

Centrifugal pumps for petroleum, petrochemical and natural gas industries

The European Standard EN ISO 13709:2003 has the status of a
British Standard

ICS 71.120.99; 75.180.20

National foreword

This British Standard is the official English language version of EN ISO 13709:2003. It is identical with ISO 13709:2003.

The UK participation in its preparation was entrusted to Technical Committee PSE/17, Materials and equipment for petroleum, petrochemical and natural gas industries, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN ISO title page, the EN ISO foreword page, the ISO title page, pages ii to vi, pages 1 to 184, an inside back cover and a back cover.

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Amendments issued since publication

Amd. No.	Date	Comments

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 4 November 2003

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ISBN 0 580 42820 6

English version

Centrifugal pumps for petroleum, petrochemical and natural gas industries (ISO 13709:2003)

Pompes centrifuges utilisées dans les industries du pétrole,
de la pétrochimie et du gaz naturel (ISO 13709:2003)

This European Standard was approved by CEN on 20 June 2003.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Foreword

This document (EN ISO 13709:2003) has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum and natural gas industries" in collaboration with Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum and natural gas industries", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2004, and conflicting national standards shall be withdrawn at the latest by April 2004.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

NOTE FROM CMC The foreword is susceptible to be amended on reception of the German language version. The confirmed or amended foreword, and when appropriate, the normative annex ZA for the references to international publications with their relevant European publications will be circulated with the German version.

Endorsement notice

The text of ISO 13709:2003 has been approved by CEN as EN ISO 13709:2003 without any modifications.

INTERNATIONAL STANDARD

ISO
13709

First edition
2003-07-01

Centrifugal pumps for petroleum, petrochemical and natural gas industries

*Pompes centrifuges pour les industries du pétrole, de la pétrochimie et
du gaz naturel*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13709 was prepared by Technical Committee ISO/TC 115, *Pumps*, Subcommittee SC 3, *Installation and special application*, in collaboration with Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, SC 6, *Processing equipment and systems*.

Introduction

This International Standard was developed from API Standard 610, 8th edition, 1995, with the intent that the 9th edition of API 610 will be the same as this International Standard.

Users of this International Standard should be aware that further or differing requirements may be needed for individual applications. This International 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 International Standard and provide details.

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

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

Annex C specifies requirements for hydraulic power recovery turbines.

Annex D specifies requirements for standard baseplates.

Annex E contains an inspector's checklist.

Annex F specifies criteria for piping design.

Annex G give 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 contains seal chamber runout illustrations.

Annex L contains forms which may be used to indicate vendor drawing and data requirements.

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

Annex N contains data sheets which purchasers are encouraged to use.

A bullet (●) at the beginning of a clause or subclause indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on data sheets or stated in the enquiry or purchase order (see examples in Annex N).

In this International Standard, where practical, US Customary units are included in brackets for information.

Centrifugal pumps for petroleum, petrochemical and natural gas industries

1 Scope

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

This International Standard is applicable to overhung pumps, between-bearings pumps and vertically-suspended pumps (see Table 1). Clause 8 provides requirements applicable to specific types of pump. All other clauses of this International Standard are applicable to all pump types. Illustrations are provided of the various specific pump types and the designations assigned to each specific type.

This International Standard is not applicable to sealless pumps.

2 Normative references

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

ISO 7-1, *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 286 (all parts), *ISO system of limits and fits*

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

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

ISO 1940-1, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 1: Specification and verification of balance tolerances*

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

ISO 5753, *Rolling bearings — Radial internal clearance*

ISO 7005-1, *Metallic flanges — Part 1: Steel flanges*

ISO 7005-2, *Metallic flanges — Part 2: Cast iron flanges*

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

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

ISO 10436, *Petroleum and natural gas industries — General-purpose steam turbines for refinery service*

ISO 10438 (all parts), *Petroleum and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries*

ISO 10441, *Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — Special purpose applications*

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

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

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

ISO 21049:—¹⁾, *Pumps — Shaft sealing systems for centrifugal and rotary pumps*

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

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmosphere*

EN 287 (all parts), *Approval testing of welders — Fusion welding* ²⁾

EN 288, *Specification and approval of welding procedures for metallic materials*

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

ABMA 7, *Shaft and housing fits for metric radial ball and roller bearings* ³⁾

AGMA 9000, *Flexible couplings — Potential unbalance classification* ⁴⁾

AGMA 9002, *Bores and keyways for flexible couplings (inch series)*

API 541, *Form-wound squirrel-cage induction motors — 250 horsepower and larger*

API 611, *General purpose steam turbines for refinery service*

API 670, *Noncontacting vibration and axial position monitoring system*

API 671, *Special-purpose couplings for refinery service*

API 677, *General-purpose gear units for petroleum, chemical and gas industry services*

ASME B1.1, *Unified inch screw threads, UN and UNR thread form* ⁵⁾

ASME B15.1, *Safety standard for mechanical power transmission apparatus*

1) To be published.

2) Comité Européen de Normalization, 36, rue de Stassart, B-1050 Brussels, Belgium.

3) American Bearing Manufacturers Association, 2025 M Street, NW, Suite 800, Washington, DC 20036, USA.

4) American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA 22314, USA.

5) American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, USA.

ASME B16.1, *Cast iron pipe flanges and flanged fittings classes 25, 125 and 250*

ASME B16.5, *Pipe flanges and flanged fittings NPS 1/2 through NPS 24*

ASME B16.11, *Forged fittings, socket-welding and threaded*

ASME B16.42, *Ductile iron pipe flanges and flanged fittings classes 150 and 300*

ASME B16.47, *Large diameter steel flanges NPS 26 through NPS 60*

ASME B17.1, *Keys and keyseats*

ASME, *Boiler and pressure vessel code, Section V, Nondestructive examination*

ASME, *Boiler and pressure vessel code, Section VIII, Pressure vessels*

ASME, *Boiler and pressure vessel code, Section IX, Welding and brazing qualifications*

AWS D1.1, *Structural welding code — Steel* ⁶⁾

DIN 910, *Heavy-duty hexagon head screw plugs* ⁷⁾

HI 1.3, *Centrifugal pumps — Horizontal baseplate design* ⁸⁾

HI 1.6, *Centrifugal pump test*

HI 2.6, *Vertical pump test*

IEEE 841, *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)* ⁹⁾

MSS-SP-55, *Quality standard for steel castings for valves, flanges and fittings and other piping components — Visual method for evaluation of surface irregularities* ¹⁰⁾

NACE MR0175, *Sulfide stress cracking resistant metallic materials for oilfield equipment item No. 21304* ¹¹⁾

NFPA 70, *National electrical code handbook* ¹²⁾

SSPC SP 6, *Surface Preparation Specification* ¹³⁾

6) American Welding Society, 550 North LeJeune Road, Miami, FL 33136, USA.

7) Deutsches Institut für Normung, Burggrafenstrasse 6, Berlin, Germany D-10787.

8) Hydraulics Institute, 9 Sylvan Way, Parsippany NJ, 07054, USA.

9) Institute of Electrical & Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331.

10) Manufacturers Standardization Society of The Valve and Fittings Industry Inc., 127 Park Street N.E., Vienna, VA 22180-4602, USA.

11) National Association of Corrosion Engineers, 1440 South Creek Drive, Houston, TX 77084-4906, USA.

12) National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101, USA.

13) Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4643, USA.

3 Terms and definitions

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

- 3.1**
axially split
split with the principal joint parallel to the shaft centreline
- 3.2**
barrel pump
horizontal pump of the double-casing type
- 3.3**
barrier fluid
fluid, at a higher pressure than the process pressure being sealed, introduced between pressurized dual (double) mechanical seals to completely isolate the pump process liquid from the environment
- 3.4**
best efficiency point
BEP
flowrate at which a pump achieves its highest efficiency
- 3.5**
buffer fluid
fluid, at a lower pressure than the process pressure being sealed, used as a lubricant or buffer between unpressurized dual (tandem) mechanical seals
- 3.6**
critical speed
shaft rotational speed at which the rotor-bearing-support system is in a state of resonance
- 3.7**
dry critical speed
rotor critical speed calculated assuming that there are no liquid effects, that the rotor is supported only at its bearings and that the bearings are of infinite stiffness
- 3.8**
wet critical speed
rotor critical speed calculated considering the additional support and damping produced by the action of the pumped liquid within internal running clearances at the operating conditions and allowing for flexibility and damping within the bearings
- 3.9**
datum elevation
elevation to which values of NPSH are referred
cf. **net positive suction head** (3.28)
- 3.10**
double casing
type of pump construction in which the pressure casing is separate from the pumping elements contained in the casing
- NOTE Examples of pumping elements include diffuser, diaphragms, bowls and volute inner casings.
- 3.11**
drive train component
item of the equipment used in series to drive the pump
- EXAMPLES Motor, gear, turbine, engine, fluid drive, clutch.

3.12**element
bundle**

assembly of the rotor plus the internal stationary parts of a centrifugal pump

3.13**cartridge-type element**

assembly of all the parts of the pump except for the casing

3.14**hydraulic power recovery turbine**

turbomachine designed to recover power from a fluid stream

3.15**hydrodynamic bearing**

bearing that uses the principles of hydrodynamic lubrication

3.16**maximum allowable speed**

highest speed at which the manufacturer's design permits continuous operation

3.17**maximum allowable temperature**

maximum continuous temperature for which the manufacturer has designed the pump (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating pressure

3.18**maximum allowable working pressure****MAWP**

maximum continuous pressure for which the manufacturer has designed the pump (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating temperature

3.19**maximum continuous speed**

highest rotational speed at which the pump, as built, is capable of continuous operation with the specified fluid at any of the specified operating conditions

3.20**maximum discharge pressure**

maximum specified suction pressure plus the maximum differential pressure the pump with the furnished impeller is able to develop when operating at rated speed with fluid of the specified normal relative density (specific gravity)

3.21**maximum dynamic sealing pressure**

highest pressure expected at the seals during any specified operating condition and during start-up and shut-down

3.22**maximum static sealing pressure**

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

3.23**maximum suction pressure**

highest suction pressure to which the pump is subjected during operation

3.24

minimum allowable speed

lowest speed (in revolutions per minute) at which the manufacturer's design permits continuous operation

3.25

minimum continuous stable flow

lowest flow at which the pump can operate without exceeding the vibration limits imposed by this International Standard

3.26

minimum continuous thermal flow

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

3.27

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

3.28

net positive suction head

NPSH

total absolute suction pressure determined at the suction nozzle and referred to the datum elevation, minus the vapour pressure of the liquid

NOTE It is expressed in metres (feet) of head of the pumped liquid.

