynamics, lubrication, material test reports, instrumentation, piping, conformance to specifications, and testing of components.

4.2 Nomenclature

A guide to sealless pump nomenclature can be found in Annex C.

5 Requirements

5.1 Units of Measure

The purchaser shall specify whether data, drawings, and maintenance dimensions of pumps shall be in the United States customary (USC) system of measurements or International System of Units (SI). Use of a USC data sheet (e.g. Annex N) indicates that the USC system of measurements shall be used. Use of an SI data sheet (e.g. Annex N) indicates that the SI 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, directives, or rules that are applicable to the equipment, its packaging, and any preservatives used. 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 Document 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 order shall govern.

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

- **5.3.3** The hierarchy of documents shall be specified by the purchaser.

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 (including driver, coupling, unit components) designed for a finite life.

6.1.3 The purchaser and the vendor have a responsibility to transfer information to each other and shall include, as a minimum, all items in 6.1.3.1 through 6.1.3.8.

6.1.3.1 The purchaser shall specify the operating conditions, site conditions, and utility conditions, including all data shown on the process data sheet (e.g. Annex N). Operating conditions should include any startup, upset, cleaning, seasonal, etc.

- **6.1.3.2** Properties of the fluid being pumped are critical to the performance of the pump. The purchaser shall furnish information including, but not limited to, the following:

- a) NPSHA;
- b) temperature/vapor pressure curve;
- c) temperature/viscosity curve;
- d) specific heat;
- e) specific gravity/temperature curve;
- f) any polymerization characteristics;
- g) any non-Newtonian characteristics of the fluid.

NOTE Pump designers prefer kinematic (cSt) viscosity in bearing design.

- **6.1.3.3** The purchaser shall furnish information on any gas entrainment or solids present including particle size, percent, and distribution.

6.1.3.4 It is important that the pumped fluid remain a liquid at all points in the pump and at all operating conditions. The vendor shall furnish information including, but not limited to, the following: NPSH3, rotor chamber temperature rise based on fluid being pumped at minimum flow, rated flow, and 120 % BEP flowrate, and fluid condition after shutdown, effect of wear, minimum continuous stable flow, and minimum continuous thermal flow.

6.1.3.5 Because sealless pumps use pumpage or other liquid to cool and lubricate the bearings, it is imperative the circulating liquid remain stable as it passes through the bearings. The vendor shall furnish the temperature and pressure profiles of the fluid recirculation flow path through the pump and rotor chamber. These profiles are to be shown at maximum specified operating temperature and are to be provided for minimum stable flow, rated conditions, and maximum flow. Refer to Annex K.

NOTE The temperature vs. pressure profile throughout the pump needs to be above the vapor pressure curve at all locations for the minimum, rated, and maximum flow conditions in the flow path for all conditions. This is to ensure that the fluid does not flash.

- **6.1.3.6** The purchaser shall provide separate data if there are additional service conditions, such as different fluids or different operating conditions. These additional services could be rare (such as an initial water run, process upset, etc.) or common (multiproduct batch).
- **6.1.3.7** The purchaser shall specify when 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;
- b) critical service pumps; and/or
- c) pumps identified in hazard and operability study (HAZOP), process safety management studies, etc., and internal company risk assessment.

NOTE 2 Both the API 685 data sheets (e.g. Annex N) and API 691 data sheets can be issued jointly to define all applicable requirements.

6.1.3.8 If API 691 is specified, the vendor shall identify all machinery components that are not “Field Qualified” per API 691 (First Edition)—subsection 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 designed for hazardous services (see Annex P).

6.1.6 Pumps shall be capable of at least a 5 % head increase at rated conditions by replacement of the impeller(s) with one of larger diameter or different hydraulic design or variable-speed capability where applicable. 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 expandability. If there is a future operating requirement, it should be specified separately and addressed in the selection.

NOTE In case of variable-speed drive, the impeller diameter giving the best efficiency is selected.

6.1.7 Pumps shall be capable of operating at least up to the maximum continuous speed (MCS). The MCS 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.

6.1.8 Variable-speed pumping system, pump, and driver shall be designed for excursions to trip speed without damage.

6.1.9 Pumps shall maintain a rotor chamber pressure greater than the suction pressure. It shall be designed so that the temperature and pressure in the rotor chamber prevent vaporization at all operating conditions, including minimum flow while providing continuous flow through the rotor chamber for cooling and bearing lubrication.

NOTE Vaporization in the bearing area of sealless pumps can occur at flows above minimum flow in the rotor area. Vapor pressure-temperature diagrams are usually reviewed to identify limitations.

6.1.10 All internal cavities shall be completely self-venting. If exception needs to be taken, the vendor shall, as a minimum, include provision for manual venting and provide a “caution” tag attached to the pump to indicate that manual venting is required before and after maintenance.

6.1.11 All internal cavities, including the rotor chamber, shall be drainable through a single connection to the pump assembly. If fluid will remain in the internal cavities when this drain connection is opened, an additional connection shall be provided for purging/flushing the rotor chamber. The vendor shall include the size and location of this connection in the proposal and specify the volume of remaining liquid in the maintenance manual and in the pump general arrangement.

6.1.12 The vendor shall specify the NPSH3 based on water at a temperature of less than 55 °C (130 °F) at the rated capacity and rated speed. A reduction or correction factor for liquids other than water (such as hydrocarbons) shall not be applied.

NOTE 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.

- **6.1.13** The purchaser shall specify the NPSHA based on system conditions at the rated flow on the data sheet (e.g. Annex N).

6.1.13.1 The datum elevation shall be the shaft centerline for horizontal pumps, the suction-nozzle centerline for vertical inline pumps, and the top of the foundation for vertically suspended pumps. Other configurations are possible, and the vendor and the purchaser shall agree on a datum in those services.

NOTE The datum elevations defined above for NPSH3 are in accordance with HI 14.6-2011 (ISO 9906).

- **6.1.13.2** The purchaser shall define the NPSH margin in addition to the NPSHA specified. NPSH margin is the NPSH that exists in excess of the pump's NPSH3 (see 3.1.39).

6.1.13.3 The NPSH margin shall be maintained at all flows (from minimum continuous stable flow to maximum expected operating flow) to protect the pump from damage caused by flow recirculation, separation, and cavitation.

NOTE 1 The heated fluid recirculated back to the pump suction will affect the NPSH margin.

NOTE 2 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.

6.1.14 Pumps that handle liquids more viscous than water shall have their water performance corrected in accordance with ANSI/HI 9.6.7 or ISO/TR 17766. Additional corrections may be necessary for viscous effects on the rotor. These additional corrections shall be highlighted in the proposal. Correction factors used for viscous liquid shall be submitted with both sales proposal curves and final test curves.

- **6.1.15** 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 80 mm (3 in.) discharge.

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

- **6.1.16** 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 pump's hydraulic design.

6.1.16.1 If a discharge orifice is used as a means of providing a continuous rise to shutoff, this use shall be stated in the proposal and submitted to the purchaser for approval.

6.1.16.2 The discharge orifice details shall be clearly specified in the pump general arrangement, data sheets, and manual.

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.

6.1.17 Pump curves shall meet the requirements of 6.1.17.1 through 6.1.17.3

6.1.17.1 Pumps shall have a preferred operating region (see 6.8.5.2) of 70 % to 120 % of best efficiency flowrate of the pump as furnished.

6.1.17.2 Rated flow shall be within the region of 80 % to 110 % of best efficiency flowrate of the pump as furnished.

NOTE 1 Setting specific limits for the preferred operating region and the location of rated flow is not intended to lead to the development of additional sizes of small pumps or preclude the use of high specific-speed pumps. Small pumps that are known to operate satisfactorily at flows outside the specified limits and high specific-speed pumps that have a narrower preferred operating region than specified can be offered, where appropriate, and their preferred operating region clearly shown on the proposal curve.

