

Recommended Practice for Subsea Pump Module Systems

API RECOMMENDED PRACTICE 17X
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Introduction

API RP 17X. relies on the principles of API Std 610 and API Std 676. The intent of this recommended practice (RP) is to provide requirements, recommendations and guidance for the specification, design, construction, transportation, installation, maintenance, operation of subsea pumps. It is intended to be applied in conjunction with the API 17 suite of documents. This RP is not intended to inhibit a manufacturer from offering innovative solutions for pumping or engineering solutions for the individual applications.

Recommended Practice for Subsea Pump Module Systems

1 Scope

This RP provides guidance for the design, manufacture, installation, and operation of subsea pumps, including rotary displacement and rotor dynamic types for single phase, and multi-phase services. The RP applies to all subsea pump modules placed at or above the mud line.

API RP 17X describes subsea pump modules that are either directly designed or “marinized” for use in an offshore/marine environment. Potential applications include:

- Offshore use near subsea wells to boost production and enhance oil recovery (EOR) from partially depleted oil fields, or:
- To boost flowline pressures to flow at higher rates or greater distances or when flowing subsea wells up to a surface facility.

The design of such system solutions requires additional equipment to power, control and otherwise operate the pumps. These are not within the scope of this document and can be found in API Std 17F, API Std 17G, API 17Z, and other relevant standards for these and associated equipment on the host facility or site.

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, except that new editions may be used on issue and shall become mandatory upon the effective date specified by the publisher or six months from the date of the revision (where no effective date is specified).

API Specification 6A, *Specification for Wellhead and Tree Equipment*

API Recommended Practice 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment, Second Edition, May 2011, Addendum 1, September 2015*

API Standard 17F, *Standard for Subsea Production Control Systems*

API Recommended Practice 17H, *Recommended Practice for Remotely Operated Tools and Interfaces on Subsea Production Systems*

API Recommended Practice 17P, *Design and Operation of Subsea Production Systems—Subsea Structures and Manifolds*

API Recommended Practice 17V, *Recommended Practice for Analysis, Design, Installation, and Testing of Safety Systems for Subsea Applications*

API Specification 20E, *Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries*

API Specification 20F, *Corrosion-resistant Bolting for Use in the Petroleum and Natural Gas Industries*

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

API Standard 546, *Brushless Synchronous Machines— 500kVA and Larger*

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

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

API Standard 676, *Positive Displacement Pumps—Rotary, Third Edition, November 2009*

API Standard 684, *API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Tensionals, and Rotor Balancing*

HI 9.6.7 ¹, *Rotodynamic Pumps—Guideline for Effects of Liquid Viscosity on Performance*

IEC 60085 ², *Electrical insulation—Thermal evaluation and designation*

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

IEC/IEEE 61886-1, *Subsea equipment—Power connectors, penetrators and jumper assemblies with rated voltage from 3 kV ($U_{\max} = 3,6 \text{ kV}$) to 30 kV ($U_{\max} = 36 \text{ kV}$)*

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

ISO 21940-11:2016 ³, *Mechanical vibration – Rotor balancing – Part 11: Procedures and tolerances for rotors with rigid behaviour*

NEMA MG 1-2014 ⁴, *Motors and Generators*

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

allowable operating envelope

Portion of a pump's hydraulic coverage over which the pump can operate, based on vibration within the upper limit of this RP or temperature rise or other limitation.

3.1.2

application specific testing

Process by which a complete manufactured system (or sub-system) is tested against the original qualification criteria and application specific objectives.

3.1.3

adjustable speed drive

ASD

Electronic equipment used to regulate the operating speed of the motor and driven equipment by controlling the frequency and voltage.

NOTE Other terms commonly used are variable speed drive (VSD), frequency converter, adjustable frequency drive (AFD), and variable frequency drive (VFD).

¹ Hydraulic Institute, 6 Campus Drive, First Floor North, Parsippany, New Jersey 07054, pumps.org.

² International Electrotechnical Commission, 3, rue de Varembe, Case postale 131, CH-1211, Geneva, Switzerland, www.iec.org.

³ International Organisation for Standardization, Chemin de Blandonnet 8, CP 401-1214, Geneva, Switzerland, www.iso.org.

⁴ National Electrical Manufacturers Association, 1300 North 17th Street Suite 900, Arlington, Virginia 22209, www.nema.org.

3.1.4**average gas volume fraction****GVF**

Time averaged ratio of gas volume to that of the total volume of the fluid (oil, water, and gas) at pump suction temperature and pressure expressed as a percentage.