3.29

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

3.30

net positive suction head required

NPSHR

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

3.31

nominal pipe size

NPS

designation, usually followed by a size designation number, corresponding approximately to the outside diameter of the pipe expressed in inches

3.32

normal operating point

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

3.33

normal-wear part

part normally restored or replaced at each pump overhaul

EXAMPLES Wear rings, interstage bushings, balancing device, throat bushing, seal faces, bearings and gaskets.

3.34

observed

inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed as scheduled, regardless of whether the purchaser or his representative is present

3.35**oil mist lubrication**

lubrication provided by oil mist produced by atomisation in a central unit and transported to the bearing housing, or housings, by compressed air

3.36**pure oil mist lubrication**

⟨dry sump⟩ systems in which the mist both lubricates the bearing(s) and purges the housing and there is no oil level in the sump

3.37**purge oil mist lubrication**

⟨wet sump⟩ systems in which the mist only purges the bearing housing

3.38**operating region**

portion of a pump's hydraulic coverage over which the pump operates

3.39**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 International Standard or temperature rise or other limitation; specified by the manufacturer

3.40**preferred operating region**

portion of a pump's hydraulic coverage over which the pump's vibration is within the base limit of this International Standard

3.41**overhung pump**

pump whose impeller is cantilevered from its bearing assembly

3.42**pressure casing**

composite of all stationary pressure-containing parts of the pump, including all nozzles, seal glands, seal chambers and other attached parts but excluding the stationary and rotating members of mechanical seals

3.43**purchaser**

owner, or owner's agent, that issues the order and specification to the vendor

3.44**radially split**

split with the principal joint perpendicular to the shaft centreline

3.45**rated operating point**

point at which the vendor certifies that pump performance is within the tolerances stated in this International Standard

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

3.46**relative density****specific gravity**

property of a liquid expressed as the ratio of the liquid's density to that of water at 4 °C (39,2 °F)

3.47

rotor

assembly of all the rotating parts of a centrifugal pump

3.48

specific speed

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

See Annex A.

3.49

standby service

normally idle or idling piece of equipment that is capable of immediate automatic or manual start-up and continuous operation

3.50

suction-specific speed

index relating flow, NPSHR and rotative speed for pumps of similar geometry

See Annex A.

3.51

throat bushing

device that forms a restrictive close clearance around the sleeve (or shaft) between the seal and the impeller

3.52

total indicator reading

total indicated runout

TIR

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

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

3.53

trip speed

(electric motor driver) synchronous speed at maximum supply frequency

3.54

trip speed

(variable-speed driver) speed at which the independent emergency overspeed device operates to shut down the driver

3.55

unit responsibility

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

NOTE The technical aspects to be considered include but are not limited to such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications and testing of components.

3.56

vendor

supplier

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

3.57**vertical in-line pump**

vertical-axis pump whose suction and discharge connections have a common centreline that intersects the shaft axis

NOTE The pump's driver is generally mounted directly on the pump.

3.58**vertically suspended pump**

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

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

3.59**witnessed**

type of inspection or test for which the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or his representative is in attendance

4 Classification and designation

4.1 General

The pumps described in this International Standard are classified and designated as shown in Table 1.

Table 1 — Pump classification type identification

Pump type			Orientation		Type code
Centrifugal pumps	Overhung	Flexibly coupled	Horizontal	Foot-mounted	OH1
				Centreline-supported	OH2
		Rigidly coupled	Vertical in-line with bearing bracket		OH3
			Vertical in-line		OH4
		Close-coupled	Vertical in-line		OH5
			High-speed integrally geared		OH6
	Between-bearings	1- and 2-stage	Axially split		BB1
			Radially split		BB2
		Multistage	Axially split		BB3
			Radially split	Single casing	BB4
				Double casing	BB5
	Vertically suspended	Single casing	Discharge through column	Diffuser	VS1
				Volute	VS2
				Axial flow	VS3
			Separate discharge	Line shaft	VS4
				Cantilever	VS5
		Double casing	Diffuser		VS6
			Volute		VS7
	NOTE Illustrations of the various types of pump are provided in 4.2.				

4.2 Pump designations

4.2.1 Pump type OH1

Foot-mounted single-stage overhung pumps shall be designated pump type OH1. (This type does not meet all the requirements of this International Standard, see Table 2.)

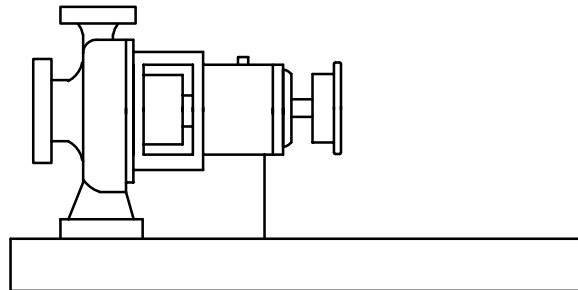


Figure 1 — Pump type OH1

4.2.2 Pump type OH2

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

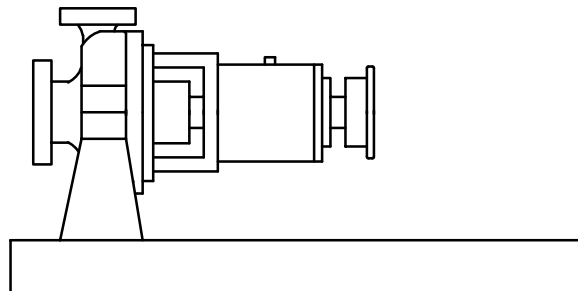


Figure 2 — Pump type OH2

4.2.3 Pump type OH3

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

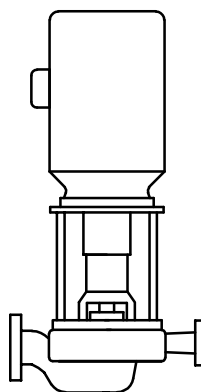


Figure 3 — Pump type OH3

4.2.4 Pump type OH4

Rigidly coupled vertical in-line single-stage overhung pumps shall be designated pump type OH4. Rigidly coupled pumps have their shaft rigidly coupled to the driver shaft. (This type does not meet all the requirements of this International Standard, see Table 2.)

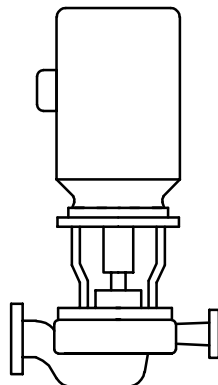


Figure 4 — Pump type OH4

4.2.5 Pump type OH5

Close-coupled vertical in-line single-stage overhung pumps shall be designated pump type OH5. Close-coupled pumps have their impellers mounted directly on the driver shaft. (This type does not meet all the requirements of this International Standard, see Table 2.)

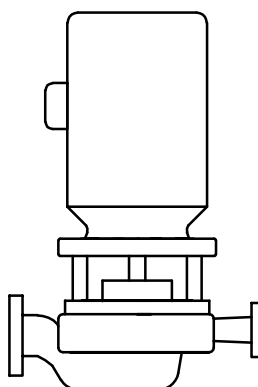


Figure 5 — Pump type OH5

4.2.6 Pump type OH6

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

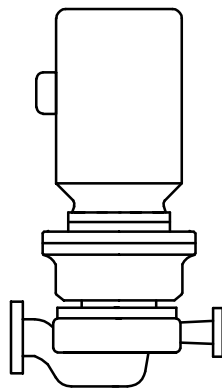


Figure 6 — Pump type OH6

4.2.7 Pump type BB1

Axially split one- and two-stage between-bearings pumps shall be designated pump type BB1.

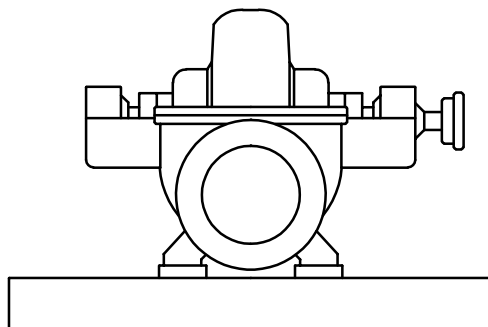


Figure 7 — Pump type BB1

4.2.8 Pump type BB2

Radially split one- and two-stage between-bearings pumps shall be designated pump type BB2.

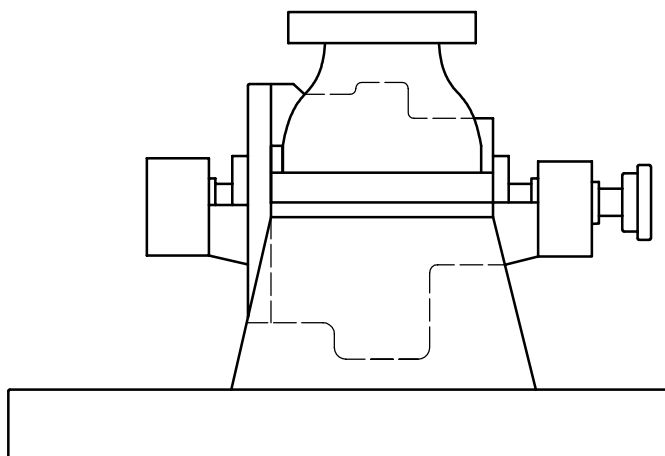


Figure 8 — Pump type BB2

4.2.9 Pump type BB3

Axially split multistage between-bearings pumps shall be designated pump type BB3.