NOTE 2 “Best efficiency flowrate of the pump as furnished” refers to the pump with the impeller diameter properly selected to meet head-flowrate performance requirements as stated on the data sheet. It is recognized that very-low-specific-speed pumps often cannot reach flow rates beyond 105 % to 110 % of their best efficiency flowrate and that such low-specific-speed pumps often have their rated flow lower than 80 % of best efficiency flowrate. In such cases, the expected flow limitations are usually indicated on the proposal curves (see Annex L, L.2.4).

6.1.17.3 The “end of curve flow” is defined as 120 % of the best efficiency flowrate. The pump’s BEP flowrate, as furnished, is preferred to be between the rated point and normal point.

NOTE 1 Very-low-specific-speed pumps (often with “Barske” type impellers) often cannot reach flow rates beyond 105 % of BEP.

NOTE 2 Limits on operating range are often dictated by pressure-temperature profile in CMPs and MDPs. For allowable operating region, see 3.1.2.

NOTE 3 The hydraulic “end of curve flow” defined as 120 % of BEP is independent of any limitation by the driver, magnetic coupling torque rating at rated temperature, or NPSH3.

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.

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

6.1.19 For pumps equipped with ASDs, the vendor shall determine the minimum and maximum allowable speeds of the equipment and record the values on the data sheet.

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

- **6.1.20.1** If specified, the A-weighted data shall be per octave band.

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

- **6.1.20.3** If specified the equipment furnished by the vendor shall conform to the maximum allowable SPL specified by the purchaser, and any features, such as acoustic insulation, required to meet the specified level shall be described.

NOTE ISO standards 3740, 3744, and 3746 can be consulted for guidance.

6.1.21 Pumps developing heads greater than 200 m (650 ft) per stage and absorbing more than 225 kW (300 hp) per stage shall have 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 design and at least 6 % of the maximum blade-tip radius for volute design.

6.1.21.1 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.

6.1.21.2 It is common practice for the impellers covered by this section to be modified after initial test to correct hydraulic performance by underfiling, overfiling, or "V"-cutting. Any such modifications shall be documented in submitted manuals.

- **6.1.21.3** If specified, overfiling and V-cutting shall require purchaser's approval prior to machining.

6.1.22 Pumps shall be designed to prevent damage from reverse rotation on starting checkouts. The pump shall be supplied with the means to detect backward rotation.

NOTE 1 Rotation indicators are available for CMP that verify direction of rotation.

NOTE 2 Motor rotation on MDP is checked with the motor coupling disconnected.

6.1.23 The need for cooling shall be determined by the vendor, and the method shall be agreed upon by the purchaser in accordance with 6.1.23.1 through 6.1.23.3.

6.1.23.1 If cooling is required, one of the plans in Annex B shall be selected.

6.1.23.2 The cooling system shall be suitable for operation with the coolant type, pressure, and temperature specified by the purchaser.

6.1.23.3 The vendor shall specify the required flow for the cooling system.

NOTE To avoid condensation, the minimum inlet water temperature to bearing housings is above the ambient air temperature.

6.1.24 Jackets, if provided, shall have cleanout connections arranged so that the entire passageway can be mechanically cleaned, flushed, and drained. The vendor shall advise if cleanout connections are not feasible due to jacket size.

6.1.25 A jacket system, if provided, shall be designed to prevent the process stream from leaking into the jacket. Jacket passages shall not open into casing joints.

6.1.26 The cooling system shall be designed for the conditions on the cooling system side as given in Table 1.

6.1.27 The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity overheat exchange surfaces result in a conflict. The criterion for velocity overheat 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 will approve the final selection.

Table 1—Water Cooling Systems—Conditions on the Water Side

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

6.1.28 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor and meet requirements of 6.1.28.1 and 6.1.28.2.

6.1.28.1 The arrangement shall provide sufficient clearance between equipment and piping and auxiliaries to allow safe access for operation and maintenance.

6.1.28.2 Provision shall be made for complete venting and draining of the system.

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 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.

6.1.29.4 Electrical codes vary by installation location. Refer to Table 2 for a tabulation of common hazardous area electrical codes in use.

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 pressure casing components and bearing housings shall be designed and manufactured to ensure accurate alignment on reassembly.

NOTE This can be accomplished by the use of shouldering, pilot or machined fits, dowels, or keys.

6.1.32 The pump and its driver shall perform on their test stands and on their permanent foundation within the vibration acceptance criteria specified in 6.8.5.6. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the pump vendor with unit responsibility.

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

6.1.34 The requirements of 6.1.34.1 and 6.1.34.2 apply to vertical inline pump designs.

6.1.34.1 For vertical designs with motor above, a flat contact surface shall be provided on the bottom of the casing to make the pump stable if free-standing on a pad or foundation. The ratio of the unit center of gravity height to contact surface width shall be no greater than 3:1. This stability may be achieved through the design of the casing or by a permanent external stand. For motor below designs, the pump and motor shall be supported by structure.

6.1.34.2 Pumps shall be designed so that they can either float with the suction and discharge piping or be bolted to a pad or foundation.

NOTE Flange loading on the pump can increase if the purchaser elects to bolt the unit down. This is an issue for the piping design.

6.1.35 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.).

6.1.36 The vendor shall advise if heat tracing using low current through the stator windings is recommended.

- **6.1.37** 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.

Table 2—Common Hazardous Area Electrical Codes

Standards Organization	Codes	Where Used	Hazardous Electrical Area Classification Designation
IEC ^a CENELEC ^b	IEC 60079 EN 60079	EU countries and worldwide, except the United States	Zone, Gas Group, Temperature Class
European Union (EU) ^c	ATEX Directive 2014/34/EC	Required, in addition to IEC, in EU countries only May be requested in other countries	Equipment Group, Category
NEC ^d	NFPA 70 Sections 500–502, 504	United States	Class, Division, Group, Temperature Class
NEC ^d	NFPA 70 Section 505	United States	Class I, Zone, Gas Group, Temperature Class
CEC ^e	CSA C22.1-06, Section 18	Canada	<i>Primary:</i> Adoption of IEC—Zone, Gas Group, Temperature Class <i>In Appendix:</i> Class, Division, Group, Temperature Class
^a International Electrotechnical Commission (IEC). ^b European Committee for Electrotechnical Standardization (CENELEC). ^c “Atmospheres Explosibles” (ATEX), “Equipment Intended for use in Potentially Explosive Atmospheres.” ^d <i>National Electrical Code (NEC)</i>, published by the National Fire Protection Association (NFPA). ^e <i>Canadian Electrical Code (CEC)</i>, published by the Canadian Standards Association (CSA). NOTE The ATEX directive, 2014/34/EC (previously 94/9/EC), applies to all equipment (mechanical and electrical) that is intended for use in a potentially explosive atmosphere, in the European Economic Area. While not a specific electrical code, it is listed in the table because most electrical products cannot be put into use in a hazardous area in the European Economic Area without ATEX certification. Also, mechanical products, which are used in the EU, in a hazardous area, conform to the ATEX directive. The ATEX directive defines categories, which determine the approach used to obtain ATEX certification. Electrical and mechanical equipment meet the essential health and safety requirements set forth in the ATEX directive.			

6.1.38 Bolting and Threads

6.1.38.1 The details of threading shall conform to ISO 261, ISO 262, ISO 724, and ISO 965 or to ASME B1.1, ASME B1.13M, or ISO 261. The vendor shall advise the type of bolting used on the pump.

6.1.38.2 If ASME B1.1 threads have been specified, the thread series shall be variable 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 Class 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.

6.1.38.3 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.