3.1.5**average water-cut****WC**

Time averaged (over longer periods of time: hours or longer) ratio of the water volume to total liquid volume at pump suction.

NOTE The ratio being expressed as a percentage.

3.1.6**breakaway torque**

Torque level required to overcome static friction of the pump system when starting the motor.

3.1.7**breakdown torque**

The maximum torque that a motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed.

3.1.8**closure bolting**

Bolting used to assemble or join pressure-containing parts, including end and outlet connections.

NOTE Examples of closure bolting include flange bolting, bonnet bolting, end connection bolting, and hub clamp bolting.

3.1.9**design life**

Planned usage time for the pump module.

NOTE Design life differs from mean time to failure in that it includes repair and retrieval of the pump module for maintenance. A pump rotor can have a shorter design life than the pressure casing or the module frame.

3.1.10**instantaneous gas volume fraction****GVFi**

Instantaneous ratio of gas volume to total volume of the fluid (oil, water, and gas) at pump suction temperature and pressure, the fraction being expressed as a percentage with a value over shorter periods of time (less than one minute).

NOTE 1 GVFi represents the variability in GVF where the long-term average value of GVFi corresponds to the expected steady-state value, GVF.

NOTE 2 GVFi can vary between 0 and 100 %.

3.1.11**instantaneous water-cut****WCI**

Instantaneous ratio of water volume to total liquid volume of the fluid (oil and water) at pump suction, the fraction being expressed as a percentage with the value over shorter periods of time (less than one minute).

NOTE The ratio being expressed as a percentage.

3.1.12**multi-phase pump**

Pump capable of continuous operation for GVF's greater than 5 % and less than 95 %.

3.1.13**multi-phase impeller**

Pump impeller design for multi-phase flow.

3.1.14**multistage pump**

Any pump that has more than a single pressure development stage.

3.1.15**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.

3.1.16**pressure casing**

Pressure-containing parts of the pump and/or motor assembly.

3.1.17**rapid gas decompression**

Failure mode in gas permeable materials (e.g. elastomers, polymers) caused by rapid pressure reduction. Damage (e.g. rupture, blisters, deformation) is caused by the associated rapid expansion of in gases, which have permeated the materials. Also known as an "explosive decompression".

3.1.18**rated operating point**

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

3.1.19**rated speed**

Highest pump speed (revolutions per minute) of any of the operating conditions and at which rated power is developed.

3.1.20**rotor dynamic pump**

Pump that uses rotating centrifugal and/or multiphase impellers to continuously impart energy to the pumped fluid.

3.1.21**running time**

The elapsed continuous time when an item is in active operating state.

NOTE "Running time" is the active part of the operating time (excluding downtime). Standby time (of any kind) is not included. Running time can also be defined in terms of hours when it is referred to as running hours.

3.1.22**settle-out pressure**

Equilibrium pressure throughout the multi-phase pump loop when the pump is tripped/stopped.

3.1.23**single-phase pump**

Pump designed for continuous operation at $GVF \leq 10\%$.

3.1.24**surge**

Instability that occurs in a rotodynamic compressor or multi-phase pump at low volumetric flow.

3.1.25**utility bolting**

All bolting that is used to mount equipment and accessories to the pump and ancillary equipment that is not closure bolting, pressure retaining, or pressure controlling.

NOTE Examples include bolting on lifting eyes, pad eyes (non-welded), nameplate, clamps for tubing, and guards.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