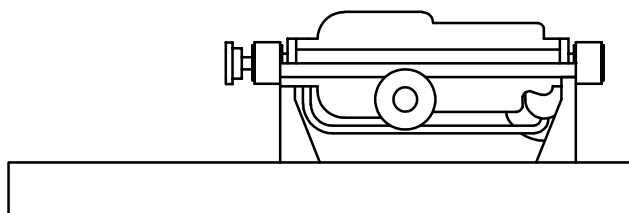


Figure 9 — Pump type BB3

4.2.10 Pump type BB4

Single-casing radially split multistage between-bearings pumps shall be designated pump type BB4. These pumps are also called ring-section pumps, segmental-ring pumps or tie-rod pumps. These pumps have a potential leakage path between each segment. (This type does not meet all the requirements of this International Standard, see Table 2.)

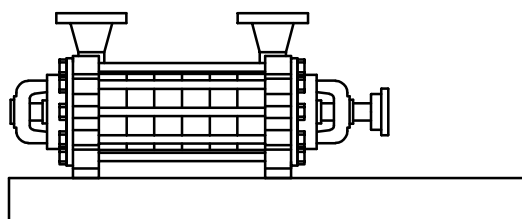


Figure 10 — Pump type BB4

4.2.11 Pump type BB5

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

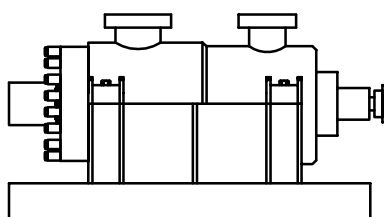


Figure 11 — Pump type BB5

4.2.12 Pump type VS1

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

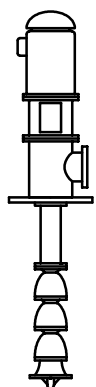


Figure 12 — Pump type VS1

4.2.13 Pump type VS2

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

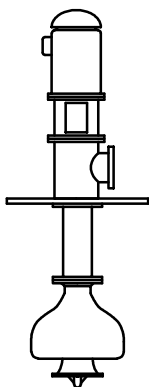


Figure 13 — Pump type VS2

4.2.14 Pump type VS3

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

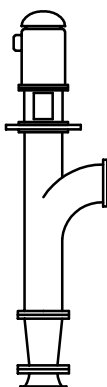


Figure 14 — Pump type VS3

4.2.15 Pump type VS4

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

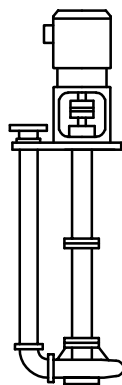


Figure 15 — Pump type VS4

4.2.16 Pump type VS5

Vertically suspended cantilever sump pumps shall be designated pump type VS5.

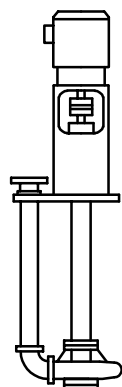


Figure 16 — Pump type VS5

4.2.17 Pump type VS6

Double-casing diffuser vertically suspended pumps shall be designated pump type VS6.

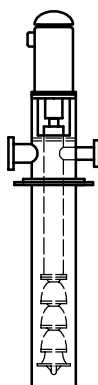


Figure 17 — Pump type VS6

4.2.18 Pump type VS7

Double-casing volute vertically suspended pumps shall be designated pump type VS7.

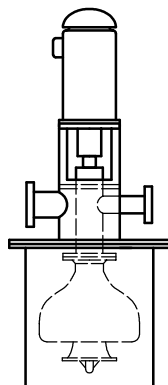


Figure 18 — Pump type VS7

4.3 Units and governing requirements

- **4.3.1** The purchaser shall specify whether drawings and maintenance dimensions of pumps shall be in SI units or US Customary (USC) units. Use of an ISO Standard datasheet (see Annex N, Figure N.1) indicates SI units shall be used. Use of a USC datasheet (see Annex N, Figure N.2) indicates that US Customary units shall be used.

4.3.2 Where requirements specific to a particular pump type in Clause 8 conflict with any other clauses, the requirements of Clause 8 shall govern.

5 Basic design

5.1 General

5.1.1 The equipment (including auxiliaries) covered by this International Standard shall be designed and constructed for a minimum service life of 20 years (excluding normal-wear parts as identified in Table 18) and at least 3 years of uninterrupted operation. It is recognized that these requirements are design criteria and that service or duty severity, misoperation or improper maintenance can result in a machine failing to meet these criteria.

The term “design” shall apply solely to parameters or features of the equipment supplied by the manufacturer. The term “design” should not be used in the purchasers enquiry or specifications because it can create confusion in understanding the order.

5.1.2 The vendor shall assume unit responsibility for all equipment and all auxiliary systems included in the scope of the order.

- **5.1.3** The purchaser shall specify the operating conditions, the liquid properties, site conditions and utility conditions, including all data shown on the process data sheet (Annex N). The purchaser shall specify if the pump is intended for use as an HPRT and if Annex C shall apply.

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

- **5.1.5** Fluids that are flammable or hazardous shall be identified by the purchaser.

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

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 considered in selection.

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

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

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

5.1.9 The conditions in the seal chamber required to maintain a stable film at the seal faces, including temperature, pressure and flow, as well as provisions for assuring the adequacy of the design for sealing against atmospheric pressure when pumps are idle in vacuum service, shall be agreed upon by the pump vendor and the seal manufacturer, approved by the purchaser, and noted on the data sheet.

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

5.1.10 The vendor shall specify on the data sheets the NPSHR based on water [at a temperature of less than 65 °C (150 °F)] at the rated flow and rated speed. A reduction or correction factor for liquids other than water (such as hydrocarbons) shall not be applied.

The purchaser should consider an appropriate NPSH margin in addition to the NPSHR specified. An NPSH margin is the NPSH that exists in excess of the pump's NPSHR. It is usually desirable to have an operating NPSH margin that is sufficient 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. The vendor should be consulted about recommended NPSH margins for the specific pump type and intended service.

In establishing NPSHA, the purchaser and the vendor should recognize the relationship between minimum continuous stable flow and the pump's suction-specific speed. In general, minimum continuous stable flow, expressed as a percentage of flow at the pump's best efficiency point, 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 levels and NPSH margins should take into account current industry and vendor experience.

Unless otherwise specified, the datum elevation shall be the shaft centreline for horizontal pumps, the suction-nozzle centreline for vertical in-line pumps, and the top of the foundation for vertically suspended pumps.

- **5.1.11** The pump suction-specific speed shall be calculated in accordance with Annex A and, if specified, limited as stated on the data sheet.

5.1.12 Pumps that handle liquids more viscous than water shall have their water performance corrected in accordance with HI 1.3 (see Clause 2). Correction factors shall be submitted with proposal and test curves.

- **5.1.13** Pumps that have stable head/flowrate curves (continuous head rise to shutoff) are preferred for all applications and are required if parallel operation is specified. If parallel operation is specified, the head rise from rated point to shutoff shall be at least 10 %. If a discharge orifice is used as a means of providing a continuous rise to shutoff, this use shall be stated in the proposal.

5.1.14 Pumps shall have a preferred operating region of 70 % to 120 % of best efficiency flowrate of the pump as furnished. Rated flow shall be within the region of 80 % to 110 % of best efficiency flowrate of the pump as furnished.

Setting 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, which are known to operate satisfactorily at flows outside the specified limits, and high specific-speed pumps, which may have a narrower preferred operating region than specified, should be offered where appropriate, and their preferred operating region clearly shown on the proposal curve. The pump specific speed shall be calculated in accordance with Annex A.

5.1.15 The best efficiency point for the pump as furnished should preferably be between the rated point and the normal point.

- **5.1.16** If specified, the vendor shall provide both maximum sound pressure and sound power level data per octave band for the equipment. Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor who has unit responsibility. The equipment furnished by the vendor shall conform to the maximum allowable sound pressure level specified. ISO 3740 [7], ISO 3744 [8] and ISO 3746 [9] may be consulted for guidance.

5.1.17 Pumps with heads greater than 200 m (650 ft) per stage and with more than 225 kW (300 hp) per stage may require special provisions to reduce vane passing-frequency vibration and low-frequency vibration at reduced flowrates. For these pumps, the radial clearance between the diffuser vane or volute tongue (cutwater) and the periphery of the impeller blade shall be at least 3 % of the maximum impeller blade-tip radius for diffuser designs and at least 6 % of the maximum blade-tip radius for volute designs. The maximum impeller blade-tip radius is the radius of the largest impeller that can be used within the pump casing (see 5.1.6). Percent clearance is calculated as follows:

$$P = 100(R_2 - R_1)/R_1$$

where

P is the percent clearance;

R_2 is the radius of volute or diffuser inlet tip;

R_1 is the maximum impeller blade tip radius.

The impellers of pumps covered by this clause shall not be modified after test to correct hydraulic performance by underfiling, overfiling or "V"-cutting without notifying the purchaser prior to shipment. Any such modifications shall be documented in accordance with 9.3.4.1.

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

- **5.1.19** The need for cooling shall be agreed upon by the purchaser and the vendor. One of the plans in Annex B shall be selected. The cooling system shall be suitable for operation with the coolant type, pressure and temperature specified by the purchaser. The vendor shall specify the required flow. To avoid condensation, the minimum temperature at the cooling-water inlet to bearing housings should be above the ambient air temperature.

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

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

5.1.22 Water-cooling systems shall be designed for the following conditions on the water side:

	SI units	US Customary units
Velocity over heat exchange surfaces:	1,5 m/s to 2,5 m/s	(5 ft/s to 8 ft/s)
Maximum allowable working pressure (MAWP), gauge:	700 kPa	(7 bar) (100 psi)
Test pressure (>1,5 MAWP), gauge:	1 050 kPa	(10,5 bar) (150 psi)
Maximum pressure drop:	100 kPa	(1 bar) (15 psi)
Maximum inlet temperature:	30 °C	(90 °F)
Maximum outlet temperature:	50 °C	(120 °F)
Maximum temperature rise:	20 K	(30 °R)
Fouling factor on water side:	0,35 m ² ·K/kW	(0,002 h·ft ² ·°R/Btu)
Shell corrosion allowance (not for tubes):	3,0 mm	(0,125 in)

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

The criterion for velocity over heat-exchange surfaces is intended to minimize waterside fouling.