6.1.38.4 Commercial fasteners shall be manufactured in accordance with the requirements of ASME B18.18.2M, ISO 898, ISO 3506 or shall be procured from distributors having quality plans in accordance with one or more of these standards.

6.1.38.5 Adequate clearance shall be provided at all bolting locations to permit the use of socket or box spanners (wrenches).

6.1.38.6 Studs shall be supplied on all main casing joints, and all other joints and connections shall be supplied with external hexagon-head bolting or socket head cap screws.

6.1.38.7 Fasteners for pressure casings shall be not less than 12 mm (0.5 in.) in diameter except for the containment shell where it may be necessary for space constraints.

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

6.2 Pressure Casings

6.2.1 The maximum discharge pressure shall be the highest of the maximum discharge pressures as calculated for all of the operating cases specified. 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 on the data sheet.

- **6.2.2** 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 that the pump can accommodate;
 - c) operation to trip or maximum speed of the driver.

The purchaser should assess the likelihood of the occurrence of items a) and/or b) before specifying either of them.

NOTE Rare occurrences can be taken as excursions into the hydrostatic test margin. The additional differential pressure developed at trip speed is normally a momentary excursion that is absorbed by the hydrostatic test margin.

6.2.3 The pressure casing (including the secondary pressure casing) shall be designed to:

- a) operate without leakage or internal contact between rotating and stationary components while subject simultaneously to the maximum allowable working pressure (MAWP) and the worst-case combination of twice the allowable nozzle loads of Table 4A and Table 4B 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 4A and Table 4B, which, in addition to pressure casing design, include other factors that affect allowable nozzle loads, such as casing support and baseplate stiffness.

6.2.4 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 3.

Table 3—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

6.2.5 The vendor's proposal shall state the source of the material properties from those listed in Table H.2 (i.e. ASTM, UNS, ISO, EN, JIS), as well as the casting factors applied. National material standards other than those listed in Annex H, Table H.2, may be used with specific purchaser approval. Design criteria for application of ceramics/composite containment shells shall be agreed between the manufacturer and the purchaser.

NOTE 1 In general, the criteria in 6.2.3 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, the bolting will 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.

6.2.6 Pressure-containing components may be designed with the aid of finite element analysis provided that the value of the stress intensity reflects a requirement to perform a hydrostatic test at 150 % of MAWP.

- **6.2.7** If specified, the barrel of vertical pumps shall be designed according to ASME *Boiler and Pressure Vessel Code (BPVC)*, Section VIII or other recognized international unfired pressure vessel manufacturing code.

6.2.8 The MAWP shall be at least the maximum discharge pressure plus 10 % of the maximum differential pressure and shall not be less than a minimum gauge pressure rating of 4 MPa (40 bar) (600 psi) at 38 °C (100 °F). The MAWP is a function of the design of the casing. The MAWP for a casing shall not be reduced based on the particular application requirements.

NOTE 1 The 10 % differential pressure margin is intended to accommodate head increases (see 6.1.6), higher speed in variable-speed pumps (see 6.1.7), and head (testing) tolerance (see Table 11).

NOTE 2 This subsection provides minimum requirements consistent with designs existing at the time of publication of this standard.

6.2.9 If vacuum conditions at the pump suction are specified, the containment shell or stator liner, as applicable, shall be designed for the resulting external pressure.

6.2.10 The minimum corrosion allowance shall be 3 mm (0.12 in.), except that containment shells and liners shall be in accordance with 9.1.2.1.1 for MDPs and both 9.2.3.1 and 9.2.4.1 for CMPs.

NOTE The vendor is encouraged to propose alternative corrosion allowances for consideration if materials of construction with superior corrosion resistance are used.

6.2.11 Axially split casings are not allowed. Pumps with radially split casings are required.

6.2.12 Pump 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.

NOTE See also 9.1.2.1.3 specific to MDP.

6.2.13 Casings shall be designed to permit removal of the rotor or inner magnet ring without disconnecting the suction or discharge piping.

6.2.14 Unless otherwise agreed, centerline supported pump casings shall be used for horizontal MDPs with pumped liquid temperatures of 175 °C (350 °F) or higher. Centerline supported pump casings are typically not required for CMPs.

NOTE 1 For MDPs with nominal impeller diameters up to 200 mm (8 in.), centerline mount is not usually required for operating temperatures exceeding 175 °C (350 °F).

NOTE 2 Misalignment from thermal growth is normally not a concern with CMPs as they have the motor integral with the pump.

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

6.2.16 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. Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly.

6.2.17 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, in addition to the allowance for corrosion, shall be left around and below the bottom of drilled and threaded holes.

6.2.18 Internal bolting shall be of a material fully resistant to corrosive attack by the pumped liquid or external flush liquid.

6.2.19 Spiral-wound gasket sealing surfaces shall have a maximum surface roughness average value, Ra, of 6.4 µm (250 µin.) and minimum surface roughness average value of 3.2 µm (125 µin.).

6.3 Nozzles and Pressure Casing Connections

6.3.1 Casing Opening Sizes

6.3.1.1 All openings or nozzles for piping connections on pressure casings shall be standard pipe sizes. Openings of nominal pipe size (NPS) 1 1/4, 2 1/2, 3 1/2, 5, 7, and 9 (DN 32, 65, 90, 125, 175, and 225) shall not be used.

NOTE DN 65 (2 1/2 NPS) and DN 125 (5 NPS) are typically accepted outside the United States.

6.3.1.2 Casing connections other than suction and discharge nozzles shall be at least NPS 1/2 (DN 15) for pumps with discharge nozzle openings NPS 2 (DN 50) and smaller. Connections shall be at least NPS 3/4

(DN 20) for pumps with discharge nozzle openings NPS 3 (DN 80) and larger, except that connections for flush piping and gauges may be NPS $\frac{1}{2}$ (DN 15) regardless of pump size.

6.3.2 Casing Nozzle Connections

6.3.2.1 All casing connection nozzles shall be flanged, except for those on pumps with forged casings, which shall be flanged or machined and studded. Suction and discharge nozzles shall be 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.

6.3.2.2 The CLASS system applies, and all nozzle flanges shall conform to the pressure ratings and dimensional requirements of ASME B16.5, except as noted in 6.3.2.2.1, 6.3.2.2.2, 6.3.2.3, and 6.3.2.4.

6.3.2.2.1 If the PN system is specified, all flanges shall conform to EN 1092-1, except as specified in 6.3.2.2.2, 6.3.2.3, and 6.3.2.4.

NOTE Applicable EN 1092-1 flanges are PN16, 25, 40, 63, 100, 250, 320, and 400.

6.3.2.2.2 For ASME B16.5 flange sizes from $\frac{1}{2}$ NPS (12 mm) to 10 NPS (250 mm) and comparable EN 1092-1 flanges, the actual outside diameters (ODs) of the flanges shall be not less than their nominal OD minus 4 mm (0.16 in.). For ASME B16.5 and EN 1092-1 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 5 mm (0.21 in.).

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

6.3.2.3 Flanges in all materials that are thicker or have a larger outside diameter than required by the relevant ASME or EN standards referenced in this standard are acceptable. Nonstandard (oversized) flanges shall be completely dimensioned on the arrangement drawing. If nonstandard flanges require stud-bolts of nonstandard length, this requirement shall be identified on the arrangement drawing.

6.3.2.4 Flanges shall be full 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.

6.3.2.5 To minimize nozzle loading and facilitate installation of piping, machined faces of pump flanges shall be parallel to the plane as shown on the general arrangement drawing [see Annex L, L.2.2.1 a)] within 0.5°. Bolt holes or studs shall straddle centerlines parallel to the main axes of the pump.

6.3.2.6 Connections welded to the casing (up to the first flange) shall meet or exceed the material and 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 260 °C (500 °F), above which UNS N06625 materials shall be used.

