Recommended Practice for Subsea Pump Module Systems

API RECOMMENDED PRACTICE 17X
FIRST EDITION, XXXX2020

BALLOT DRAFT NOVEMBER 2020

American
Petroleum
Institute

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be used. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Washington, DC 20001.

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

Contents

1 Scope ... 7
2 Normative References ... 7
3 Definitions, and Abbreviations ... 8
3.1 Definitions ... 8
3.2 Acronyms, Abbreviations, Symbols, and Units ... 13

4 System Design Requirements ... 15
4.1 System Configuration ... 15
4.2 General Design Requirements ... 16
4.3 Rotor Dynamics Analysis ... 20

5 Component Design Requirements ... 22
5.1 Pressure Casing ... 22
5.2 Static Seals ... 22
5.3 Clearances and Wear ... 23
5.4 Pump Bearings ... 23
5.5 Rotor Balancing ... 24
5.6 Thrust Management ... 24
5.7 Mechanical Shaft Seals ... 24
5.8 Motor Design ... 25
5.9 Shaft Couplings ... 28
5.10 Pump Control Systems ... 29
5.11 Motor Instrumentation ... 30
5.12 Pump Module Requirements ... 30

6 Materials and Welding ... 32
6.1 Process Wetted Materials ... 32
6.2 Pump Module Structure and Piping ... 33
6.3 Pump and Motor Casing Specifications ... 33

7 Marking and Manufacturing Documentation ... 34
7.1 Manufacturing Documentation ... 34
7.2 Marking ... 34

8 Qualification and Testing ... 37
8.1 Qualification Testing ... 37
8.2 Pump Performance Testing ... 40
8.3 Factory Acceptance Testing ... 44
8.4 Site Receival Testing ... 46
8.5 System Integration Testing ... 46

9 Transportation and Preservation ... 47
9.1 General ... 47
9.2 Lifting Arrangements ... 47
9.3 Preservation ... 47

10 Installation and Intervention ... 49
10.1 General ... 49
10.2 Design Requirements for Retrieval ... 49

11 Reliability, Operations and Maintenance ... 49

11.1 Reliability and Maintenance Data 49
11.2 Module Operations and Maintenance 50
11.3 Module Retrieval 50

Annex A........ 51
Pump Design Data Sheets Minimum Requirements 51
Annex B........ 13
Qualification Testing........ 13
Annex C........ 20
Application Specific Testing 20
Annex D........ 26
Pump Manufacturing Data Check List and Schedule 26
Bibliography 39

List of Figures:

Figure 1—Subsea Pump System Classification and Designation 15
Figure 2—Vibration Limits for GVF < 40% in a Rotodynamic Pump with Hydrodynamic Bearings 41
Figure 3—Vibration Limits for GVF > 40% in a Rotodynamic Pump with Hydrodynamic Bearings 42
Figure 4—Illustration of Recommended Placement for Proximity Probes During Testing 43

List of Tables:

Table 1—Pump Classification Type Identification 16
Table 2—Pump module interfaces 21
Table 3—Insulation Thermal Classes used for Subsea Motors 27
Table 4—Bolting Requirement 33
Table 5—Classification by Installation Depth 35
Table 6—Classification by Sea Water Temperature 35
Table 7—Classification by Process Fluid Temperature 35
Table 8—Casing Rated Pressure Class 35
Table 9—Pre-accepted Configuration Changes 38
Table 10—Scope of Test Object 38

Introduction

This RP is the first edition of API 17X. The document relies on the principles of API 610 and API 676. The intent of this recommended practice is to provide requirements, recommendations and guidance for the specification, design, construction, transportation, installation, maintenance, operation of subsea pumps. It ~~should~~ 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.

1 Scope

This recommended practice provides guidance for the design, manufacture, installation and operation of subsea pumps, including rotary displacement and rotodynamic types for single phase, and multi-phase services. The recommended practice 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 a 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 17F, API 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 ~~Christmas~~ Tree Equipment.*

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

API Standard 610, *Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries, Eleventh Edition, September 2010, Errata July 2011*

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

ASTM D1418 - 10a(2016)[1], *Standard Practice for Rubber and Rubber Latices—Nomenclature*

HI[2] 9.6.7 *Rotodynamic Pumps - Guideline for Effects of Liquid Viscosity on Performance*

IEC 60085[3], *Electrical insulation - Thermal evaluation and designation*

IEC 60034, *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 (Umax = 3,6 kV) to 30 kV (Umax = 36 kV)*

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

~~ISO 1940-1:2003[4] *Mechanical vibration – Balance quality requirements for rotors in a constant (rigid) state – Part 1: Specification and verification of balance tolerances*~~

ISO 21940-11:2016[5] *ISO 21940-1:2003 Mechanical vibration – Balance quality requirements for rotors in a constant (rigid) state – Part 1: Specification and verification of balance tolerances*

NEMA MG 1-2014[6]*, Motors and Generators*

3 Definitions, and Abbreviations

3.1 Definitions

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

3.1.1

allowable operating envelope

[1] American Society for Testing and Materials, 100 Barr Harbor Dr., P.O. Box C700, West Conshocken, PA, 19428-2959 USA, www.astm.org

[2] Hydraulic Institute, 6 Campus Drive, First Floor North, Parsippany, NJ 07054, USA, pumps.org

[3] International Electrotechnical Commission, 3, rue de Varembé, Case postale 131, CH-1211, Geneva, Switzerland, www.iec.org.

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

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

[5] National Electrical Manufacturers Association, 1300 North 17th St. Ste 900, Arlington VA 22209, USA, www.nema.org

Portion of a pump's hydraulic coverage over which the pump can operate, based on vibration within the upper limit of this recommended practice 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

~~NOTE Application-specific performance maps may be generated~~

3.1.3

adjustable speed drive
ASD
~~An electronic~~ 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)~~, however, use of these terms is discouraged~~.