5.1.23 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance.

- **5.1.24** Motors, electrical components and electrical installations shall be suitable for the area classification (class, group, and division or zone) specified by the purchaser and shall meet the requirements of the applicable sections of IEC 60079 or NFPA 70, Articles 500, 501, 502, 504 and 505 as well as any local codes specified and furnished on request by the purchaser.

5.1.25 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.

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

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

5.1.28 The pump and its driver shall perform on their test stands and on their permanent foundation within the acceptance criteria specified in 5.9.3. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

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

5.1.30 Equipment, including all auxiliaries, shall be designed for outdoor installation and the specified site environmental conditions. The vendor shall advise 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.).

5.1.31 Bolting for pressure casings shall conform to the following criteria.

- The details of threading shall conform to ISO 261, ISO 262, ISO 724 and ISO 965, or to ASME B1.1.
- Adequate clearance shall be provided at all bolting locations to permit the use of socket or box spanners (wrenches).

- c) External hexagon-head bolting is required unless otherwise agreed.
- d) Fasteners shall be not less than 12 mm (0,5 in) diameter.
- e) Fasteners (excluding washers and headless set-screws) shall have the material grade and manufacturers identification symbols applied to one end of studs 10 mm (3/8 in) in diameter and larger and to the heads of bolts 6 mm (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's identification symbol marked on the other end. Studs shall be marked on the exposed end.

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

- f) Metric fine and UNF threads shall not be used.

5.2 Pump types

The pump types listed in Table 2 have special design features and shall be furnished only if specified by the purchaser and if the manufacturer has proven experience for the specific application. Table 2 lists the features requiring special consideration for these pump types, and gives in parentheses the relevant subclause(s) of this International Standard.

Table 2 — Special design features of particular pump types

Pump type	Features requiring special consideration
Close-coupled (impeller mounted on motor shaft), OH5	a) Motor construction (6.1) b) Motor bearing and winding temperature at high pumping temperatures c) Seal removal (5.8.2)
Rigidly coupled vertical in-line, OH4	a) Motor construction (6.1) b) Rotor stiffness (5.6.9) c) Product-lubricated guide bearing (5.10.1.1) d) Shaft runout at seal (5.6.8, 5.8.5)
Horizontal foot-mounted overhung, OH1	a) Pressure rating (5.3.5) b) Casing support (5.3.11)
Two-stage overhung	a) Rotor stiffness (5.6.9)
Double-suction overhung	a) Rotor stiffness (5.6.9)
Ring-section casing (multistage), BB4	a) Pressure containment (5.3.3, 5.3.10) b) Dismantling (5.1.27)
Built-in mechanical seal (no separable seal gland)	a) Seal removal (5.8.2)

5.3 Pressure casings

5.3.1 The maximum discharge pressure shall be the maximum suction pressure plus the maximum differential pressure the pump is able to develop when operating with the furnished impeller at the rated speed and specified normal relative density (specific gravity).

NOTE The basis of determining maximum discharge pressure is an application issue.

- **5.3.2** If specified, the maximum discharge pressure shall be increased by the additional differential pressure developed during one or more of the following operating circumstances:
 - a) the maximum specified relative density at any specified operating condition;
 - b) installation of an impeller of the maximum diameter and/or number of stages that the pump can accommodate;
 - c) operation to trip speed.

The purchaser should assess the likelihood of the circumstances above occurring before specifying them.

The additional differential pressure developed at trip speed is normally a momentary excursion to be absorbed by the hydrotest margin.

5.3.3 The pressure casing shall be designed to:

- a) operate without leakage or internal contact between rotating and stationary components while subject simultaneously to the MAWP (and corresponding temperature) and the worst-case combination of twice the allowable nozzle loads of Table 4 applied through each nozzle;
- b) withstand the hydrostatic test (see 7.3.2).

NOTE The twice-nozzle-load requirement is a pressure-casing design criterion. Allowable nozzle loads for piping designers are the values given in Table 4. Other factors such as casing support or baseplate stiffness affect allowable nozzle loads.

5.3.4 The tensile stress used in the design of the pressure casing for any material shall not exceed 0,25 times the minimum ultimate tensile strength for that material at the maximum specified operating temperature and, for castings, multiplied by the appropriate casting factor as given in Table 3. The manufacturer shall state the source of the material properties, such as ASTM, as well as the casting factors applied in his proposal.

NOTE 1 In general, the criteria in 5.3.3 result in deflection (strain) being the determining consideration in the design of pump casings. 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, the bolting will be tightened to produce a tensile stress higher than the design tensile stress. Values in the range of 0,7 times yield are common.

Table 3 — Casting factors

Type of NDE	Casting factor
Visual, magnetic particle and/or liquid penetrant	0,8
Spot radiography	0,9
Ultrasonic	0,9
Full radiography	1,0

5.3.5 Except as noted in 5.3.6, the MAWP shall be at least the maximum discharge pressure (see 5.3.1 and 5.3.2) plus 10 % of the maximum differential pressure, and shall not be less than:

- a) for axially split one- and two-stage between-bearings pumps and single-casing vertically suspended pumps: a pressure rating equal to that of an ISO 7005-2 PN20 cast iron or ISO 7005-1 PN20 steel flange of a material grade corresponding to that of the pressure casing.

NOTE For the purpose of this provision, ASME B16.1 Class 125 and ASME B16.5 Class 150 are equivalent to ISO 7005-2 PN20 and ISO 7005-1 PN20, respectively.

- b) for all other pumps: a minimum gauge pressure rating of 4 000 kPa (40 bar) (600 psi) at 38 °C (100 °F), or at least ISO 7005-1 PN50.

NOTE 1 The 10 % differential pressure margin is intended to accommodate head increases (5.1.6), higher speed in variable-speed pumps (5.1.7) and head (testing) tolerance (see 7.3.3.4).

NOTE 2 For the purposes of this provision, ASME B16.5 Class 300 flange is equivalent to ISO 7005-1 PN50.

NOTE 3 This subclause provides minimum requirements consistent with designs existing at the time of publication. For future designs, it is considered desirable that the case MAWP match the pressure capabilities of the adjacent flanges.

- **5.3.6** Unless otherwise specified, vertically suspended, double-casing, integral gear-driven (type OH6) and horizontal multistage pumps (pumps with three or more stages) may be designed for dual pressure ratings. If specified, suction regions shall be designed for the same MAWP as the discharge section.

The purchaser should consider installation of relief valves on the suction side of such installations.

5.3.7 The pressure casing shall be designed with a corrosion allowance to meet the requirements of 5.1.1. Unless otherwise specified, the minimum corrosion allowance shall be 3 mm (0,12 in).

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

5.3.8 The inner casing of double-casing pumps shall be designed to withstand the maximum differential gauge pressure or 350 kPa (3,5 bar) (50 psi), whichever is greater.

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

- a) a pumping temperature of 200 °C (400 °F) or higher (a lower temperature limit should be considered if thermal shock is probable);
- b) a flammable or hazardous pumped liquid with a relative density of less than 0,7 at the specified pumping temperature;
- c) a flammable or hazardous pumped liquid at a rated discharge pressure above 10 000 kPa (100 bar) (1 450 psi).

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

5.3.10 Radially split casings shall have metal-to-metal fits, with confined controlled-compression gaskets, such as an O-ring or a spiral wound type.

5.3.11 Centreline-supported pump casings shall be used for all horizontal pumps except as allowed in 8.2.1.2.

5.3.12 O-ring sealing surfaces, including all grooves and bores, shall have a maximum surface roughness average value (R_a) of 1,6 μm (63 micro-inches) for static O-rings and 0,8 μm (32 micro-inches) 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°.

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

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

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

Studs shall be supplied on all main casing joints unless cap screws are specifically approved by the purchaser.

5.4 Nozzles and pressure casing connections

5.4.1 Casing opening sizes

5.4.1.1 Openings for nozzles and other pressure casing connections shall be standard pipe sizes. Openings of DN 32, 65, 90, 125, 175 and 225 (NPS 1 1/4, 2 1/2, 3 1/2, 5, 7 and 9) shall not be used.

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

5.4.2 Suction and discharge nozzles

5.4.2.1 Suction and discharge nozzles shall be flanged, except those on pumps with forged casings, which shall be flanged or machined and studded. One- and two-stage pumps shall have suction and discharge flanges of equal rating.

5.4.2.2 Cast iron flanges shall be flat-faced and, except as noted in 5.4.2.4, conform to the dimensional requirements of ISO 7005-2 and the flange finish requirements of ASME B16.1 or ASME B16.42. PN 20 (Class 125) flanges shall have a minimum thickness equal to that of PN 40 (Class 250) flanges for sizes DN 200 (NPS 8) and smaller.

5.4.2.3 Flanges other than cast iron shall, as a minimum requirement, conform to the dimensional requirements of ISO 7005-1 PN 50 except as noted in 5.4.2.4 and the flange finish requirements of ASME B16.5 or ASME B16.47.

NOTE For the purpose of this provision, ASME B16.5 Class 300 and ASME B16.47 Class 300 are equivalent to ISO 7005-1 PN 50.

5.4.2.4 Flanges in all materials that are thicker or have a larger outside diameter than required by the relevant ISO (ASME) standards in this International Standard are acceptable. Non-standard (oversized) flanges shall be completely dimensioned on the arrangement drawing. If oversized flanges require studs or bolts of non-standard length, this requirement shall be identified on the arrangement drawing.

5.4.2.5 Flanges shall be full faced or spot faced on the back and shall be designed for through bolting, except for jacketed casings.