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

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

6.3.2.9 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.

6.3.3 Auxiliary Connections

6.3.3.1 Auxiliary connections include vents, drains, and external connections used with the external cooling and lubrication plans.

6.3.3.2 Auxiliary connections to the primary pressure casing shall be integrally flanged, socket-welded, or butt-welded as specified by the purchaser. Seal welding of threaded connections is not permitted.

6.3.3.3 Auxiliary connections to the secondary casing may be threaded per 6.3.3.3.1 through 6.3.3.3.4.

6.3.3.3.1 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.

6.3.3.3.2 Cylindrical threads shall be sealed with a contained face gasket of suitable material sealing to a machined face (see Figure 1).

6.3.3.3.3 The chosen method and details of threaded connection shall be approved by the purchaser.

6.3.3.3.4 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 over torqued.

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 over torque (extruding of the gasket). Surface finish and condition of the gasket mating faces are critical for proper sealing.

- **6.3.3.4** If specified, special threaded fittings for transitioning from the casing or nipple to tubing for circulation piping may be used provided a secondary sealing feature, such as O-rings, is used and the joint does not depend on thread contact alone to seal fluid (see Figure 1). The connection boss shall have a machined face suitable for sealing contact.

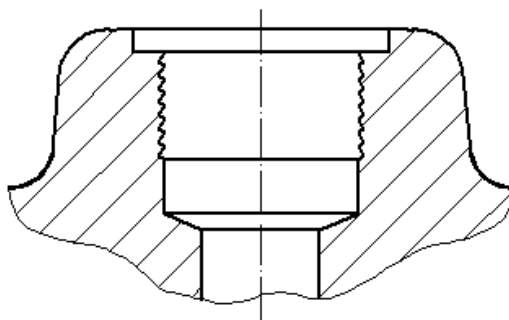


Figure 1—Machined Face Suitable for Gasket Containment if Using Cylindrical Threads

6.3.3.5 The first segment of piping connected to the casing shall not be more than 150 mm (6 in.) long and shall be a minimum of schedule 160 seamless for sizes DN 25 (NPS 1) and smaller and a minimum of schedule 80 for sizes DN 40 (NPS 1 1/2) 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 9.1.5.3.3). On small pumps, if this causes interference with the suction nozzle, for example, this requirement is impractical.

6.3.3.6 Taper-threaded plugs shall be long shank solid round-head, or long-shank hexagon-head, bar stock plugs in accordance with ASME B16.11. If cylindrical threads are used, plugs 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.

- **6.3.3.7** If specified, auxiliary connections to the pressure casing shall be machined and studded. These connections shall conform to the facing and drilling requirements of ASME B16.5 or to EN 1092-1. 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 each stud shall be removed.

6.3.3.8 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. 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 A pump is considered functionally self-venting if the nozzle arrangement and the casing configuration permit sufficient venting of gases from the impeller, volute, bearing and drive areas to prevent loss of prime during the starting sequence.

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

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

6.3.3.11 With the exception of flushing connections, 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:

- gussets shall be of a material compatible with welding to the pressure casing and the piping;
- for C-6 casings, 316L gussets shall be used;
- gussets shall be made of either flat bar with a minimum cross section of 25 mm by 3 mm (1 in. by 0.12 in.) or round bar with a minimum diameter of 9 mm (0.38 in.);
- gusset design shall be as shown in Figure 2;
- 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 the 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;
- gusset welding shall meet the fabrication requirements (see 6.10.3), including post-weld heat treatment (PWHT) if required, and the inspection requirements of this standard (see 8.2.2);
- gussets may also be clamped or bolted to the casing with purchaser approval and if done prior to the hydrostatic test.

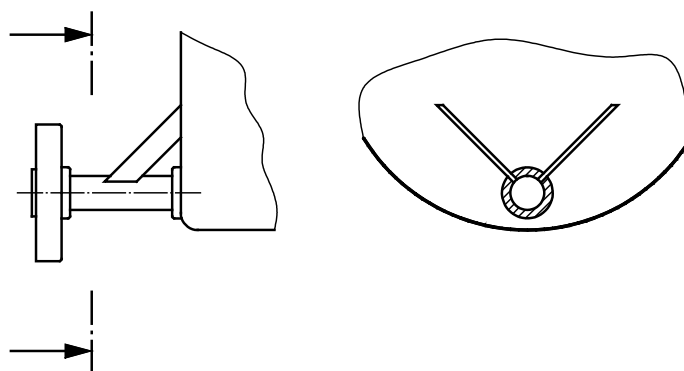


Figure 2—Typical Gusset Design

6.4 External Nozzle Forces and Moments

6.4.1 Steel and alloy-steel horizontal pumps and their baseplates, and vertical inline pumps with supports anchored to the foundation shall be designed for satisfactory performance if subjected to the forces and moments in Table 4A and Table 4B 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 distortion of the pump casing (see 6.2.3) and misalignment of the pump and driver shafts (MDPs only) (see 9.1.5.3.20).

Table 4A—Nozzle Loading (SI Units)

Location/ Orientation	Nozzle-loading Forces 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	10230
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
Moments (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
NOTE 1 See Figure 3 and Figure 4 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; for example, 160 indicates a range from -160 to +160.									

Table 4B—Nozzle Loading (USC Units)

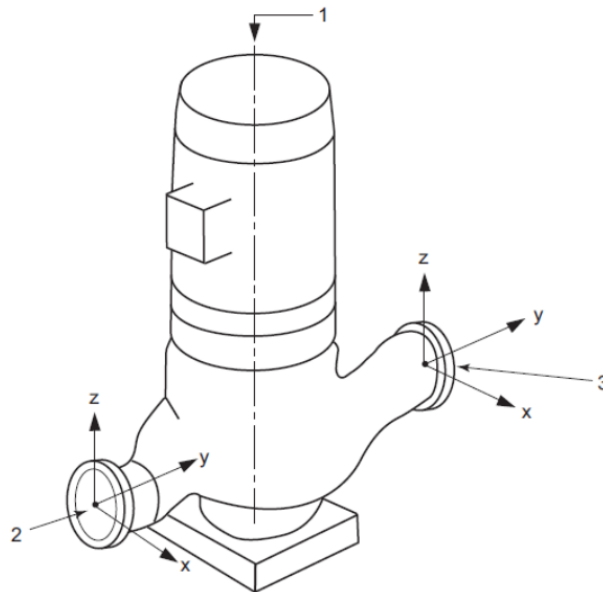
Location/ Orientation	Nozzle-loading Force as a Function of Flange Size (USC Units)								
	lbf								
	Nominal Size of Flange (NPS)								
	≤ 2	3	4	6	8	10	12	14	16
Each top nozzle									
F_X	160	240	320	560	850	1200	1500	1600	1900
F_Y	130	200	260	460	700	1000	1200	1300	1500
F_Z	200	300	400	700	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
Moments (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 3 and Figure 4 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; for example, 160 indicates a range from -160 to +160.									

6.4.2 Allowable forces and moments for vertical inline pumps, with supports not anchored to the foundation, may be twice the values in Table 4A and Table 4B for side nozzles.

6.4.3 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 4A and Table 4B.