3.1.3\b
average gas volume fraction
GVF
~~Time averaged (over longer periods of time: hours or longer) ratio of gas volume to that of the total volume of the fluid (oil, water, and gas) at pump suction temperature and pressure, the fraction being expressed as a percentage of pump suction volume~~

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.

~~NOTE: GVF represents the long-term (hours or longer) average value of GVFi and corresponds to the expected steady-state value.~~

3.1.4

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.

3.1.5

breakaway torque

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

3.1.6

breakdown torque

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

3.1.7

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.

3.1.8

~~**Dead-head start-up**~~
~~Start-up of the pump with blocked or closed discharge.~~

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 ~~may~~ can have a shorter design life than the pressure casing or the module frame.

3.1.10

~~**forging specification level**~~
~~**FSL**~~
~~A method for determining testing and documentation levels~~

3.1.11

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 ~~may~~ can, ~~because of multi-phase flow behavior, hold-up, transient operations, and start-up and shut-down effects,~~ vary between 0 and 100%.

3.1.12

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.

3.1.13

multi-phase pump
Pump capable of continuous operation for ~~between~~ GVFs ~~>~~greater than ~~-~~5% and ~~<~~ less than 95%

3.1.14

multi-phase impeller
Pump impeller design for multi-phase flow ~~typically helical rotors~~

3.1.15

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

3.1.16

net positive suction head required
NPSH3
~~Net positive suction head~~ NPSH that results in a 3 % loss of head (first-stage head in a multistage pump) determined by the vendor by testing with water

3.1.17

~~**preferred operating envelope**~~
~~Optimum The range of parameters in which operations will result in ideal, continuous equipment performance~~

~~The range of operating parameters over which the pump's vibration is within the base limit of this Standard."~~

~~NOTE: Applies to multi-phase pumps.~~

3.1.18

pressure casing
~~Pressure and liquid containing vessels which encapsulate the pump and motor~~

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

3.1.19

rapid gas decompression

~~Failure mode in elastomeric (and polymeric) materials caused by rapid pressure reductions and the rapid expansion resulting from the dissolution of low molecular weight gases (such as CO_2, H_2S, and other molecules) which have penetrated permeable materials.~~

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 a "explosive decompression".

3.1.20

rated operating point
~~Point at which the pump performance will be certified as falling within the tolerances~~ Point at which the vendor certifies that pump performance is within the tolerances stated in this document.

3.1.21

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

3.1.22

rotodynamic pump
Pump that uses rotating centrifugal and/or ~~helicoaxial~~ multiphase impellers to continuously impart energy to the pumped fluid

3.1.23

running time
The elapsed continuous time when an item is in active operating state
NOTE: ~~Runing~~ "Running time" is the active part of the operating time (excluding downtime). Standby time (of any kind) is not included. Running time ~~may~~ can also be defined in terms of hours when it is referred to as running hours.

3.1.24

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

3.1.25

single-phase pump
Pump designed for continuous operation at GVF≤ 10%

3.1.26

surge
~~Compressor term for a condition defining minimum stable flowrate at given tip speed and head which is characterized by vibration, performance and/or efficiency losses~~ Instability that occurs in a rotodynamic compressor or multi-phase pump at low volumetric flow.

3.1.27

utility bolting
All bolting that is ~~required~~ 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, Abbreviations, Symbols, and Units

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
~~ASD~~	~~adjustable speed drive~~
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
~~BEP~~	~~best efficiency point~~
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
~~GVF~~	~~[average] gas volume fraction~~
~~GVFi~~	~~instantaneous gas volume fraction~~
HI	Hydraulics Institute
HPU	hydraulic power unit
IEC	International Electrotechnical Commission

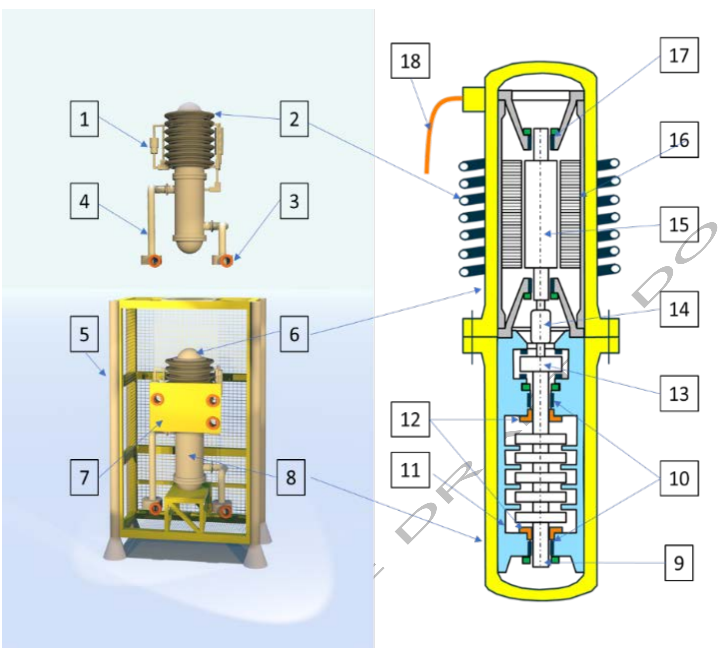
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
MAWP	maximum allowable working pressure
MPP	multi-phase pump
MRB	manufacturing record book
MSDS	material safety data sheet
NEMA	National Electrical Manufacturers Association
NORSOK	Norsk Sokkel Konkuranseposisjon
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	Systeme 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 section 3.1.3)
VSD	variable speed drive (see ASD in section 3.1.3)
~~WC~~	~~[average] water-cut~~
~~WCi~~	~~instantaneous water-cut~~

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~~. Other portions of Figure 1 are included for reference. Reference is also made to API 610, API 674, API 675, API 676, and API 685 for the various components that may be incorporated into subsea pump systems.~~