5.4.3 Auxiliary connections

5.4.3.1 For non-flammable non-hazardous liquids, auxiliary connections to the pressure casing may be threaded.

5.4.3.2 Unless otherwise specified, pipe threads shall be tapered threads conforming to ISO 7-1. Openings and bosses for pipe threads shall conform to ASME B16.5.

NOTE For the purpose of this provision, ASME B1.20.1 is equivalent to ISO 7-1.

- **5.4.3.3** If specified, cylindrical threads conforming to ISO 228-1 shall be used. If cylindrical threads are used, they shall be sealed with a contained face gasket, and the connection boss shall have a machined face suitable for gasket containment (see Figure 19).

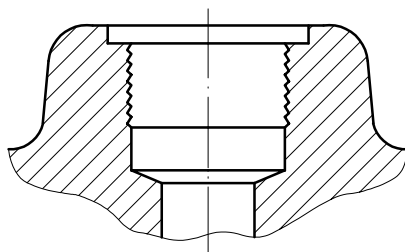


Figure 19 — Machined face suitable for gasket containment if using cylindrical threads

5.4.3.4 For flammable or hazardous liquids, auxiliary connections to the pressure casing, except seal gland, shall be socket-welded, butt-welded or integrally flanged. Purchaser interface connections shall terminate in a flange.

5.4.3.5 Connections welded to the casing shall meet or exceed the material requirements of the casing, including impact values, rather than the requirements of the connected piping. All connection welding shall be completed before the casing is hydrostatically tested (see 7.3.2).

5.4.3.6 Pipe nipples screwed or welded to the casing should 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 DN 40 (NPS 1 1/2)

5.4.3.7 Threaded openings not connected to piping are only allowed in seal glands and in pumps of material classes I-1 and I-2 (see Annex H). If supplied, they shall be plugged. 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 specified in 5.4.3.3, 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 vapour-tight. Plastic plugs are not permitted.

- **5.4.3.8** At interfaces with the purchaser's equipment, the use of machined and studded connections requires the approval of the purchaser. If approved, they shall conform to the facing and drilling requirements of ISO 7005-1 or ISO 7005-2. Studs and nuts shall be furnished installed. The first 1,5 threads at both ends of each stud shall be removed.

NOTE For the purpose of this provision, ASME B16.1 and ASME B16.5 are equivalent to ISO 7005-1 and ISO 7005-2, respectively.

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

5.4.3.10 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.

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

5.4.3.11 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.

5.5 External nozzle forces and moments

5.5.1 Steel and alloy steel horizontal pumps and their baseplates and vertically suspended pumps shall be designed for satisfactory performance if subjected to the forces and moments in Table 4. For horizontal pumps, two effects of nozzle loads are considered: Distortion of the pump casing (see 5.3.3 and 5.3.4) and misalignment of the pump and driver shafts (see 6.3.5).

5.5.2 Allowable forces and moments for vertical in-line pumps shall be twice the values in Table 4 for side nozzles.

5.5.3 For pump casings constructed of materials other than steel or alloy steel or for pumps with nozzles larger than DN 400 (NPS 16), the vendor shall submit allowable nozzle loads corresponding to the format in Table 4.

Table 4 — Nozzle loadings

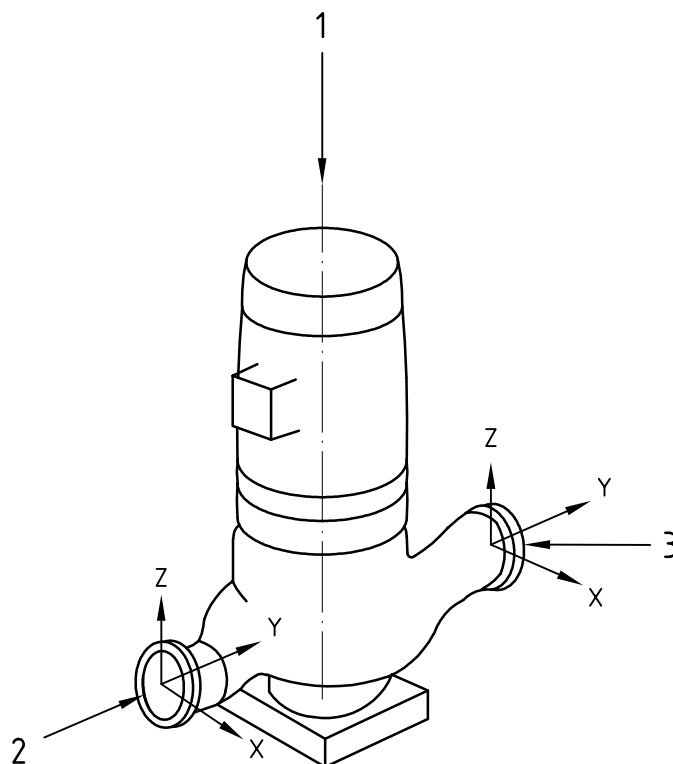
	SI units								
	Nominal size of flange (DN)								
	≤ 50	80	100	150	200	250	300	350	400
Forces (N)									
Each top nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_Z	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each side nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each end nozzle									
F_X	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Y	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Moments (N·m)									
Each nozzle									
M_X	460	950	1 330	2 300	3 530	5 020	6 100	6 370	7 320
M_Y	230	470	680	1 180	1 760	2 440	2 980	3 120	3 660
M_Z	350	720	1 000	1 760	2 580	3 800	4 610	4 750	5 420
M_R	620	1 280	1 800	3 130	4 710	6 750	8 210	8 540	9 820

Table 4 — Nozzle loadings (*continued*)

	US Customary units								
	Nominal size of flange (NPS)								
	≤ 2	3	4	6	8	10	12	14	16
	Forces (lbf)								
Each top nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	130	200	260	460	700	1 000	1 200	1 300	1 500
F_Z	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each side nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each end nozzle									
F_X	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Y	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
	Moments (ft·lbf)								
Each nozzle									
M_X	340	700	980	1 700	2 600	3 700	4 500	4 700	5 400
M_Y	170	350	500	870	1 300	1 800	2 200	2 300	2 700
M_Z	260	530	740	1 300	1 900	2 800	3 400	3 500	4 000
M_R	460	950	1 330	2 310	3 500	5 000	6 100	6 300	7 200
NOTE 1 See Figures 20 through 24 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.									

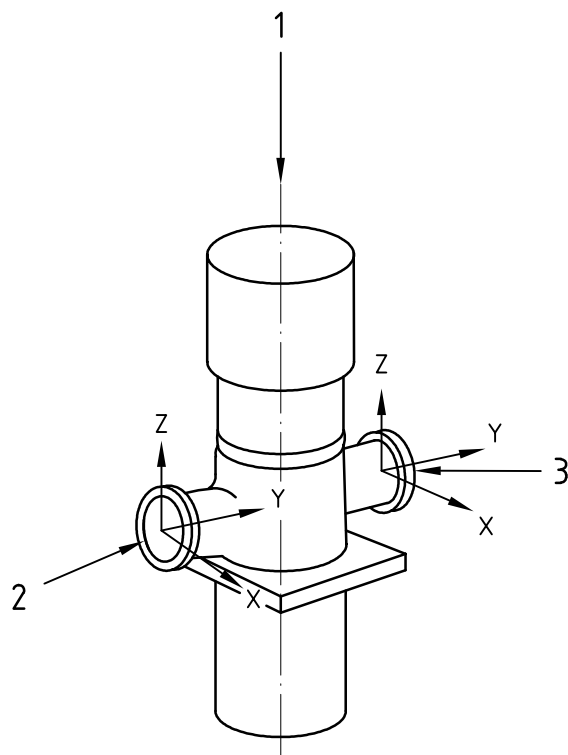
5.5.4 The coordinate system(s) shown in Figures 20 through 24 shall be used to apply the forces and moments in Table 4.

- **5.5.5** Annex F gives methods of qualifying nozzle loads in excess of those in Table 4. These methods may be used if approved by the purchaser, and the purchaser should then direct the piping designer accordingly. The purchaser should be aware that the use of Annex F methods can result in up to 50 % greater misalignment than would occur using the loads of Table 4.

**Key**

- 1 shaft centreline
- 2 discharge
- 3 suction

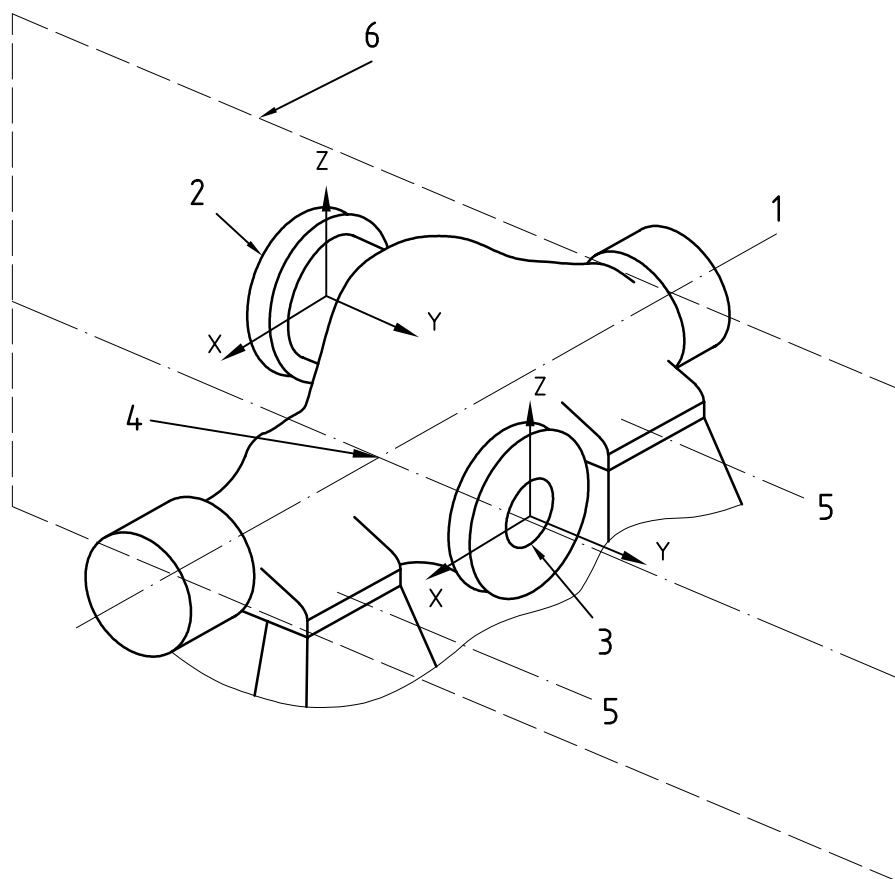
Figure 20 — Coordinate system for the forces and moments in Table 4 — Vertical in-line pumps