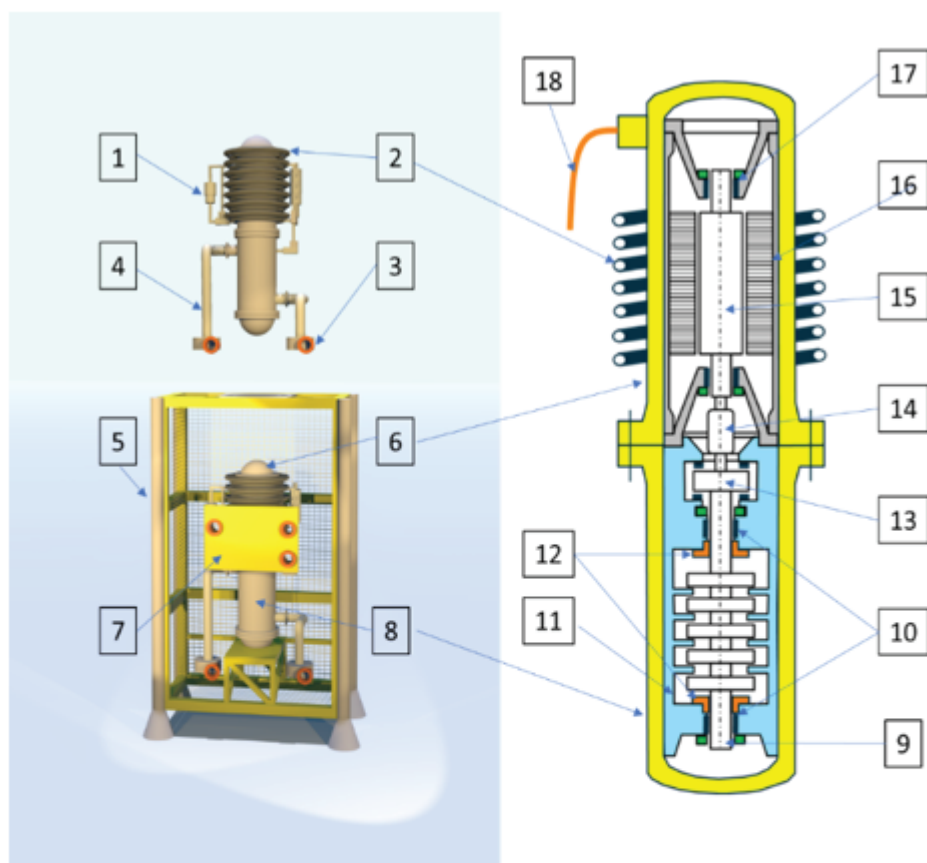
A	amplitude of vibration
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BF	barrier fluid
BSL	bolting specification level
CFD	computational fluid dynamics
CRA	corrosion resistant alloy
DNVGL	Det Norske Veritas Germanische Lloyds (also known as DNV)
DOL	direct online
EFAT	extended factory acceptance test
EMF	electromagnetic field
EPR	ethylene propylene rubber
ESD	emergency shutdown
FAT	factory acceptance test
FFT	fast Fourier transform
FSL	forging specification level
HI	Hydraulics Institute
HPU	hydraulic power unit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
MAWP	maximum allowable working pressure
MPP	multi-phase pump
MRB	manufacturing record book
MSDS	material safety data sheet
NEMA	National Electrical Manufacturers Association

NORSOK	Norsk Sokkel Konkuranseposisjon
NPSH	net positive suction head
P&ID	process and instrumentation diagram
PSD	process shutdown
PSL	product specification level
RMS	root mean square
ROV	remotely operated vehicle
RP	recommended practice
SCM	subsea control module
SEM	subsea electronics module
SEPS	Subsea Electrical Power Standardization
SI	Système International (d'unites)
SRT	site receipt test
TRL	technology readiness level
UNS	unified numbering system
USC	United States customary units
VFD	variable frequency drive (see ASD in 3.1.3)
VSD	variable speed drive (see ASD in 3.1.3)
XLPE	crosslinked polyethylene

4 System Design Requirements

4.1 System Configuration

Figure 1 provides an overview of the subsea pump system covered by this document. The labelled items are directly covered in this document.



Key

- | | |
|----------------------------------|-------------------------|
| 1 Barrier Fluid System | 11 Pump Diffuser/Stator |
| 2 Motor Cooler | 12 Shaft Seals |
| 3 Connectors | 13 Thrust Bearings |
| 4 Piping | 14 Couplings |
| 5 Frame | 15 Motor Rotor |
| 6 Motor Pressure Casing | 16 Motor Stator |
| 7 ROV and Control Interfaces | 17 Motor Bearings |
| 8 Pump Pressure Casing | 18 Penetrator |
| 9 Pump Rotor and Shaft | |
| 10 Bearings and Proximity Probes | |

Figure 1—Subsea Pump System Classification and Designation

The pumps described in this RP are classified and designated by the type codes, as shown in Table 1 and are further described in API Std 610 and API Std 676.