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

Figure 1—Subsea Pump System Classification and Designation

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

Table 1—Pump Classification Type Identification

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

4.2 General Design Requirements

~~The design of the equipment~~ pump module ~~shall ensure the following:~~

a) Equipment, including all auxiliaries, shall be designed ~~or~~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 ~~operating~~ continuous speed of at least 105% of the rated speed.

g) The pump shall be designed to tolerate any transient condition including emergency shut down and power failure.

h) The pump system shall be capable of starting from the specified cold restart conditions.

i) The pump system shall be capable of starting after a specified long-term standstill.

j) The ~~equipment~~ pump system shall be capable of operating within the entire ~~performance map~~ operating region for single-phase or operating envelope for multi-phase, at all specified operating conditions.~~, including~~ ~~such as~~ ~~conditions such as momentary surge, settle-out, trip, and start-up.~~

k) The pump system shall tolerate transient conditions during startup, shutdown emergency shut down and power failure.

l) For single-phase flow, the calculated preferred operating ~~envelope~~ region shall be identified in accordance with API 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 ~~required~~ identified for each set of specified inlet operating conditions (GVF, suction pressure, fluid composition).

m) 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.

n) The required ~~service~~ design life of the equipment shall be as specified in the datasheets in Annex A.

o) 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).

p) Erosion and abrasion analyses within the pump should be performed using ~~CFD based on~~ validated functions to describe particle behavior.

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

~~q) The fundamental sizing and rating criteria shall be derived from inputs as listed in 11.1.~~

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

~~Valve closing times, pumps shutdown times and other data necessary for surge analyses (water hammer) shall be provided.~~

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.

The design processes shall ~~meet~~ conform to the requirements of API Q1.

The safety system shall conform to the requirements of API 17V.

~~A recycle control system should be implemented as protection against unstable flow regimes, for pump operation at minimum flow conditions and as a provision for start-up.~~ A recycle control system shall be designed for use during startup and to protect the pump against unstable flow regimes.

NOTE 3 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.

~~NOTE~~ 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 used for viscous single-phase liquids should be provided or included with the pump curves~~

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.

~~Fluid data related to fluid viscosity changes resulting from temperature change, phase transitions, wax gelation and emulsions, and non-Newtonian behavior shall be provided in a pump datasheet (see Annex A).~~

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 ~~tests~~ shall be performed as specified in a Pump Design Data Sheets (see Annex A).

~~For multistage pumps, performance predictions should include interstage heating (including slippage) which can significantly impact performance for high viscosity fluids.~~

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

$$\cancel{\left|\frac{\partial P}{\partial Q}\left(\frac{Q}{P}\right)\right| > 0.25} \quad \left(\frac{Q_{rated}}{P_{rated}}\right)\frac{\partial P}{\partial Q} < -0.05$$

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 610 shall not be less than 1.5 meters (4.6 ft.) of liquid for all operating points within the preferred operating region.~~ For single-phase applications, the NPSH margin in conformance to API 610 shall be chosen to satisfy a 40,000hr life of the first stage impeller.

The pump performance curves should include the following:

- The preferred operating range
- The NPSH3 curve.

~~NOTE 1: For single phase applications, due to the changing process conditions and rates at subsea pump inlets, it may can be difficult to maintain the pumps operation within the preferred operating region of 70% to 120% as described in API 610, Section 6.~~

~~NOTE 2: For multi-phase applications, NPSHA, NPSH3 and NPSH margin and associated API 610 requirements are not relevant when GVF is greater than zero.~~

Pump performance curves shall indicate the following operating limitations ~~such as~~:

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 regions~~s~~ (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) ~~may~~ has been shown to potentially provide additional electrical influences ~~which may,~~ and thus, affect corrosion potentials. This ~~may~~ 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.

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

~~NOTE 2 With respect to ASD harmonics,~~ 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 ~~3~~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 ~~4~~3 ~~If ASDs are required to work with a ground fault, then the effect of the unbalance voltage and current can cause negative and zero sequence current to flow. It can cause overheating on the rotor shaft and can cause failure.~~

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

~~The following shall apply:~~

a) 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 610 Annex I for model input, methods and result evaluation.

b) For pump/motor systems using non-rigid couplings between the pump and the motor, the pump and motor shall be analyzed separately.

c) The analysis of the pump unit shall follow API 610 Annex I.

d) The motor unit shall be analyzed using methods in API 541, API 610, API 684.

e) A torsional analysis shall be performed as per the methods described in API 610.

~~NOTE: A stress analysis will likely be required as subsea control systems seldom include methods for limiting or blocking frequencies in pumps which are controlled by ASDs.~~

~~f) Appropriate vibration acceptance criteria shall be specified in the Pump Design Data Sheets (see Annex A)~~

g) Half coupling mass and its respective center of gravity shall be included in the lateral analysis in conformance to the methods in API 610.

h) The effect of motor liquids in the motor rotor-stator gap shall be included in the rotordynamic analyses.

i) The eccentricity in the rotor-stator gap shall be included in the rotordynamic analyses.

~~j) Evaluation and acceptance criteria shall be defined in the Pump Design Data Sheets (see Annex A)~~

k) Evaluation and acceptance criteria applicable to the specific pump shall:

- conform to the requirements of this document

- 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. ~~Where an unbalanced response analysis is required, the methodology of API 610 shall apply.~~

3) Shaft displacements shall be reported at critical locations including bearing, seals, and locations with small radial clearances

4) Stiffness and other rotodynamic properties of balance devices

~~5) The effect of a magnetic coupling on rotor dynamics shall be included in the pump rotordynamic analyses~~

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

Unbalanced response analyses shall conform to API 610.

4.3.1 Pump Module Interfaces

The pump module interfaces are described in Table 2.

Table 2—Pump module interfaces

Interface	Description
Process	Inlet and outlet process connections for the pump.
Mechanical	Supporting structures and guidance / installation aids.
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). ~~May~~ 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). ~~May~~ Can also include an ROV sampling interface used to check fluid cleanliness.
Chemicals	Jumpers supplying chemicals to the pump module (primarily ~~methanol~~hydrate inhibitors).