Key

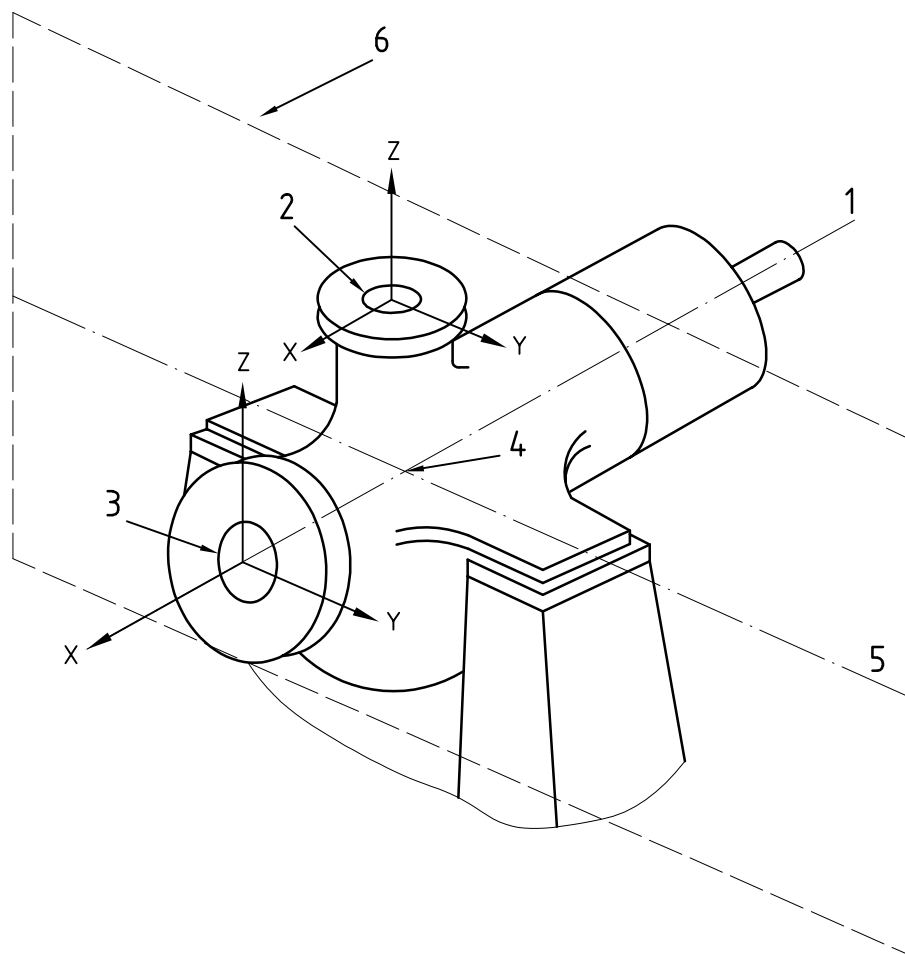
- 1 shaft centreline
- 2 discharge
- 3 suction

Figure 21 — Coordinate system for the forces and moments in Table 4 — Vertically suspended double-casing pumps

**Key**

- 1 shaft centreline
- 2 discharge nozzle
- 3 suction nozzle
- 4 centre of pump
- 5 pedestal centreline
- 6 vertical plane

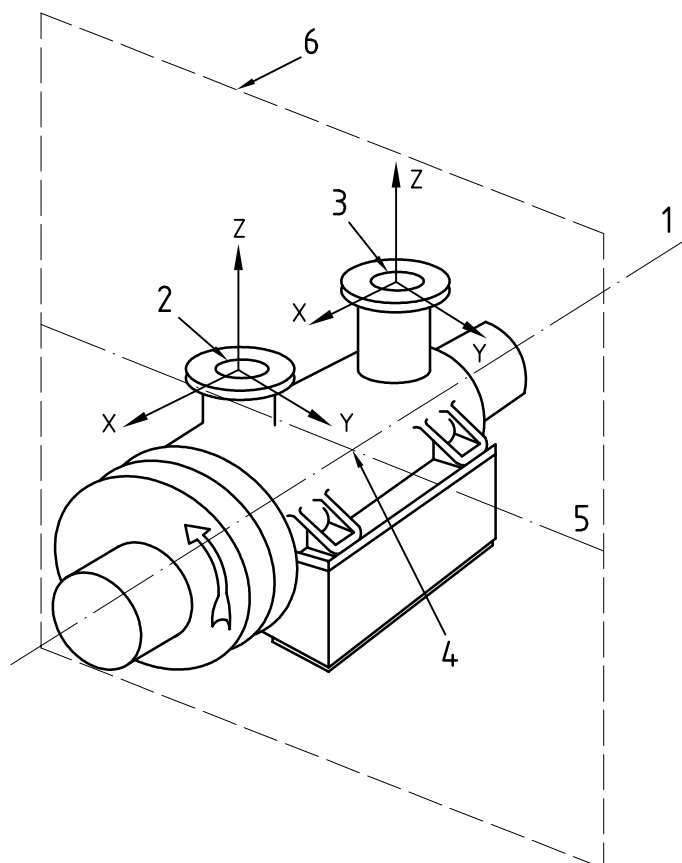
Figure 22 — Coordinate system for the forces and moments in Table 4 — Horizontal pumps with side suction and side discharge nozzles



Key

- 1 shaft centreline
- 2 discharge nozzle
- 3 suction nozzle
- 4 centre of pump
- 5 pedestal centreline
- 6 vertical plane

Figure 23 — Coordinate system for the forces and moments in Table 4 — Horizontal pumps with end suction and top discharge nozzles



Key

- 1 shaft centreline
- 2 discharge nozzle
- 3 suction nozzle
- 4 centre of pump
- 5 pedestal centreline
- 6 vertical plane

Figure 24 — Coordinate system for the forces and moments in Table 4 — Horizontal pumps with top nozzles

5.6 Rotors

5.6.1 Unless otherwise approved by the purchaser, impellers shall be of the fully enclosed type.

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

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

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

5.6.3 Impellers shall be keyed to the shaft. Pinning of impellers to the shaft is not acceptable. With the purchaser's approval, collets may be used in vertically suspended pumps. Overhung impellers shall be secured to the shaft by a cap screw or cap nut that does not expose shaft threads. The securing device shall be threaded to tighten by liquid drag on the impeller during normal rotation, and a positive mechanical locking method (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 reduce stress concentrations.

5.6.4 Impellers shall have solid hubs. Impellers may be made from a cored pattern if the core is completely filled with a suitable metal that has a melting point of not less than 260 °C (500 °F) for pumps with cast iron casings and not less than 540 °C (1 000 °F) for pumps with cast steel casings.

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

5.6.5 For shafts that require sleeve gaskets to pass over threads, at least 1,5 mm (0,06 in) radial clearance shall be provided between the threads and the internal diameter of the gasket, and the diameter transition shall be chamfered in accordance with 5.3.12.

5.6.6 The shaft-to-seal sleeve fit(s) shall be h6/G7 in accordance with ISO 286 (all parts).

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

5.6.8 Shafts shall be machined and finished throughout their length so that the TIR is not more than 25 µm (0,001 in).

5.6.9 To obtain satisfactory seal performance, the shaft stiffness shall limit the total deflection under the most severe dynamic conditions over the allowable operating range of the pump with maximum diameter impeller(s) and the specified speed and fluid to 50 µm (0,002 in) at the primary seal faces. This shaft deflection limit may be achieved by a combination of shaft diameter, shaft span or overhang, and casing design (including the use of dual volutes or diffusers). For one- and two-stage pumps, no credit shall be taken for the fluid stiffening effects of impeller wear rings. For multistage pumps, fluid stiffening effects shall be considered and calculations shall be performed at both one and two times the nominal design clearances. The fluid stiffness of product-lubricated bearings and bearing bushings shall be calculated at both one and two times the nominal design clearances.

5.6.10 If non-contacting vibration probes are furnished in accordance with 6.4.2.2, the shaft sensing areas (both radial vibration and axial position) to be observed by radial vibration probes shall

- a) be concentric with the bearing journals,
- b) be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway, for a minimum distance of one probe tip diameter on each side of the probe,
- c) not be metallized, sleeved, or plated on rotors of materials that exhibit consistent electrical properties,
- d) have a final surface finish of 0,8 µm (32 micro-inches) *Ra* or smoother, preferably obtained by honing or burnishing,
- e) be properly demagnetized to the levels specified in API 670, or otherwise treated so that the combined total electrical and mechanical runout does not exceed the following:
 - 1) for areas to be observed by radial vibration probes, 25 % of the allowed peak-to-peak vibration amplitude or 6 µm (0,25 mil), whichever is greater;
 - 2) for areas to be observed by axial position probes, 13 µm (0,5 mil).

5.6.11 If the shaft is made of material that exhibits inconsistent electrical properties, the shaft sensing areas may be produced by shrink-fitting sleeves or “target rings” to the shaft. Target rings shall be finished in accordance with 5.6.10. The use of target rings requires specific purchaser approval.

Materials known to exhibit inconsistent electrical properties are high chromium alloys such as 17-4 PH, duplex stainless steel and ASTM A479 grade XM-19.