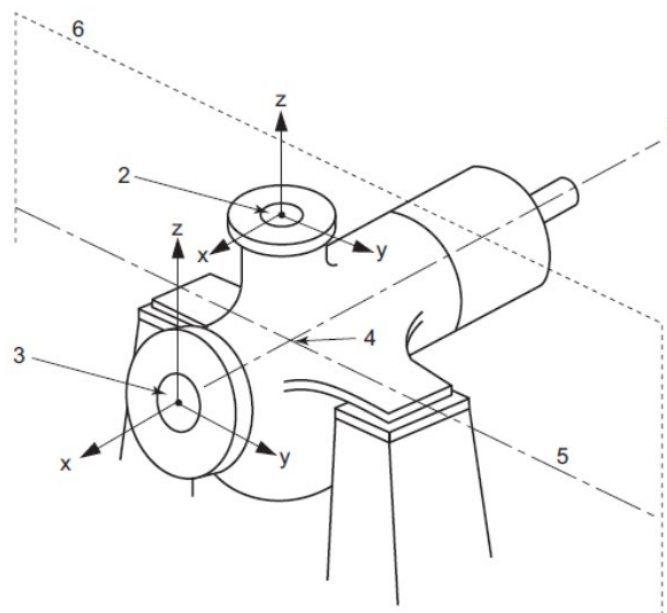
6.4.4 The coordinate system(s) shown in Figure 3 and Figure 4 shall be used to apply the forces and moments in Table 4A and Table 4B.

6.4.5 Annex F gives methods of qualifying nozzle loads in excess of those in Table 4A and Table 4B. 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 4A and Table 4B 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.

**Key**

- 1 shaft centerline
- 2 discharge (D)
- 3 suction (S)

Figure 3—Coordinate System for the Forces and Moments in Table 4A and Table 4B: Vertical Inline Pumps

**Key**

- | | |
|--------------------|-----------------------|
| 1 shaft centerline | 4 center of pump |
| 2 discharge nozzle | 5 pedestal centerline |
| 3 suction nozzle | 6 vertical centerline |

Figure 4—Coordinate System for the Forces and Moments in Table 4A and Table 4B: Horizontal Pumps

6.5 Rotors

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

NOTE Enclosed (closed) impellers commonly used 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.

6.5.2 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.

6.5.3 Impellers shall be keyed to the shaft. Pinning of impellers to the shaft is not acceptable. 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 (for example, 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 decrease stress concentrations.

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

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

6.5.5 Shafts shall be single-piece construction, machined and finished throughout their length so that the total indicator runout (TIR) is not more than 25 µm (0.001 in.).

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

6.5.7 Shaft stiffness and fluid stiffening of product-lubricated bearings shall limit the total impeller displacement under the most severe dynamic conditions over the allowable operating range of the pump—with maximum impeller diameter and the specified speed and liquid—to one-half the minimum impeller wear ring clearance. This displacement limit may be achieved by a combination of shaft diameter, shaft span or overhang, bearing design, and casing design (including the use of dual volutes or diffusers). No credit shall be taken for the fluid stiffening effects of impeller wear rings. The fluid stiffening of product-lubricated bearings shall be calculated at both minimum and maximum design clearances for the full range of product properties, temperature, viscosity, and vapor pressure.

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

6.6 Wear Rings and Running Clearances

6.6.1 Radial running clearances shall be used to limit internal leakage and, where necessary, control axial thrust. Sealless pumps normally have product-lubricated axial thrust bearings and devices, therefore close axial clearances are a necessity in sealless pump designs to control axial thrust. For enclosed impellers, renewable wear rings shall be provided in the pump casing. Impellers shall have either integral wear surfaces or renewable wear rings, where required. For low-specific-speed pumps with Barske type impellers, impeller(s) may be semi-open design with ample clearances. The vendor to describe method of axial thrust compensation in proposal.

6.6.2 Mating wear surfaces of hardenable materials shall have a difference in Brinell hardness number of at least 50 unless both the stationary and the rotating wear surfaces have Brinell hardness numbers of at least 400.

6.6.3 Renewable wear rings shall be held in place by a press fit with locking pins, screws (axial or radial) or by tack welding. The diameter of a hole in a wear ring for a radial pin or threaded dowel shall not be more than one-third the width of the wear ring, and the locking hole shall be located in the center of the wear ring width.

6.6.4 Running clearances shall meet the requirements of 6.6.5 through 6.6.7.

6.6.5 When establishing running clearances between wear rings and between other moving parts, the vendor shall evaluate pumping temperatures, suction conditions, liquid properties, the thermal expansion and galling characteristics of the materials, and pump efficiency. Clearances shall be sufficient to ensure dependability of operation and freedom from seizure under all specified operating conditions.

6.6.6 For hardened 11 % to 13 % chromium steel, and materials with similarly low galling tendencies, the minimum clearances given in Table 5 shall be used. For materials with higher galling tendencies and for all materials operating at temperatures above 260 °C (500 °F), 125 µm (0.005 in.) shall be added to these diametric clearances.

6.6.7 For nonmetallic wear ring materials with very low or no galling tendencies (see Table H.3), clearances less than those given in Table 5 may be proposed by the vendor. Factors such as distortion and thermal gradients shall be evaluated, to ensure clearances are sufficient to provide dependability of operation and freedom from seizure under all specified operating conditions.

NOTE There are published data showing successful applications of nonmetallic wear ring materials with API clearances (see Table 5) reduced by 50 %. Reasonable reductions in clearances are believed to be dependent on the materials applied and other service conditions, such as cleanliness and temperature.

6.7 Secondary Control/Containment

- **6.7.1** Unless Annex P is invoked, the purchaser will specify which of the following control/containment options the pump shall have:

- a) secondary control design (see 3.1.72);
- b) secondary control with primary leakage monitoring device(s)—(secondary control system; see 3.1.73);
- c) secondary containment design (see 3.1.70);

NOTE Secondary containment design is standard basic design for CMP.

- d) secondary containment with primary leakage monitoring device(s)—(secondary containment system; see 3.1.71).

NOTE The hazard-based selection procedure in Annex P can be applied to select the required control/containment option.

6.7.2 The secondary control system shall have a standby life of at least 25,000 hours in a pump-operating mode and shall be designed to have a functional life of at least 24 hours in the event of containment shell failure.

6.7.3 The control system vent/drain piping shall be sized to remove the full flow of fluid being circulated through the rotor cavity. The vendor shall advise the maximum flow rate to be handled.

6.7.4 The secondary control or containment system shall be rated for the same pressure as the pressure casing.

6.7.5 Provisions for monitoring primary containment breach shall be included in the secondary control/containment system. Monitoring device(s) shall be provided by the pump vendor if control/containment system is specified.

6.7.6 Material of the secondary pressure casing(s) shall be carbon steel as a minimum.

6.7.7 Secondary pressure casings are by definition pressure-containing components and shall meet the requirements of 6.2.1 through 6.2.3, as specified.

6.7.8 All secondary control and containment system joints shall be rabbeted and sealed with controlled compression gasket(s), sealed with O-rings of material compatible with the process liquid, or welded.

- **6.7.9** If specified, drain connections shall be provided that completely drain and provide the capability to flush all internal areas of the secondary pressure casing.

NOTE Due to explosion protection certification of the secondary pressure casing, this requirement is not always feasible for CMPs.