NOTE : The ~~methanol~~ hydrate inhibitor supply interface is important as they are typically used for:

- Preservation during shutdown and/or prior to restart.
- Displacement prior to pump module retrieval.
- Pressure equalization while pump is not operating

~~For adjustable speed electric motor starting (ASD start), the The start-up procedures for ASD driven motors (e.g. maximum acceleration / deceleration rate, and idlingminimum speed, waiting time between start attempts, etc.) shall be provided.~~

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 ~~to prevent detrimental distortion caused by~~ the worst combination of the following operating conditions and variables:

- Temperature~~,~~
- Pressure (including hydrostatic test pressure)~~,~~
- Torque~~,~~
- GVF
- Densities
- Dynamic ~~Surge~~ surge loads
- Viscosities
- Seismic loads
- External forces and moments. Pressure containing casings and forgings should be designed according to ASME Section VIII div2.

NOTE ~~1~~ The motor and pump pressure casing can be bolted together ~~as one single pressure~~ container to form a single pressure envelope.

~~NOTE 2~~ 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.

~~The choice of rated pressure should reflect the requirement in API 6A that all valves and flanges on connected equipment are designed to one of the lettered pressure classes in Table 8.~~ Valves and flanges shall be in accordance with API 6A and use the applicable pressure and temperature ratings.

~~Similarly, the~~ 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~~ rapid gas decompression (RGD) resistant materials.

~~The design of internal~~ 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 ~~and comply with the following.~~

l) All loads shall be calculated at 1x design internal clearances and at 2x design internal clearances.

m) Thrust forces for flexible metal-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

n) The thrust bearing duty shall include internal gear reactions.

o) The axial forces transmitted through any flexible couplings shall be included as a part of the duty of any thrust bearing.

p) Thrust forces for flexible metal-element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

q) 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 610 or API 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 rotodynamic system. To compensate, a high dynamic balance grade for the rotor ~~will ensure improved rotodynamic performance and higher GVF~~ provides improved rotordynamic performance when operating on high GVF.

5.6 Thrust Management

~~The design of the~~ 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 such as hard coatings, to mitigate sand production erosion are allowed for balance devices.~~

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 only be used to isolate the process fluid containing sections of the pump module against the motor/bearing section, and not be used as primary barriers between the process fluid containing portions of the pump body and the subsea environment.~~

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 ~~1~~ 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 2 This information ~~will be~~ is used to determine the size of the barrier fluid system pump.

Mechanical seals shall be ~~separately~~ qualified at the following conditions:

a) at minimum and maximum differential pressures,

b) for transient conditions such as emergency shut-down or reverse pressure

c) using the appropriate fluids (liquids and gases) at the process side.

d) at minimum and maximum speed.

All tests to be performed dynamically (with the test seal under rotation).

5.8 Motor Design

Motor rotors shall be dynamically balanced in a minimum of two planes.

The stator lamination pack shall be compressed to avoid vibration between the individual laminations.

1) All metal parts that can come into contact with windings shall have smooth surfaces and be deburred with defined radii on corners.

2) All significant natural frequencies of the stator housing and laminations shall (throughout the motor operation range with a margin of 15%) be outside the range of the following:

– rotor bar passing frequency,

– rotor magnet excitation frequency

– slot harmonics

5.8.1 Induction Motors

Induction motors shall be designed according to API 541.

5.8.1.1 Performance and Torque

~~Induction motors shall be designed according to API 541 and the following additional requirements.~~

a) For ASD driven motors, the performance requirements shall be met throughout the frequency range and match the characteristics of the specified drive-system.

b) For single speed motors, the minimum breakdown torque shall be no less than 160% of the rated torque.

c) For DOL-started motors the minimum locked rotor torque (cold-start conditions) with 80% of the rated voltage shall be a minimum 1.1 times the pump unit breakaway torque (stiction torque) for all pump conditions.

d) For ASD-started motors the starting voltage and frequency shall be selected so that the minimum locked rotor torque shall be a minimum 1.1 times the pump unit breakaway torque (stiction torque) for all pump conditions.

e) Harmonic torques shall be included if the load torque safety margin differs from specified in API 541.

5.8.1.2 Winding and Current Management Requirements

a) The stator winding may be either form-wound or fully insulated cables

b) Due to the variations in temperature between the start-up condition and maximum operating temperatures, the effect of variations in rotor resistance shall be included in system evaluations.

c) For adjustable speed electric motor starting (ASD start), the start-up procedure (e.g. maximum acceleration rate and idling speed, waiting time between start attempts~~, etc.~~) shall be provided

d) For ASD driven or started induction motors with rolling element bearings, current through the bearings shall be interrupted or diverted in accordance with NEMA MG 1-2014. This bearing electrical bypass shall be verified during the motor FAT.

The maximum continuous peak winding temperature for the worse case operating conditions shall not exceed the maximum hotspot winding temperature in Table 3.

NOTE The worst case operating conditions for winding is typically the rated torque and speed with +/- 10 % voltage variation from the rated voltage or in the field weakening region

The maximum continuous operation temperature of the winding should not exceed the value for one class below ~~(or a minimum of 20 ºC below)~~ the thermal class of the insulation system to ensure durability of the insulation. For class Y systems, the maximum hotspot winding temperature of the winding should not exceed 80ºC.

Table 3—Insulation Thermal Classes used for Subsea Motors

Thermal class (IEC60085)	Previous letter designation	Maximum hotspot winding temperature
90	Y	90 ºC (194 ºF)
105	A	105 ºC (221 ºF)
120	E	120 ºC (248 ºF)
130	B	130 ºC (266 ºF)
155	F	155 ºC (311 ºF)
180	H	180 ºC (356 ºF)

Thermal analysis of the motor windings shall be performed, using validated models and the expected loads for the operating and test data points, to define the thermal class and to determine optimum locations for temperature sensors within the windings.