5.6.12 If it is specified that equipment shall have provisions for mounting non-contacting vibration probes (6.4.2.2), the shaft shall be prepared in accordance with the requirements of 5.6.10 and API 670.

5.6.13 If non-contacting vibration probes are furnished, accurate records of electrical and mechanical runout for the full 360° at each probe location shall be included in the mechanical test report.

5.6.14 All shaft keyways shall have fillet radii conforming to ASME B17.1.

NOTE This requirement applies to all shaft keyways, not just those at the coupling(s).

5.6.15 The rotor of one- and two-stage pumps shall be designed so its first dry-bending critical speed is at least 20 % above the pump's maximum continuous operating speed.

5.7 Wear rings and running clearances

5.7.1 Radial running clearances shall be used to limit internal leakage and, where necessary, balance axial thrust. Impeller pumping vanes or close axial clearances shall not be used to balance axial thrust. Renewable wear rings shall be provided in the pump casing. Impellers shall have either integral wear surfaces or renewable wear rings.

5.7.2 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.

5.7.3 Renewable wear rings, if used, 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.

5.7.4 Running clearances shall meet the requirements of 5.7.4 a) through 5.7.4 c) below.

- a) When establishing running clearances between wear rings and other moving parts, consideration shall be given to pumping temperatures, suction conditions, the liquid properties, the thermal expansion and galling characteristics of the materials, and pump efficiency. Clearances shall be sufficient to assure dependability of operation and freedom from seizure under all specified operating conditions.
- b) For cast iron, bronze, hardened martensitic stainless 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 diametral clearances.
- c) For non-metallic wear ring materials with very low or no galling tendencies (see Annex H, Table H.4), clearances less than those given in Table 5 may be proposed by the vendor. Factors such as distortion and thermal gradients shall be considered, to ensure clearances are sufficient to provide dependability of operation and freedom from seizure under all specified operating conditions.

Table 5 — Minimum 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
NOTE For diameters greater than 649,99 mm (25,999 in), the minimum diametral 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).			

5.8 Mechanical shaft seals

- **5.8.1** Pumps shall be equipped with mechanical seals and sealing systems in accordance with ISO 21049, including pump and seal interface dimensions (see Table 6 and Figure 25). The purchaser shall specify the category of seal required. The purchaser should use the data sheets in ISO 21049 for this purpose.

NOTE For the purpose of this provision, API 682 is equivalent to ISO 21049.

5.8.2 The seal cartridge shall be removable without disturbing the driver.

5.8.3 The seal chamber shall conform to the dimensions shown in Figure 25 and Table 6. For pumps with flange and pressure ratings in excess of the minimum values in 5.3.5, the gland stud size and circle may increase. Larger studs shall be furnished only if required to meet the stress requirements of 5.3.4 or to sufficiently compress spiral-wound gaskets in accordance with manufacturer's specifications.

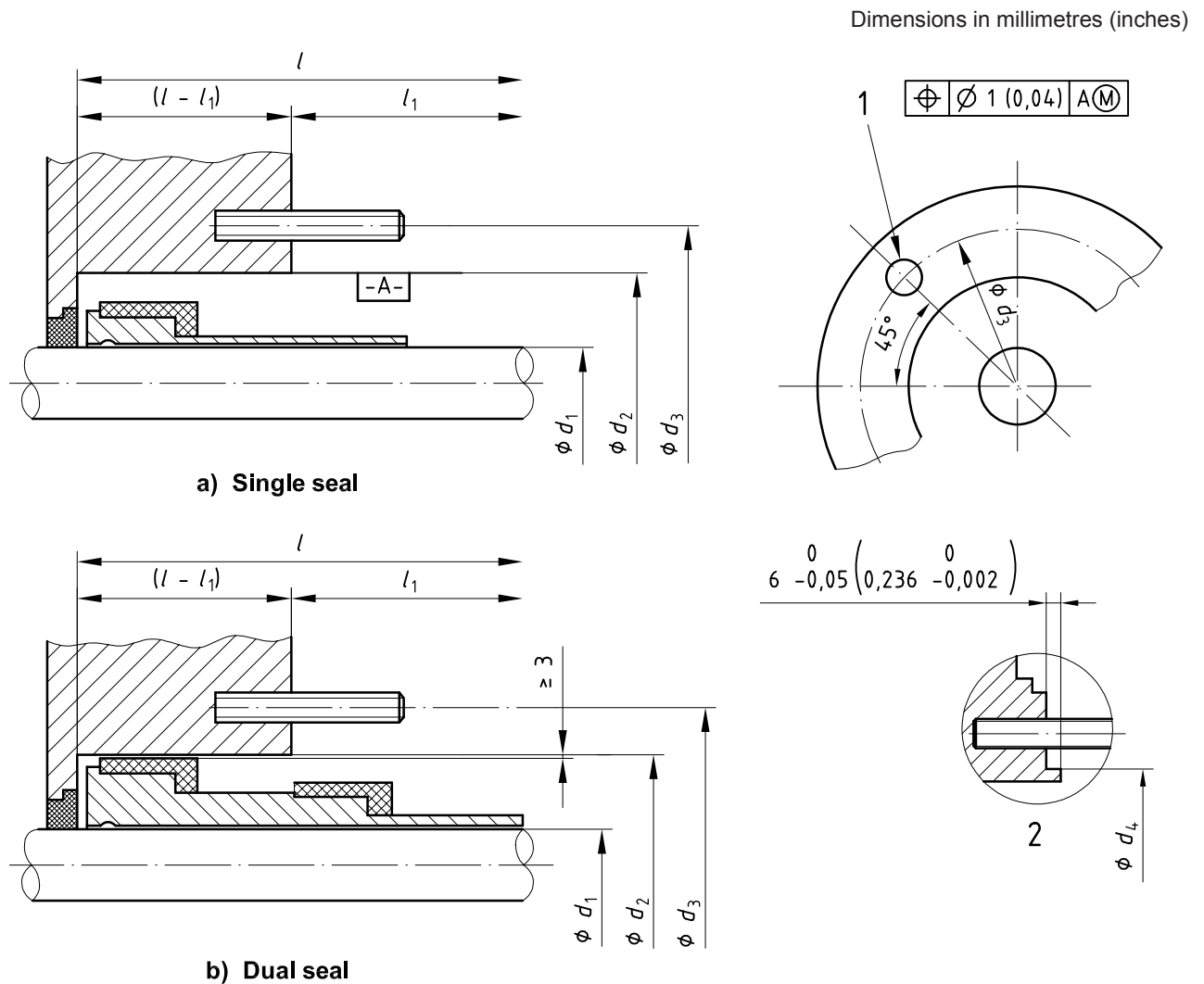


Figure 25 — Chamber diagrams

Table 6 — Standard dimensions for seal chambers, seal gland attachments and cartridge mechanical seal sleeves (see Figure 25)

Dimensions in millimetres (inches)

Seal chamber size	Shaft diameter max. ^a	Seal chamber bore ^b	Gland stud circle	Outside gland rabbet ^c	Total length min. ^d	Clear length min. ^d	Stud size	
	d_1	d_2	d_3	d_4	l	l_1	SI	(USC)
1	20,00 (0,787)	70,00 (2,756)	105 (4,13)	85,00 (3,346)	150 (5,90)	100 (3,94)	M12 × 1,75	1/2"-13
2	30,00 (1,181)	80,00 (3,150)	115 (4,53)	95,00 (3,740)	155 (6,10)	100 (3,94)	M12 × 1,75	1/2"-13
3	40,00 (1,575)	90,00 (3,543)	125 (4,92)	105,00 (4,134)	160 (6,30)	100 (3,94)	M12 × 1,75	1/2"-13
4	50,00 (1,968)	100,00 (3,937)	140 (5,51)	115,00 (4,528)	165 (6,50)	110 (4,33)	M16 × 2,0	5/8"-11
5	60,00 (2,362)	120,00 (4,724)	160 (6,30)	135,00 (5,315)	170 (6,69)	110 (4,33)	M16 × 2,0	5/8"-11
6	70,00 (2,756)	130,00 (5,118)	170 (6,69)	145,00 (5,709)	175 (6,89)	110 (4,33)	M16 × 2,0	5/8"-11
7	80,00 (3,150)	140,00 (5,512)	180 (7,09)	155,00 (6,102)	180 (7,09)	110 (4,33)	M16 × 2,0	5/8"-11
8	90,00 (3,543)	160,00 (6,299)	205 (8,07)	175,00 (6,890)	185 (7,28)	120 (4,72)	M20 × 2,5	3/4"-10
9	100,00 (3,937)	170,00 (6,693)	215 (8,46)	185,00 (7,283)	190 (7,48)	120 (4,72)	M20 × 2,5	3/4"-10
10	110,00 (4,331)	180,00 (7,087)	225 (8,86)	195,00 (7,677)	195 (7,68)	120 (4,72)	M20 × 2,5	3/4"-10
^a Dimensions to Tolerance Class h6. ^b Dimensions to Tolerance Class H7; for axially split pumps, an additional tolerance of $\pm 75 \mu\text{m}$ (0,003 in) to allow for gasket thickness. ^c Dimensions to Tolerance Class f7. ^d Shaft deflection criteria (5.6.9) may require (l) and (l_1) dimensions on size 1 and size 2 seal chambers to be reduced below the minimum values listed, depending on specific pump construction and casing design.								

5.8.4 Provisions shall be made to centre the seal gland and/or chamber with either an inside or outside diameter register fit. The register fit surface shall be concentric to the shaft and shall have a total indicated runout of not more than 125 μm (0,005 in). Using the seal gland bolts to centre mechanical seal components is not acceptable (see Annex K).

5.8.5 Seal chamber face runout (TIR) shall not exceed 0,5 $\mu\text{m}/\text{mm}$ (0,000 5 in/in) of seal chamber bore (see Annex K).

5.8.6 Specified seal and pump connections shall be identified by symbols permanently marked into the component (such as stamped, cast, or chemically etched). Symbols shall be in accordance with those specified in ISO 21049.