Table 1—Pump Classification Type Identification

Subsea Pump Type	Working Principle
Rotary Displacement	Vane
	Lobe
	Gear
	Multi-Screw
Rotor dynamic	Centrifugal
	Multi-phase Impeller
	Combined Centrifugal and Multi-phase Impeller

4.2 General Design Requirements

The general design requirements are as follows:

- a) Equipment, including all auxiliaries, shall be designed, and selected for subsea installation and the specified site environmental conditions as specified in the Pump Design Data Sheets (Annex A).
- b) Materials for the pump module internal components shall be compatible with the specified production fluid, seawater, and chemicals in accordance with the Pump Design Data Sheets (Annex A).
- c) External materials shall be compatible with seawater and the cathodic protection system.
- d) External coatings and insulation shall be compatible with internal production fluids, chemicals, seawater, and the cathodic protection systems in accordance with the Pump Design Data Sheets (Annex A).
- e) The motor power rating (as a function of speed for ASD driven motors) shall include a margin of 10 % to the pump power for all specified operating conditions.
- f) The motor shall have a maximum continuous speed of at least 105 % of the rated speed.
- g) The pump system shall be capable of starting from the specified cold restart conditions.
- h) The pump system shall be capable of starting after a specified long-term standstill.
- i) The pump system shall be capable of operating within the entire operating region for single-phase or operating envelope for multi-phase, at all specified operating conditions.
- j) The pump system shall tolerate transient conditions during start-up, shutdown, emergency shut down and power failure.
- k) For single-phase flow, the calculated preferred operating region shall be identified in accordance with API Std 610. For multi-phase flow, the preferred operating envelope shall be described in the Pump Design Data Sheets (Annex A).

NOTE 1 The key parameters of the operating envelope are minimum speed, maximum speed, surge, choke, and maximum power.

NOTE 2 A separate operating envelope is typically identified for each set of specified inlet operating conditions (GVF, suction pressure, fluid composition).

- l) The pump envelope should extend 5 % past the lowest and highest specified operating conditions for the following parameters at the specified GVFs:

- differential pressure (or head),
- flow.

- m) The required design life of the equipment shall be as specified in the datasheets in Annex A.
- n) Performance objectives and/or requirements (such as technical availability or reliability) shall be stated in the datasheets in Annex A. The pump system shall be designed and manufactured to meet the specified performance objectives (e.g. availability, reliability).
- o) Erosion and abrasion analyses within the pump should be performed using validated functions to describe particle behavior.

NOTE Currently, CFD based methods provide the most appropriate basis for the analysis.

- p) Multi-phase pump systems shall tolerate or mitigate occasional upset operation at 100 % GVFi at the pump inlet.

NOTE 1 Unstable flow regimes, gas-filled well start-up conditions or gas-filled pump conditions are to be expected.

NOTE 2 Mechanical seals can experience significant temperature and pressure deviations when operating near 100 % GVFi.

- q) The design processes shall conform to the requirements of API RP Q1.
- r) The safety system shall conform to the requirements of API RP 17V.
- s) A recycle control system shall be designed for use during startup and to protect the pump against unstable flow regimes.

NOTE The recycle line is often designed to have a continuous flow as a method to prevent hydrate formation and other solids accumulation in the line.

4.2.1 Viscosity Correction

Viscosity corrections shall be determined using computational fluid dynamics analyses or test data.

Centrifugal pumps that are designed for single-phase fluids, more viscous than water, may have their water performance corrected per ISO 17766 or HI 9.6.7.

Correction factors applied to both hydraulic performance and axial thrust used for single-phase liquids more viscous than water shall be provided and included with the pump curves.

Pump system shall be designed for the specified fluid data (e.g. viscosity changes resulting from temperature change, phase transitions, wax gelation and emulsions, and non-Newtonian behavior).

Fluid property dependent testing shall be performed as specified in a Pump Design Data Sheets (see Annex A).

For multistage pumps, performance predictions shall include interstage heating (including slippage).

NOTE Interstage heating can significantly impact performance for high viscosity fluids.

4.2.2 Pump Performance Curves

At the rated point, the head/flowrate curve (s) shall show a gradient of

$$\left(\frac{Q_{rated}}{P_{rated}} \right) \frac{\partial P}{\partial Q} < -0.05 \quad (1)$$

where

P is absolute pressure at rated point

Q is flow rate at rated point

For single-phase applications, the NPSH margin in conformance to API Std 610 shall be chosen to satisfy a 40,000-hour life of the first stage impeller.

The pump performance curves should include the following:

- 1) The preferred operating range.
- 2) The NPSH3 curve.

Pump performance curves shall indicate the following operating limitations:

- a) Surge and choke limits with regards to speeds, (multi-phase pumps).
- b) GVF values and limits (multi-phase pumps).
- c) Suction pressure limits.
- d) Flowrate limits.
- e) Minimum flow (both thermal and steady-state) for continuous operation (single-phase pumps).
- f) Safe operation limits including the necessary separation margins.
- g) Preferred operating region (single-phase pumps) or preferred operating envelope (multi-phase pumps).