FEP, XLPE or EPR may be ~~added as an acceptable~~ accepted as a cable insulation material.

5.8.2 Permanent Magnet Motors

Permanent magnet motors shall be designed per API 546

5.8.2.1 Performance and Torque

~~Permanent magnet motors shall be designed per API 546 and the following shall apply.~~

a) For ASD driven motors, the performance requirements shall be met throughout the frequency range and match the characteristics of the specified drive-system.

b) At the defined starting frequency and maximum 25% of the rated current, the minimum locked rotor torque (cold start conditions) should be minimum 1.1 times the pump unit breakaway torque (stiction torque) for all pump conditions.

5.8.2.2 Winding and Current Management Requirements

Due to the variations in temperature between the cold condition and maximum operating temperatures, the effect of variations on the de-magnetization, the rotor magnet shall be included in system evaluations.

Thermal class requirements and other thermal requirements are as per 5.8.1.

For liquid-filled motors:

— The rotor/stator gap shall be optimized to achieve good balance between overall efficiency, motor thermal, electrical and mechanical performance including rotordynamic stability.

~~Motor rotors shall be dynamically balanced in a minimum of two planes.~~

~~The stator lamination pack shall be compressed to avoid vibration between the individual laminations.~~

3) All metal parts that can come into contact with windings shall have smooth surfaces and be deburred with defined radii on corners.

4) All significant natural frequencies of the stator housing and laminations shall (throughout the motor operation range with a margin of 15%) be outside the range of the following:

- rotor bar passing frequency,
- rotor magnet excitation frequency
- slot harmonics

5.8.3 Motor Cooling Systems

The motor cooling system shall be sized and designed to dissipate remove heat from all electrical and mechanical sources ~~in the motor~~ in the pump module (not just the motor itself).

Cooler design shall include:

- Fouling factors on the internal and external surfaces
- The impact of potential cooler bypass flow (e.g. through a filter path).

5.9 Shaft Couplings

5.9.1 Mechanical Couplings

Mechanical couplings shall be as per API 610, API 671 ~~and, if relevant for the design,~~ or API 676.

5.9.2 Magnetic Couplings

~~Magnetic couplings are used to transfer the motor shaft torque to the pump shaft without physical contact between the two shafts.~~ When magnetic couplings are used, the membrane or gap cup between the motor and pump sides of the coupling ~~should~~ shall be designed for the same pressure rating as the pump pressure casing.

NOTE: Magnetic couplings are used to transfer the motor shaft torque to the pump shaft without physical contact between the two shafts.

Magnetic couplings shall ~~be designed and tested per~~ conform to API 685. The magnetic coupler external design pressure shall at least be equal to the pump casing internal design pressure. The magnetic coupling external design pressure shall be at least equal to the motor casing internal design pressure.

5.9.3 Torque Couplings ~~Speed Control~~

A means shall be provided to dissipate heat generated in the coupling during all phases of pump operation, including unusual conditions such as back driving the pump.

A means shall be provided to indicate and/or notify the supervisory control system of a loss of connection between the motor and pump.

For magnetic torque coupled speed control a means shall be provided to contain and/or mitigate eddy currents during all phases of pump operation.

For magnetic torque coupled speed control a means shall be provided to assure that there is no detrimental electromagnetic interference (EMI) in any circuits within the pump, motor or control circuitry.

For hydraulic torque coupled speed control a means shall be provided to assure safe operation and controlled stop in the event of a control system failure.

The overall operating speed envelope for the torque couplings (minimum to maximum speeds) shall be provided.

5.10 Pump Control Systems

5.10.1 General

The control systems for control, protection and monitoring systems of subsea pumps shall be designed in accordance requirements provided by API 17F.

5.10.2 Pump Control System Functional Requirements

The pump control system shall:

a) supply (or control) electric and/or hydraulic power

b) provide communication with the pump system

c) control and monitoring of pump system

d) provide for chemical injection

e) ensure safe operation

f) include provisions for recording and storing data

g) provide for individual or multiple operation of all remotely controlled subsea pumps

At minimum, the pump control system shall provide a means to measure the following pump operating parameters:

1) Power Consumption of the pump motor

2) Number of hours the pump has run

3) Suction and discharge pressure

4) Suction and discharge temperatures

5) ~~t~~The consumption of barrier fluid (if relevant for design)

6) Coolant temperatures (at cooler inlet and outlet)

7) Motor pressure, if relevant~~,~~

8) Operating speeds

9) Vibration

Vibration sensors, such as accelerometers, key phasor and/or proximity probes shall be supplied, installed, and tested as specified in the datasheets in Annex A in addition to the requirements provided by API 17F.

All sensors shall be placed at locations chosen to ensure reliable operation (output data quality and operating life) for all conditions expected during system operation.

5.11 Motor Instrumentation

~~Winding temperature sensors should be evaluated as per the requirements in API 541.~~

A method for measuring and monitoring hotspots and winding temperatures shall be documented and provided upon request. ~~For cable wound motors, in lieu of winding temperature detectors, temperatures can be inferred from operating conditions.~~ Confirmation of analytic temperature calculated in the windings shall be obtained during qualification-testing.

A method for measuring and monitoring motor performance shall be documented and provided upon request. The methods may include:

- Temperature
- Pressure
- Current

5.12 Pump Module Requirements

5.12.1 General

Connectors, piping, structural elements, valves and auxiliaries in the module and supporting structures shall be designed and manufactured in accordance with the requirements described by API SPEC 17D, API RP 17F, API RP 17H, API RP 17P, API RP 17R, and API RP 17S.

Valve closing times, pump shutdown times and other data necessary for surge analyses (water hammer) shall be provided in the datasheets (see Annex A).