5.8.7 Seal glands and seal chambers shall have provision for only those connections required by the seal flush plan. If additional tapped connection points are specified and are not used, they shall be plugged in accordance with 5.4.3.7.

5.8.8 Provision shall be made to ensure complete venting of the seal chamber.

- **5.8.9** If specified, jackets shall be provided on seal chambers for heating. Heating requirements shall be agreed upon by the purchaser, vendor, and seal manufacturer for high melting point products.

5.8.10 Mechanical seals and glands for all pumps, except vertically-suspended pumps shipped without drivers mounted, shall be installed in the pump before shipment and shall be clean and ready for initial service. If seals require final adjustment or installation in the field, the vendor shall attach a metal tag warning of this requirement.

5.8.11 The mating joint between the seal gland and the seal chamber face shall incorporate a confined gasket to prevent blowout. The gasket shall be of the controlled compression type, for example an O-ring or a spiral-wound gasket, with a metal-to-metal joint contact. If space or design limitations make this requirement impractical, an alternative seal gland design shall be submitted to the purchaser for approval.

5.9 Dynamics

5.9.1 General

The topics of critical speed and lateral analysis are covered in the subclause dealing with each specific pump type.

5.9.2 Torsional analysis

5.9.2.1 Unless otherwise specified, a torsional analysis shall be performed by the manufacturer having unit responsibility if the driver is one of the following:

- a) electric motor, or turbine, through gear rated 1 500 kW (2 000 hp) or higher;
- b) internal combustion engine rated 250 kW (335 hp) or higher;
- c) synchronous motor rated 500 kW (670 hp) or higher;
- d) electric motor with variable-frequency drive (VFD) rated 1 000 kW (1 350 hp) or higher.

The analysis shall be for the train as a whole unless the train includes a device that has weak dynamic coupling, for example a hydraulic coupling or torque converter.

5.9.2.2 For the corresponding list item in 5.9.2.1, excitation at the following frequencies shall be evaluated:

- a) train with gear(s): $1 \times r/\text{min}$ and $2 \times r/\text{min}$ of either shaft;
- b) engine drive: $n \times r/\text{min}$;
- c) synchronous motor: $n \times \text{slip frequency}$, $1 \times \text{line frequency}$ and $2 \times \text{line frequency}$;
- d) variable-frequency drive: $n \times r/\text{min}$, $1 \times \text{line frequency}$ and $2 \times \text{line frequency}$

where

r/min is the rotor speed, expressed in revolutions per minute;

n is an integer determined by the drive manufacturer;

— for engines: derived from the number of power strokes per revolution;

— for motors: derived from the number of poles.

The excitation frequencies for motor drives, items c) and d), include transient and steady-state conditions.

5.9.2.3 The torsional natural frequencies of the complete train shall be at least 10 % above or 10 % below any possible excitation frequency within the specified range of operating speeds (from minimum to maximum continuous speed).

5.9.2.4 If torsional resonances are calculated to fall within the margin specified in 5.9.2.3 (and the purchaser and the vendor have agreed that all efforts to remove the resonance from within the limiting frequency range have been exhausted), a stress analysis shall be performed to demonstrate that the

resonances have no adverse effect on the complete train. The assumptions made in this analysis regarding the magnitude of excitation and the degree of damping shall be clearly stated. The acceptance criteria for this analysis shall be agreed upon by the purchaser and the vendor.

5.9.2.5 If a torsional analysis is performed, a Campbell diagram shall be furnished to the purchaser for information only.

- **5.9.2.6** If specified, the manufacturer shall furnish a detailed report of the torsional analysis. The report shall include the following:

- a) description of the method used to calculate the natural frequencies;
- b) diagram of the mass elastic system;
- c) table of the mass moment and torsional stiffness of each element of the mass elastic system;
- d) Campbell diagram;
- e) mode-shape diagram with peak stresses shown for each resonant frequency, if a stress analysis is performed.

5.9.3 Vibration

5.9.3.1 Centrifugal pump vibration varies with flow, usually being a minimum in the vicinity of best efficiency point flow and increasing as flow is increased or decreased. The change in vibration as flow is varied from best efficiency point 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.

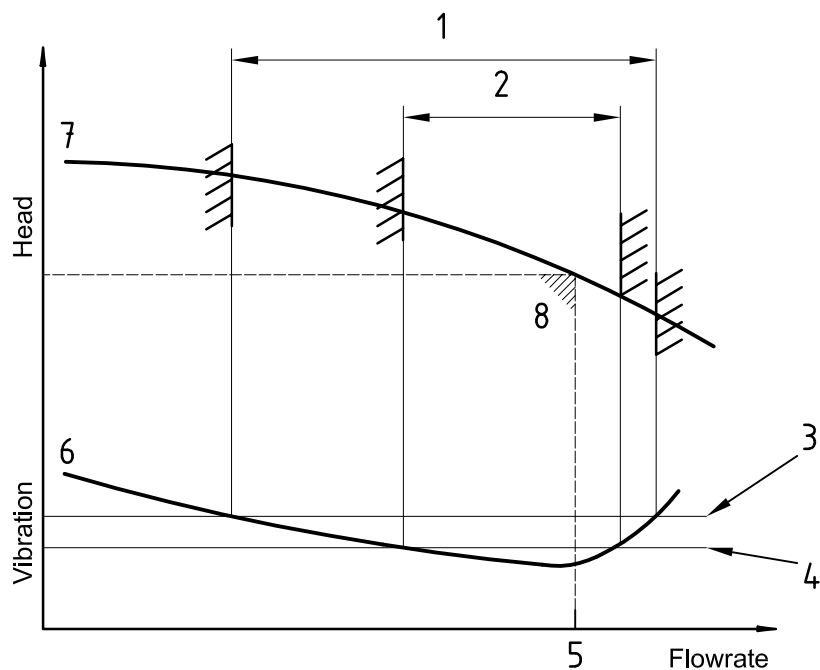
With these general characteristics, a centrifugal pump's operating flow range can be divided into two regions, one termed the best efficiency or preferred operating region, over which the pump exhibits low vibration, the other termed the allowable operating region, with its limits defined as those capacities at which the pump's vibration reaches a higher but still "acceptable" level. Figure 26 illustrates the concept. Factors other than vibration, for example, temperature rise with decreasing flow or NPSHR with increasing flow, may dictate a narrower allowable operating region. See also 5.1.14.

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.

5.9.3.2 During the performance test, overall vibration measurements over a range of 5 Hz to 1 000 Hz and a Fast Fourier Transform (FFT) spectrum shall be made at each test point except shutoff. The vibration measurements shall be made at the following locations:

- a) on the bearing housing(s) or equivalent location(s) of all pumps, at the positions shown on Figure 27 and Figure 28;
 - b) on the shaft of pumps with hydrodynamic bearings with proximity probes, if the pump has provisions for proximity probes.
- **5.9.3.3** 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; in multistage pumps with different impellers, Z is the highest number of impeller vanes in any stage). If specified the plotted spectra shall be included with the pump test results.

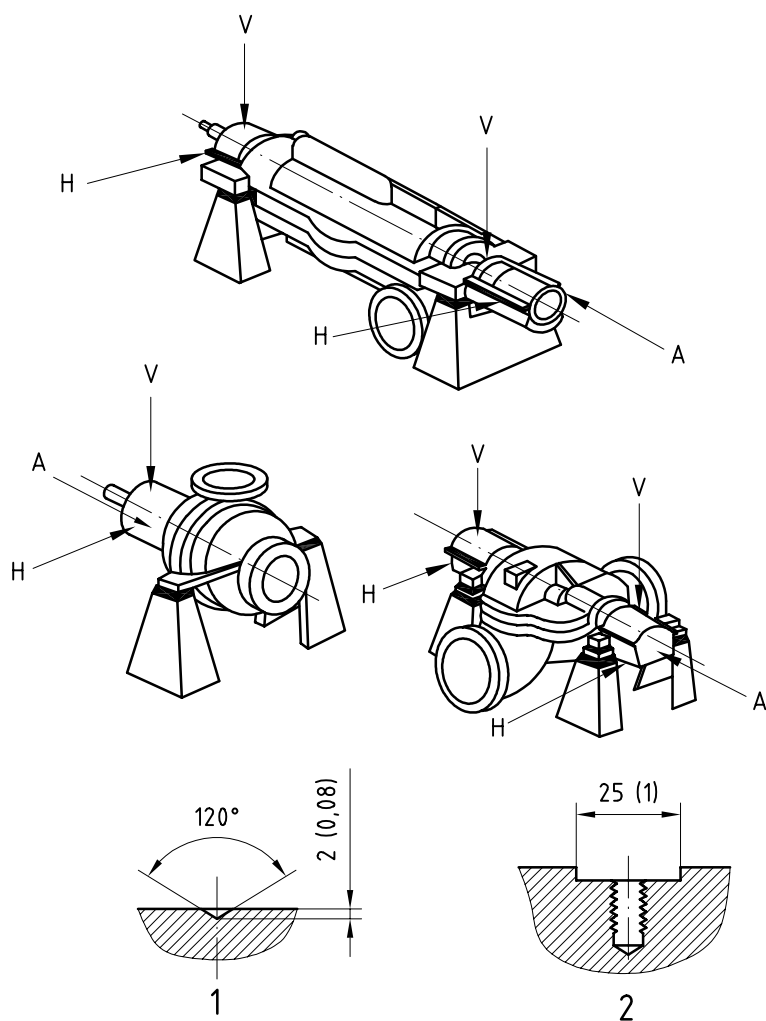
NOTE The discrete frequencies 1,0, 2,0, and Z times running speed are associated with various pump phenomena, and are therefore of particular interest in the spectra.

**Key**

- 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 26 — Relationship between flow and vibration

Dimensions in millimetres (inches)



Key

- 1 dimple (see 5.10.2.10)
- 2 optional arrangement for mounting vibration-measuring equipment (see 5.10.2.11)
- A axial
- H horizontal
- V vertical

Figure 27 — Locations for taking vibration readings on horizontal pumps