Table 5—Minimum Internal Running Clearances

Diameter of Rotating Member at Clearance (mm)	Minimum Diametral Clearance (mm)	Diameter of Rotating Member at Clearance (in.)	Minimum Diametral Clearance (in.)
< 50	0.25	< 2.000	0.010
50 to 64.99	0.28	2.000 to 2.499	0.011
65 to 79.99	0.30	2.500 to 2.999	0.012
80 to 89.99	0.33	3.000 to 3.499	0.013
90 to 99.99	0.35	3.500 to 3.999	0.014
100 to 114.99	0.38	4.000 to 4.499	0.015
115 to 124.99	0.40	4.500 to 4.999	0.016
125 to 149.99	0.43	5.000 to 5.999	0.017
150 to 174.99	0.45	6.000 to 6.999	0.018
175 to 199.99	0.48	7.000 to 7.999	0.019
200 to 224.99	0.50	8.000 to 8.999	0.020
225 to 249.99	0.53	9.000 to 9.999	0.021
250 to 274.99	0.55	10.000 to 10.999	0.022
275 to 299.99	0.58	11.000 to 11.999	0.023
300 to 324.99	0.60	12.000 to 12.999	0.024
325 to 349.99	0.63	13.000 to 13.999	0.025
350 to 374.99	0.65	14.000 to 14.999	0.026
375 to 399.99	0.68	15.000 to 15.999	0.027
400 to 424.99	0.70	16.000 to 16.999	0.028
425 to 449.99	0.73	17.000 to 17.999	0.029
450 to 474.99	0.75	18.000 to 18.999	0.030
475 to 499.99	0.78	19.000 to 19.999	0.031
500 to 524.99	0.80	20.000 to 20.999	0.032
525 to 549.99	0.83	21.000 to 21.999	0.033
550 to 574.99	0.85	22.000 to 22.999	0.034
575 to 599.99	0.88	23.000 to 23.999	0.035
600 to 624.99	0.90	24.000 to 24.999	0.036
625 to 649.99	0.95	25.000 to 25.999	0.037
For diameters greater than 649.99 mm (25.999 in.), the minimum diametric clearances shall be 0.95 mm (0.037 in.) plus 1 µm for each additional 1 mm of diameter or fraction thereof (0.001 in. for each additional 1 in.).			

6.8 Dynamics

6.8.1 Pump rotors shall be designed such that their first (dry) bending critical speed is at least 20 % above the pump's maximum continuous operating speed.

6.8.2 Resonances of structural support systems (base, frame, and bearing housings) may adversely affect rotor vibration amplitude. Therefore, resonance of support systems within the vendor's scope of supply shall not occur within 10 % of the operating speed of a fixed speed machine.

- **6.8.3** In case of an ASD application, the purchaser shall specify the applicable continuous operating speed range. Resonance of support systems within the vendor's scope of supply shall not occur from 10 % below to 10 % above the operating range.

NOTE Regarding ASD applications, due to potentially large operating speed ranges, it is often not possible to satisfy all of the applicable frequency separation margin requirements. Acceptability of such conditions can be proven by means of vibration measurements taken during a variable speed performance test (if applicable). In case acceptability cannot be proven, the purchaser and the vendor can agree on further measures aimed at reducing vane-pass excitation levels. In the field, ASDs can be programmed to avoid certain small operating speed ranges from continuous operation. It is also important to note that, due to the reduced energy in the pump, resonance conditions at lower operating speeds are not nearly as critical as resonances at higher speeds.

- **6.8.4** If specified, a lateral analysis shall be performed per Annex I.

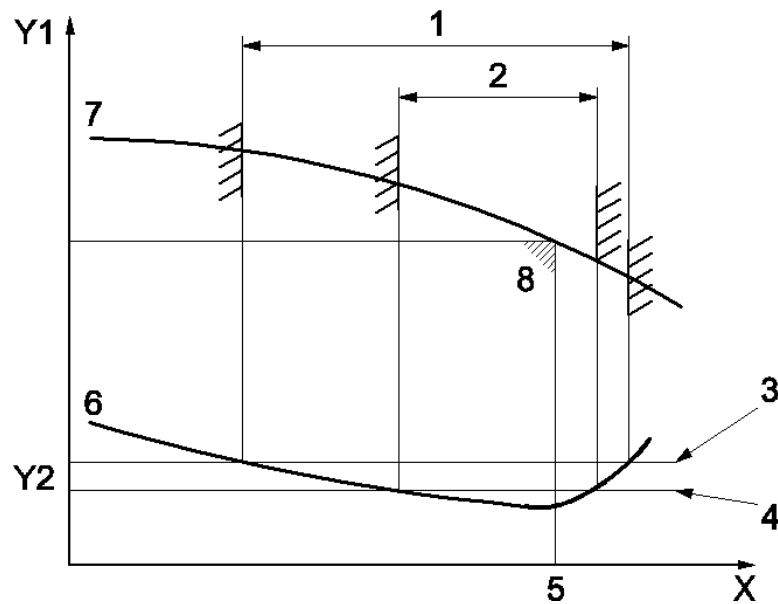
NOTE Pumps are designed to be classically stiff and rarely require such analysis.

6.8.5 Vibration

6.8.5.1 Centrifugal pump vibration varies with flow, usually being a minimum in the vicinity of BEP flow and increasing as flow is increased or decreased. The change in vibration as flow is varied from BEP flow depends upon the pump's energy density, its specific speed, and its suction-specific speed. In general, the change in vibration increases with increasing energy density, higher specific speed, and higher suction-specific speed.

6.8.5.2 With the general characteristics of 6.8.5.1, a centrifugal pump's operating flow range can be divided into two regions, one termed the preferred operating region, over which the pump exhibits low vibration, the other termed the allowable operating region, with the limits, both high and low, defined as those flow rates at which the pump's vibration reaches a higher but still "acceptable" level. Figure 5 illustrates the concept. Factors other than vibration, for example, temperature rise with decreasing flow or NPSH3 with increasing flow, or pressure and temperature characteristics in the rotor cavity, can dictate a narrower allowable operating region.

6.8.5.3 The allowable operating region shall be stated in the proposal. If the allowable operating region is limited by a factor other than vibration, that factor shall also be stated in the proposal.

**Key**

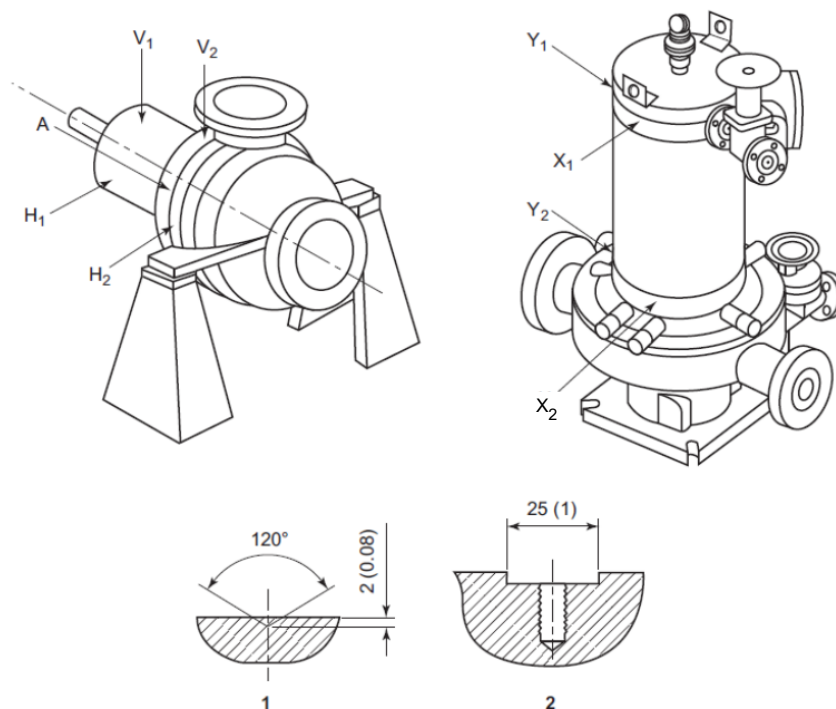
- X flowrate
- Y_1 head
- Y_2 vibration
- 1 allowable operating region of flow
- 2 preferred operating region of flow
- 3 maximum allowable vibration limit at flow limits
- 4 basic vibration limit
- 5 best efficiency point, flowrate
- 6 typical vibration vs. flowrate curve showing maximum allowable vibration
- 7 head-flowrate curve
- 8 best efficiency point, head, and flowrate

Figure 5—Relationship between Flow and Vibration

6.8.5.4 During the performance test, overall vibration measurements over a range of 5 Hz to 1000 Hz and discrete vibration measurements using a fast Fourier transform (FFT) spectra shall be made at a minimum of five test points.