The following shall be documented in a vibration analysis report:

a) A description of the analyzed model, the methods and assumptions made during the analysis,

b) The calculated natural vibration frequencies from 0 Hz and up to minimum 150 % of maximum continuous speed (frequency) and including plots showing their corresponding mode shapes.

c) The response analysis shall include both displacement (mm) and ~~vibration~~ velocity (mm/s) caused by a unit load (for instance 1000 N) on each pump and motor bearing locations.

d) The response analysis shall be run continuously from 0 Hz up to minimum 150 % of maximum continuous speed, delta frequency shall not exceed (1 Hz). API 17P provides guidance on structural design for the calculated vibration data.

NOTE To avoid resonances between the natural frequencies of the Pump Module, Support Structure, and the operational frequency of the unit, it is ~~very~~ advantageous to have the first natural frequencies of the structure well below the operational frequencies to make the unit “mass dependent.” Subsea pump units typically contain sufficient mass in the motor and pump casing to avoid inappropriate vibration responses.

5.12.2 Pump Module and Infrastructure Rated Pressure

Piping contained in shall be designed according to the requirements of API 17P.

~~The following items should be included in the pipe design:~~Piping shall be suitable for:

a) maximum shut-in/settle out pressure in the system

b) response times and required pressures from the barrier fluid system

c) potential exposure of the system to pressures resulting from dynamic kills or high- pressure chemical supplies.

d) mitigations to prevent overheating of enclosed volumes (recirculation system)

e) requirements for dead-head operation operation with blocked discharge

~~f) requirements for dead-head start-up~~ start-up against a blocked discharge

g) leakage through mechanical seals

h) the potential combination of maximum inlet pressure in combination with the pump dead-head operating pressure.

NOTE 1: The maximum inlet pressure ~~may be~~ can, be the maximum shut-in tubing pressure for pumps used for production systems or suction pressure on water injection pumps.

NOTE 2: Pressure excursions can be expected to influence the barrier-fluid and other chemical injection systems. Because these events ~~may~~ can occur with some frequency, the use of steady-state design criteria occurs at the risk of pressure-containment. (See NTL 2011 N-11 and 30 CFR § 250 .875)

5.12.3 ~~Recycle Valves~~Minimum Continuous Flow

~~Recycle or surge control valves are part of the pump control system. They are used to ensure operability; they shall be designed and sized to meet the minimum flow requirements of the pump.~~

Valves for controlling a minimum continuous flow shall be included in the pump control system to prevent damage to the pump.

~~The Contractor shall perform a control valve sizing calculation based on IEC 60534-2 or ISA RP75.01.01 as part of the preparation of the requisition. The determination of a control valve flow capacity required for a given flow rate under specified pressure and temperature conditions should be carried out in accordance with IEC 60534-2-1 Part 2-1 and the following as applicable:~~

- IEC 60534-2-4 Part 2-4, or
- IEC 60534-8-3 Part 8-3, or
- IEC 60534-8-4 Part 8-4.

6 Materials ~~and Welding~~

6.1 Process Wetted Materials

Materials for pump internals shall be selected based on the guidance provided in API 17A. with the following aspects considered:

- Produced fluid composition
- Chemical injection for mitigation and remediation
- Erosion potential
- Corrosion potential
- Exposure to well treatment fluids

A materials philosophy document shall be developed based on the information provided in Annex A. The materials philosophy should include the following:

a) A complete equation of state characterization data set including fluid composition and the full component characterizations should be provided including details of the chosen equation of state and any tuning parameters (including values for transport properties).

b) A set of reference data in the form of a phase envelope and matching data from petroleum fluid studies (including viscosity tuning data) should be provided including

- Expected variation in fluid composition over time as well as appropriately matched turndown requirements (flows and temperatures at: minimum condition, expected condition, and maximum conditions).
- Expected production rates of and properties for sand and other solids.
- Expected extremes in temperatures.

— A complete list of production and intervention chemicals (including seawater) to which the pump module ~~may~~ can be exposed during normal operation or installation and retrieval.

6.2 Pump Module Structure and Piping

6.2.1 General

The material requirements for the structure, cathodic protection, piping, tubing and valves and including coatings and welding found on a pump module shall conform to API 17P.

6.2.2 Fasteners

Threaded fasteners shall conform to ~~the requirements~~ one of the two specifications ~~of~~ Table 4.

Table 4—Bolting Requirement

	Material	Specification ~~Options~~	
Pressure-controlling Bolting	Alloy steel and carbon steel	API 20E BSL-2	NORSOK M-001
	Stainless steel and CRA	API 20F BSL-2	NORSOK M-001
Closure Bolting	Alloy steel and carbon steel	API 20E BSL-3	NORSOK M-001
	Stainless steel and CRA	API 20F BSL-3	NORSOK M-001
Pressure-retaining Bolting	Alloy steel and carbon steel	API 20E BSL-3	NORSOK M-001
	Stainless steel and CRA	API 20F BSL-3	NORSOK M-001
Structural Load Bearing Bolting	Alloy steel and carbon steel	API 20E BSL-2	NORSOK M-001
	Stainless steel and CRA	API 20F BSL-2	NORSOK M-001
Utility Bolting	Alloy steel and carbon steel	Mfg. Spec.(1)	Mfg. Spec.(1)
	Stainless steel and CRA	Mfg. Spec.(1)	Mfg. Spec.(1)

NOTE:
(1) Based on manufacturer's written specification

6.3 Pump and Motor Casing Specifications

6.3.1 Specifications and Material Choice

All metallic and non-metallic pressure-containing or pressure-controlling parts shall require a written material specification. Material selection shall be made in accordance with API 17A.

6.3.2 Metallic Material Requirements

Pump and motor casing materials shall meet the requirements of API SPEC 6A PSL 3. The pressure casing shall be treated as a body as described in API SPEC 6A.

API SPEC 20B and API STANDARD 20C ~~for~~ apply for FSL levels 2.

DNVGL-RP-0034 may be used as a purchasing guideline for pressure casing forgings noting further that the items are fatigue sensitive and fall into SFC 3.