4.2.3 Motor/Pump System Performance

The motor power penetrators, subsea power jumper assemblies, and wet-mate connectors shall be designed in accordance with IEC/IEEE 61886-1.

NOTE 1 The addition of significant power loads (and potentially the addition of electric actuation) has been shown to potentially provide additional electrical influences and thus, affect corrosion potentials. This can impact cathodic protection systems or influence control equipment.

The motor shall conform to the Harmonic Voltage Factor (HVF) tolerance requirements of IEC 60034-1.

The motor shall conform to the Total Harmonic Distortion (THD) requirements of IEC 60034-1.

ASD harmonic modes which are in resonance with any motor excitation frequency, may be allowed if they can be proven to be well damped

NOTE 2 ASD harmonic profile can change during the life of motor operation due to firmware update, addition of sine filter, harmonic correction algorithm, etc.

NOTE 3 ASDs with ground faults can cause negative and zero sequence current to flow due to unbalance voltage and current. This can cause overheating and failure.

4.3 Rotor Dynamic Analysis

- For pump/motor system using rigid couplings connecting the motor and pump shaft, rotor dynamic analyses shall be performed for the combined motor and pump rotor in accordance with API Std 610 Annex I for model input, methods, and result evaluation.
- For pump/motor systems using non-rigid couplings between the pump and the motor, the pump and motor shall be analyzed separately.
- The analysis of the pump unit shall follow API Std 610 Annex I.
- The motor unit shall be analyzed using methods in API Std 541, API Std 610, and API RP 684.
- A torsional analysis shall be performed as per the methods described in API Std 610.
- Half coupling mass and its respective center of gravity shall be included in the lateral analysis in conformance to the methods in API Std 610.
- The effect of motor liquids in the motor rotor-stator gap shall be included in the rotor-dynamic analyses.
- The eccentricity in the rotor-stator gap shall be included in the rotor-dynamic analyses.
- Evaluation and acceptance criteria applicable to the specific pump shall conform to the requirements of this document and shall be included in the Pump Design Data Sheets (see Annex A).

A lateral critical speed analysis throughout the operating speed range of the machine is required and shall include:

- 1) Damped natural frequencies and damping ratios.
- 2) Shaft vibration predictions from unbalance response analysis for the unbalance distributions that excite different rotor mode shapes.
- 3) Shaft displacements shall be reported at critical locations including bearing, seals, and locations with small radial clearances.
- 4) Stiffness and other rotor dynamic properties of balance devices.

Magnetic coupling effects on rotor dynamics shall be included in the pump rotor-dynamic analyses.

Unbalanced response analyses shall conform to API Std 610.

4.3.1 Pump Module Interfaces

The pump module interfaces are described in Table 2.

NOTE The hydrate inhibitor supply interface is typically used for displacement prior to pump module retrieval, pressure equalization while pump is not operating, and preservation during shutdown and/or prior to restart.

Table 2—Pump Module Interfaces

Interface	Description
Process	Inlet and outlet process connections for the pump.
Mechanical	Supporting structures and guidance/installation aids.

Table 2—Pump Module Interfaces (Continued)

Interface	Description
Pump Power	Jumpers connecting the pump motor to the subsea power distribution equipment. Indirectly (via the control system) the ASD (for ASD driven systems)
Controls	Jumpers routing electrical signals from the pump module sensors to the subsea control module (SCM). Can also be used to actuate electrically operated barrier fluid valves and/or supply power, to flowmeters located on the pump module.
Hydraulic Fluid	Jumpers supplying hydraulic fluid to hydraulically operated valve actuators located on the pump module (gate valves, chemical injection valves, chokes, etc.).
Barrier Fluid	Jumpers supplying barrier fluid to the pump motor (if required). Can also include an ROV sampling interface used to check fluid cleanliness.
Chemicals	Jumpers supplying chemicals to the pump module (primarily hydrate inhibitors).

5 Component Design Requirements

5.1 Pressure Casing

The casing and pressure-retaining parts and structural supports shall be designed to operate without external leakage or internal contact between rotating and stationary components while subject to the worst combination of the following operating conditions and variables:

- Temperature
- Pressure (including hydrostatic test pressure)
- Torque
- GVF
- Densities
- Dynamic surge loads
- Viscosities
- Seismic loads
- External forces and moments. Pressure containing casings and forgings should be designed according to ASME Section VIII Division 2.