6.8.5.4.1 These points shall include the rated flow point and the points defining the minimum and maximum flows for the allowable and preferred operating ranges. Vibration measurements are not required at shutoff.

6.8.5.4.2 The vibration measurements shall be taken on the bearing housing(s) or equivalent location(s) at the positions shown in Figure 6 (it is recommended that vibration readings be taken in both horizontal and vertical planes at the rated point and at all other points in the same plane as the higher reading).

**Key**

1	dimple (see 6.9.8.1)	V ₂	vertical front bearing holder
2	threaded connection for permanent mount (see 6.9.8.2)	X ₁	transverse top bearing of motor (CMP)
A	axial	X ₂	transverse bottom bearing of motor (CMP)
H ₁	horizontal power frame bearing (MDP)/rear bearing (CMP)	Y ₁	inline top bearing of motor
H ₂	horizontal, front bearing holder	Y ₂	inline bottom bearing of motor
V ₁	vertical, power frame bearing (MDP)/rear bearing (CMP)		

Figure 6—Locations for Taking Vibration Readings on Horizontal and Vertical Inline Pumps

6.8.5.4.3 The FFT spectra shall include the range of frequencies from 5 Hz to 2Z times running speed (where Z is the number of impeller vanes). The plotted spectra shall be included with the pump test results.

NOTE The discrete frequencies such as 1.0, 2.0, and Z times running speed are associated with various pump phenomena and are therefore of particular interest in the spectra.

6.8.5.5 Bearing housing overall vibration measurements shall be made in root mean square (RMS) velocity, expressed in mm/s (in./s).

6.8.5.6 The vibration measured during the performance test shall not exceed the values shown in Table 6.

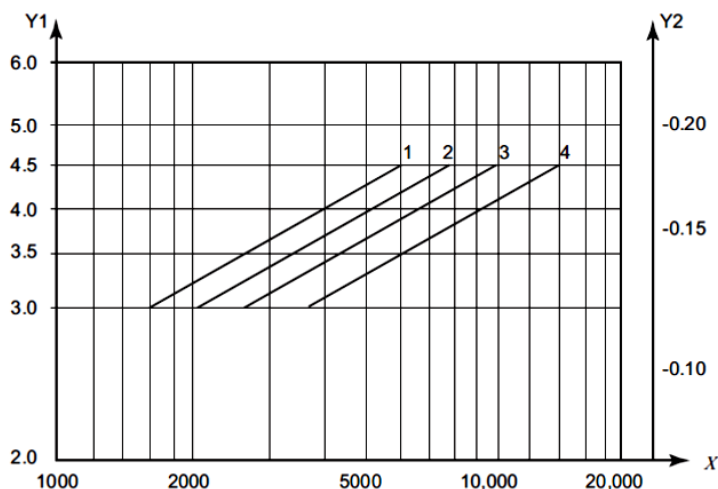
NOTE Bearing housing overall vibration limits are defined for RMS measurements only.

6.8.5.7 At any speed greater than the MCS, up to and including the trip speed of the driver, the vibration shall not exceed 150 % of the maximum value allowable at the maximum continuous speed.

6.8.5.8 Variable-speed pumps shall operate over their specified speed range without exceeding the vibration limits of this standard.

Table 6—Vibration Limits for Overhung Pumps

Criteria	Vibration at Any Flowrate Within the Pump's Preferred Operating Region
Overall	For pumps running at up to 3600 r/min and absorbing up to 300 kW (400 hp): $v_u < 3.0$ mm/s RMS (0.12 in./s RMS)
	For pumps running above 3600 r/min or absorbing more than 300 kW (400 hp), see Figure 7.
Discrete frequencies	For pumps running at up to 3600 r/min and absorbing up to 300 kW (400 hp): $v_f < 2.0$ mm/s RMS (0.08 in./s RMS)
	For pumps running above 3600 r/min or absorbing more than 300 kW (400 hp), see Figure 7.
Allowable increase in vibration at flows outside the preferred operating region but within the allowable operating region	30 %
Power calculated for BEP of rated impeller with liquid relative density (specific gravity) equal to 1.0. Vibration velocity calculated from the basic limits shall be rounded off to two significant figures, where: v_u is the measured overall velocity; v_f is the discrete frequency velocity, measured with FFT spectrum using a Hanning window and a minimum frequency resolution of 400 lines.	

**Key**

X	rotational speed, n expressed in revolutions per minute	1	$P \geq 1000$ kW/stage (1400 hp/stage)
Y_1	vibrational velocity, v_u expressed in millimeters per second, RMS	2	$P = 700$ kW/stage (1000 hp/stage)
Y_2	vibrational velocity, v_u expressed in inches per second, RMS	3	$P = 500$ kW/stage (700 hp/stage)
		4	$P \leq 300$ kW/stage (400 hp/stage)

NOTE 1 The equation for transition from 3.0 mm/s to 4.5 mm/s (0.12 to 0.18 in./s) is as follows:

$$v_u = 3.0(n/3600)^{0.30}[P/300]^{0.21}$$

NOTE 2 The allowable vibration limit for discrete frequencies is as follows: $v_f < 0.67 v_u$ from Figure 7.

Figure 7—Vibration Limits for Pumps Running Above 3600 r/min or Absorbing More Than 300 kW (400 hp)

6.8.6 Balancing

6.8.6.1 Impellers and similar major rotating components shall be dynamically balanced to ISO 21940-11 grade G2.5. The mass of the arbor used for balancing shall not exceed the mass of the component being balanced. Shafts are not required to be balanced.

NOTE In ISO 21940-11 standards, unbalance is expressed as a balance quality grade. Each of the ISO balance quality grades covers a range of unbalance. The nominal equivalent USC unit limits given throughout this standard correspond approximately to the midpoint of the ISO range.

- **6.8.6.2** If specified, impellers and similar major rotating components shall be dynamically balanced to ISO 21940-11 grade G1.0.
- **6.8.6.3** If specified, impellers and similar major rotating components shall be dynamically balanced to:

$$U = 4W/n$$

In USC units, where

U is the unbalance per plane, expressed in ounce-inches;

W is the component mass (for components), expressed in pounds; or the load per balancing machine journal (for rotors), expressed in pounds;

n is the rotational speed of the pump, expressed in revolutions per minute.

NOTE $4W/n$ is a balance tolerance denominated solely in USC units. With modern balancing machines, it is feasible to balance components mounted on their arbors to $U = 4W/n$ (USC units) or even lower depending upon the mass of the assembly, and to verify the unbalance of the assembly with a residual unbalance check. However, balancing to ISO grade G1 or $U = 4W/n$ (USC units) is generally not repeatable when the components are dismantled and remounted on their arbors because of the minute mass eccentricity values associated with these fine levels of unbalance requirements.