Processing methods such as Hot Isostatic Pressing are covered by ISO 17782 and NORSOK M-650 and are subject to the qualification procedures covered by the referenced standards.

7 Marking and Manufacturing Documentation

7.1 Manufacturing Documentation

The manufacturing data to be supplied shall conform with API 610, API 676 or DNVGL-RP_O101.

The manufacturing and engineering documentation process should be that of API Q1 or other internationally recognized quality management system such as ISO 29001.

If specified by purchaser, the information specified in Annex D shall be provided.

7.2 Marking

7.2.1 Pump Nameplates

A nameplate shall be attached at a visible location on the equipment and on major pieces of auxiliary equipment.

Rotation arrows should, where practical, be cast/forged/machined/stamped in or attached to each major item of rotating equipment in a readily visible location.

Nameplates and rotation arrows (if attached) shall be of ~~ANSI Standard Type 300 stainless steel or of nickel-copper alloy such as UNS N04400~~ of a material suitable for the marine environment at the application site. Attachment pins shall be of the same material. Welding shall not be permitted.

The nameplate information shall include:

a) the purchaser’s item number,

b) the vendor’s name,

c) the machine’s serial number,

d) the machine’s type,

e) the machine’s rating data (including pressures, temperatures, speeds, power, and critical speeds)-

f) Units combined with motors shall also include motor power, insulation class, line voltage and frequency ranges as well as torque capacities

g) USC or SI units shall be consistent with units on the datasheet.

Pump units shall be marked in accordance with Table 5, Table 6, Table 7, and Table 8.

Marking shall use low-stress (dot, vibration or rounded V) stamps. Conventional sharp V-stamping shall only be permitted in low-stress areas.

Table 5—Classification by Installation Depth

Depth class	Depth	
A	0 to < 500 meter	0 to < 1640 ft
B	500 to < 1500 meter	1640 to < 4920 ft
C	1500 to < 3000 meter	4920 to < 9840 ft
D	3000 to 5000 meter	9840 ft to 16400 ft

Table 6—Classification by Sea Water Temperature

Temperature class	Temperature Range	
A	-2 ºC to < +10 ºC	+28 ºF to < +50 ºF
B	+10 ºC to < +20 ºC	+50 ºF to < +68 ºF
C	+20 ºC to +30 ºC	+68 ºF to +86 ºF

Table 7—Classification by Process Fluid Temperature

Temperature Classification	Minimum Temperature		Maximum Temperature	
S	-18 °C	0 °F	60 ºC	140 °F
T	-18 °C	0 °F	82 ºC	180 °F
U	-18 °C	0 °F	121 ºC	250 °F
V	2 °C	35 °F	121 ºC	250 °F
W	-18 °C	0 °F	149 ºC	300 °F
X	2 °C	35 °F	149 ºC	300 °F
Y	-18 °C	0 °F	177 ºC	350 °F
Z	2 °C	35 °F	177 ºC	350 °F

Table 8—Casing Rated Pressure Class

Pressure Class	Rated Pressure	
A	138 bara	2,000 psia
B	207 bara	3,000 psia
C	345 bara	5,000 psia
D	690 bara	10,000 psia
E	1035 bara	15,000 psia
F	1380 bara	20,000 psia

7.2.2 Motor Nameplates

Motors connected separately to pumps via torque converters or magnetic couplers shall have the following nameplate data.

1) the item number,

2) the vendor’s name,

3) the machine's serial number,

4) the machine's type,

5) the machine's rating data (including pressures and temperatures, speeds, power, torque capacities and critical speeds)-

6) the machine's insulation class, line voltage and frequency ranges

7) USC or SI units shall be consistent with units on the datasheet.

Motor units shall be marked in accordance with Table 5, Table 6, Table 7, and Table 8.

7.2.3 Valves Markings

Minimum flow valves and actuators shall be treated as chokes and marked as per API 17D. Electric actuators shall be marked with:

a) input voltage

b) input frequency

c) power rating

d) communication protocol

e) motor torque rating

f) motor rotational direction / manual override direction

g) maximum input torque (if equipped with manual override)

h) electrical storage capacity

If mounted separately from the pump and motor, in addition to the marking requirements in API 17D, 17F and 17H, external heat exchangers shall be marked with:

- design duty rating
- design seawater depth
- design seawater temperature
- design seawater current (in velocity units)
- design internal fluid temperature
- primary internal flow direction

8 Qualification and Testing

8.1 Qualification Testing

8.1.1 General

~~Qualification testing is required when the following apply:~~ Qualification testing shall be performed if any of the following apply:

a) new or modified, designs

b) new applications

c) new operating conditions

d) new configurations

e) systems with a TRL below 4 as defined in API 17N and 17Q, or Table I.8 in ISO 20815:2018..

~~Qualification tests are required to meet at least TRL 4, as defined in API 17N and 17Q, or Table I.8 in ISO 20815:2018.~~

Qualification testing results shall include the following data:

1) Power

2) Flowrate

3) Head or differential pressure

4) Rotational Speed

5) Maximum pressure

6) Maximum operating temperature

7) Orientation

8) Water Depth

9) GVF tolerance (range and variation)

10) Change in barrier fluid composition

11) Barrier fluid consumption rate, pressures, and temperatures (if relevant for design)

12) Static and dynamic mechanical shaft sealing pressures (if relevant for design)

Table 9 provides guidance for design changes and their influence on qualification status. Changes not discussed in Table 9 should be reviewed using the methods described in 17N and 17Q.

Table 9—Pre-accepted Configuration Changes

Nr	Change	Rationale
1	Motor-penetrator pairing	Covered by IEC/IEEE 61886-1
2[1]	Power umbilical step-out	Qualification by analysis, Qualified simulation models exist
3[1]	BF umbilical step-out	Qualification by analysis subject to model validation
4	Change in BF composition	Qualification by compatibility testing and component testing (sub-assemblies such as seal assemblies, bearings, and motor insulation).
5	Changes in hydraulic stack	Hydraulic and rotor dynamic analysis (using a validated model, ie one verified by testing).
~~NOTES:~~ ~~1 - Umbilical mechanical qualification testing may still be required~~		

Umbilical mechanical qualification testing may still be required

8.1.2 Qualification Test Scope

The qualification tests are described in further detail in Annex B.