NOTE The motor and pump pressure casing can be bolted together container to form a single pressure envelope.

Threaded holes for test ports, drainage and venting may be allowed for use during the assembly and test period.

The rated pressures and temperatures for the system shall be as specified in the Pump Design Data Sheets in Annex A.

Valves and flanges shall be in accordance with API Spec 6A and use the applicable pressure and temperature ratings.

The choice of rated temperature should reflect the classes listed in Table 7.

5.2 Static Seals

Primary seals between production fluids and the environment shall be metal-to-metal.

Secondary seals may be elastomeric.

Seal materials shall be compatible with all specified services.

Elastomeric seal materials should conform to either ISO 23936-2 or Norsok M-710.

In pumps where gas is present (multi-phase pumps), all polymer seals exposed to production fluids shall be of rapid gas decompression (RGD) resistant materials.

Internal sealing clearances between the casing and internal pump parts shall include the thermal expansion differences between the casing and pump internals.

NOTE Because of high heat transfer rates to the surrounding seawater, subsea pump casings will be exposed to large, transient thermal gradients between internal and external conditions. Thermal expansion between the pump casing, internal parts, and other interfaces can result in sealing issues, and stresses.

5.3 Clearances and Wear

Mating wear surfaces shall have a difference in Brinell hardness number of at least 50 unless both materials have Brinell hardness numbers of above 400.

Renewable wear rings shall be held in place by a press fit with locking pins, screws (axial or radial) or by tack welding.

Renewable wear rings shall be provided in the pump casing.

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.

Internal running clearances and tolerances shall be evaluated over the full range of the operating envelope.

5.4 Pump Bearings

Bearings shall be designed for all specified operating points including normal start-ups and planned and unplanned shutdowns.

Thrust bearings shall be sized for continuous operation under all specified conditions, including maximum differential pressure.

- a) All loads shall be calculated at 1x design internal clearances and at 2x design internal clearances.
- b) Thrust forces for flexible metal-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.
- c) The thrust bearing duty shall include internal gear reactions.
- d) The axial forces transmitted through any flexible couplings shall be included as a part of the duty of any thrust bearing.
- e) Thrust forces for flexible metal-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

- f) The bearings shall be designed for the specified viscosities of operation across the pump operating range and expected modes of operation including start-up after long-term stoppage.

5.5 Rotor Balancing

The pump rotor shall be capable of being dynamically balanced according to the requirements in API Std 610 or API Std 676 if rotary positive displacement.

A dynamic balance grade of ISO 21940-11 G2.5 or better shall be achieved for the pump rotor assembly (independent of the motor).

A dynamic balance grade of ISO 21940-11 G1.0 or better shall be achieved for individual components of the pump rotor assembly.

NOTE The absence of liquid in a multi-phase pump reduces the amount of stiffness and dampening present in the rotor dynamic system. To compensate, a high dynamic balance grade for the rotor provides improved rotor-dynamic performance when operating on high GVF.

5.6 Thrust Management

The thrust management system shall include an evaluation of the effects of varying fluid rheologies and their impact on the system behavior.

Mechanical clearances of thrust balance devices should follow the same principles as the other pump wear parts.

Wear resistance strategies shall be used to mitigate abrasion and erosion if sand or other abrasives are specified.

5.7 Mechanical Shaft Seals

Mechanical shaft seals shall not be the primary barrier between the process fluid and the subsea environment.

NOTE 1 Mechanical shaft seals are the primary barrier between the process fluid and the motor/bearing sections

The static pressure rating of the mechanical seal gland between the barrier and process fluids shall be defined in the pump datasheets (see Annex A).

The mechanical seal rotating sleeve shall be mechanically locked in both circumferential and axial directions.

NOTE 2 Hydraulically locking in one axial direction is acceptable if the net axial force on the seal is present (or maintained) throughout all operating conditions.

The mechanical seal shall be pressure-balanced and designed for bidirectional rotation.

Limitations of the seal on reverse rotation of the pump shall be provided.

An analysis of transient cases, including resulting barrier fluid system responses, shall be included in mechanical seal selection criteria (See Annex A).

The maximum mechanical seal leakage at the specified operating conditions shall be stated in the data sheets (see Annex A) and final documentation.

NOTE 3 This information is used to determine the size of the barrier fluid system pump.

Mechanical seals shall be qualified at the following conditions:

- a) at minimum and maximum differential pressures,