6.8.6.4 Component balancing may be single plane if the ratio D/b (see Figure 8) is 6.0 or greater.

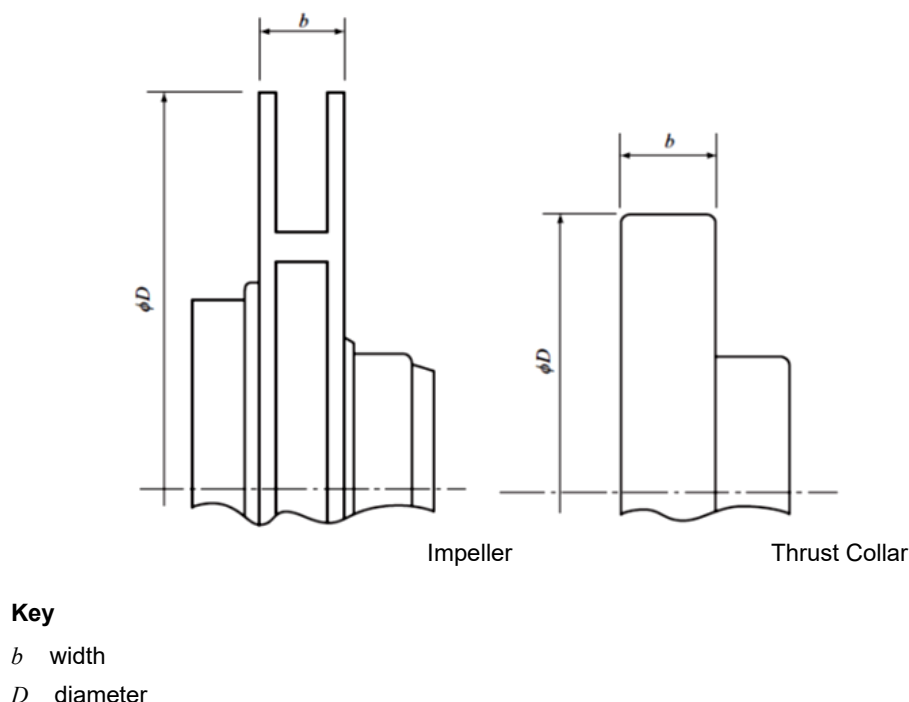


Figure 8—Rotating Component Dimensions to Determine if Single-plane Balancing Is Allowed

6.8.6.5 If a rotor is balanced as an assembly, a residual unbalance test shall be performed. The check shall be carried out after final balancing of the rotor, following the procedure given in Annex J.

6.9 Process Cooled/Lubricated Bearings and Bearing Housings

6.9.1 Process cooled/lubricated bearings shall be of the precision bored sleeve type. These bearings shall be positively secured in the axial and radial directions to avoid rotation relative to the component on which it is mounted.

6.9.2 Sleeve bearings and thrust bearings shall have a surface finish of not more than $0.4 \mu\text{m}$ (16 $\mu\text{in.}$) R_a .

6.9.3 Bearing materials such as silicon carbide with low coefficients of thermal expansion shall have a radial clearance designed to accommodate relative thermal expansions at the maximum and minimum operating temperature specified on the pump data sheet.

6.9.4 Tolerance rings or similar bearing mounting devices shall be used to allow for relative thermal expansion and provide a resilient mounting surface for the bearings.

6.9.5 Unless otherwise approved by the purchaser, bearings shall incorporate groove(s) for heat removal and flushing of foreign particles.

6.9.6 Thrust bearings shall be designed for thrust in both directions and sized for continuous operation under all conditions within the allowed operating range, including start-up and shutdown conditions as described in the manufacturer's operating manual. All loads shall be determined at minimum design internal clearances and also at maximum design internal clearances. Thrust bearings shall provide load capabilities if the normal direction of thrust is momentarily reversed.

NOTE Hydraulically balanced thrust loads are sometimes designed to be in one direction and only reverse in momentary conditions of starting, stopping, and upset. Therefore, smaller thrust bearings are common in some designs for thrust in the abnormal direction.

6.9.7 Lubrication/cooling of the bearings shall be by the pumped liquid or by a clean liquid from an external source. The use of an external system requires purchaser's approval (see Annex B). For low viscosity (typically below 0.2 cP), it is necessary to make sure that the design of the pump and of the bearings allows good lubrication and cooling.

6.9.8 Bearing housings for sealless pumps shall include features for vibration measurement as noted in 6.9.8.1 through 6.9.8.3.

6.9.8.1 All bearing housings shall be dimpled at the locations shown in Figure 6 to facilitate consistent vibration measurements. The dimples shall be suitable for accurate location of a hand-held vibration transducer with an extension "wand." Dimples may be cast or machined and shall be nominally 2 mm (0.080 in.) deep with an included angle of 120° .

- **6.9.8.2** If specified, bearing housings shall have a threaded connection(s) for permanently mounting vibration transducers in accordance with API 670. If metric fasteners are supplied, the threads shall be M8.
- **6.9.8.3** If specified, a flat surface at least 25 mm (1 in.) in diameter shall be supplied for the location of magnetic based vibration measuring equipment.

6.10 Materials

6.10.1 General

- **6.10.1.1** The purchaser shall specify the material class for pump parts from Table H.1. Table G.1 provides a guide showing material classes that can be appropriate for various services. Pump materials shall be in accordance with Table H.2. Alternative materials, including materials that can improve life and performance in service, may also be included in the vendor's proposal and listed on the final data sheets.

- **6.10.1.2** If specified, wear parts of nonmetallic materials from Table H.3 shall be provided. If nonmetallic wear parts are provided, the material class from Table H.1 shall be modified by addition of the letter C, such as S-5C. The nonmetallic material shall be agreed to by the vendor and the purchaser.

6.10.1.3 The material specification of all components listed in Table H.1 shall be clearly stated in the vendor's proposal. Materials shall be identified by reference to applicable international standards, including the material grade (Table H.2 and Table H.3 may be used for guidance). If standard materials are not available, then national standards may be used. If no such designations are available, the vendor's material specification, giving physical properties, chemical composition, and test requirements, shall be included in the proposal.

6.10.1.4 The material specification of all gaskets and O-rings exposed to the pumped fluid shall be identified in the proposal. O-rings shall be selected and their application limited in accordance with API 682, Fourth Edition—Annex B.

6.10.1.5 Pump parts having strength or pressure-integrity requirements are designated as "full compliance" materials in Table H.1 and shall meet all the requirements of the agreed specifications. For any other part (e.g. if corrosion resistance is the primary concern), it is necessary to comply only with the specified chemical composition.

- **6.10.1.6** The purchaser shall specify optional tests and inspection requirements that are necessary to ensure that materials are satisfactory for the service.

6.10.1.7 If austenitic stainless steel parts exposed to conditions that promote intergranular corrosion are fabricated, hard faced, overlaid, or repaired by welding, they shall be made of low-carbon or stabilized grades.

NOTE Overlays or hard surfaces that contain more than 0.10 % carbon can sensitize both low-carbon and stabilized grades of austenitic stainless steel unless a buffer layer that is not sensitive to intergranular corrosion is applied.

- **6.10.1.8** If specified, the vendor shall furnish material certificates that include chemical analysis and mechanical properties for the heats from which the material is supplied (or batch for nonmetallic) for pressure-containing castings and forgings, impellers, shafts, and fabricated pressure containment shell. Piping nipples, auxiliary piping components, and bolting are excluded from this requirement.
- **6.10.1.9** The purchaser will specify any erosive or corrosive agents (including trace quantities) present in the process fluids and in the site environment, including constituents that can cause stress-corrosion cracking or attack elastomers.

NOTE 1 Typical agents of concern are hydrogen sulfide, amines, chlorides, bromides, iodides, cyanides, fluorides, naphthenic acid, and polythionic acid. Other agents affecting elastomer selection include ketones, ethylene oxide, sodium hydroxide, methanol, benzene, and solvents.

NOTE 2 If chlorides are present in the pumped fluid in a concentration above 10 mg/kg (10 ppm), it is necessary to use caution when applying stainless steel.

- **6.10.1.10** If specified, coatings of a type agreed between the purchaser and the vendor shall be applied to impellers and other wetted parts to minimize erosion or to improve efficiency. If coatings are applied to rotating components, the acceptance balance shall be performed after coatings have been applied. The sequence of procedures for balancing and coating of rotating components shall be agreed between the purchaser and the vendor.

6.10.1.11 If mating parts such as studs and nuts of austenitic stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound compatible with the material(s) and specified process liquid(s) operating conditions.

NOTE Torque loading values required to achieve the necessary preload can vary considerably depending upon the thread lubricant.