Qualification tests shall include:

a) Start-up and Shutdown

b) Normal Performance Operation

c) Liquid Slugging

d) Extended Performance and Operation

e) Break-away Torque

8.1.3 Test infrastructure

The system to be tested ~~should~~ shall include a minimum level of system components as described in Table 10. When use of full-scale components is not feasible, components may be simulated. Components from the larger system may be required for some tests on the pump and motor. For example, an umbilical can be simulated using an umbilical simulator.

An assessment of the Technology Readiness Level of the proposed solution ~~should~~shall be performed at the module level and at the system level. This evaluation can be to determine the required qualification scope.

Table 10—Scope of Test Object

Test Component	Qualification	Application Specific Test
Power Distribution and Communications:		
Subsea power interface/connectors	Required	Required

Test Component	Qualification	Application Specific Test
Subsea power umbilical [a]	Optional	Emulated
Subsea or topsides transformers [b]	Emulated	If Available
Variable speed drive	Emulated	If Available
SCM or equivalent [c]	If Applicable	If Applicable
Pump Module:		
Pump and motor	Required	Required
Barrier fluid system	If Applicable	If Applicable
Pump sump	If Integrated	If Integrated
Pressurization system [d]	Emulated	Required
Motor/lubricant cooler (s)	Required	Required
Pump Station:		
Buffer tank (for MPP)	For Slug Tests	Required
Liquid extraction unit	If Applicable	If Applicable
Recycle valve	If Applicable	If Applicable
Recycle coolers	If Applicable	If Applicable

FOOTNOTE~~S~~

[a]The power umbilical is an application specific item with the details of the manufacturing solution affecting the design of the emulator.

~~[b]The emulation of the subsea transformer may be based on the use of the topsides equivalent model.~~

~~[c]An SCM may not always be implemented. Alternative solutions may be included as a portion of the qualification/application specific program.~~

~~[d]The dynamics of the solution used for pressurization are application specific. Application specific tests may be performed with an appropriate HPU and relevant umbilical emulation.~~

- The emulation of the subsea transformer may be based on the use of the topsides equivalent model.
- An SCM may not always be implemented. Alternative solutions may be included as a portion of the qualification/application specific program.
- The dynamics of the solution used for pressurization are application specific. Application specific tests may be performed with an appropriate HPU and relevant umbilical emulation.

8.1.4 Post Qualification Test Internal Inspection Data and Criteria

After qualification testing is complete, the pump shall be disassembled and inspected ~~for wear or damage to the following components~~.

a) Visual inspection of the disassembled pump and motor components, including the mechanical seal, radial and thrust bearings Mechanical seal, radial and thrust bearings shall be visual inspected

b) Bearing pad wear ~~should~~ shall be ~~such that the bearing is~~ within original manufacturing tolerances ~~after the test~~

c) Bearing edge wear ~~should~~ shall be ~~recorded using photographs~~ photographed and reviewed.~~:~~ ~~polishing and deburring are acceptable.~~ After inspection bearings may be polished and deburred.

d) If feasible, bearing clearances ~~should~~ shall be reported.

NOTE Dimensional and clearance changes to bearings can be difficult to assess without special instrumentation (if at all feasible).

e) Any deterioration of seal or bearing components shall be reported

f) The dimensions of mechanical seal components shall be measured before and after testing

g) ~~If specified,~~ Microscopic inspection of seal faces and elastomers ~~may~~shall be performed.

~~h) No evidence of debris generation from the pump/motor should be present in the barrier fluid system.~~ Barrier fluid/cooling system shall have no evidence of debris generation from the pump/motor. Filters may be added to the barrier fluid / cooling system during testing to capture debris.

i) ~~Flushing does not necessarily remove all particles from a complex assembly.~~ Care should be taken on inspection of the pump and motor internals to determine if any debris remains. If found, the material should be analyzed to determine if it is a wear product.

NOTE: Flushing does not necessarily remove all particles from a complex assembly

j) Barrier fluid/cooling system shall have no evidence of debris generation from the pump/motor. Filters may be added to the barrier fluid / cooling system during testing to capture debris.

~~NOTE Filters can be added to the barrier fluid / cooling system during testing to capture debris~~

k) Any contamination of the barrier fluid shall be recorded.

l) The torque required to rotate the pump ~~should~~ shall be measured prior to disassembly.

~~Pump disassembly is not required after either factory acceptance or application specific testing.~~ Analysis of operating data is sufficient to confirm that the pump has not been damaged.

~~Suitable images of key~~ Images of the specified or agreed inspection points shall be gathered / taken before and after qualification testing and compared to pre-test condition.

8.2 Pump Performance Testing

8.2.1 Operating Data

The data listed in Annex A shall be monitored and included in the performance test report:

8.2.2 Performance Testing Acceptance Criteria

8.2.2.1 General

Acceptance criteria shall be described in the datasheets (See Annex A) and documented in the test procedure. ~~shall~~ The test acceptance criteria should include performance requirements and tolerances for:

a) Pump and motor power

b) Head / pressure rise and flow rate

c) Barrier fluid (if applicable for the pump design) consumption, control response and process fluid contamination of the barrier fluid

d) Bearing and motor temperatures (measured as specified)

e) Vibration (Pump)

f) Vibration (Motor)

8.2.2.2 Vibration

The vibration measured during the pump performance tests for vertical pumps shall not exceed the values shown in Figure 2 and Figure 3 for rotodynamic pumps with hydrodynamic support bearings operating within their preferred operating envelope.

For horizontal pumps the acceptance criteria shall be subject to agreement between purchaser and vendor. API 610 section 6.9.3 acceptance criteria apply when testing with water.

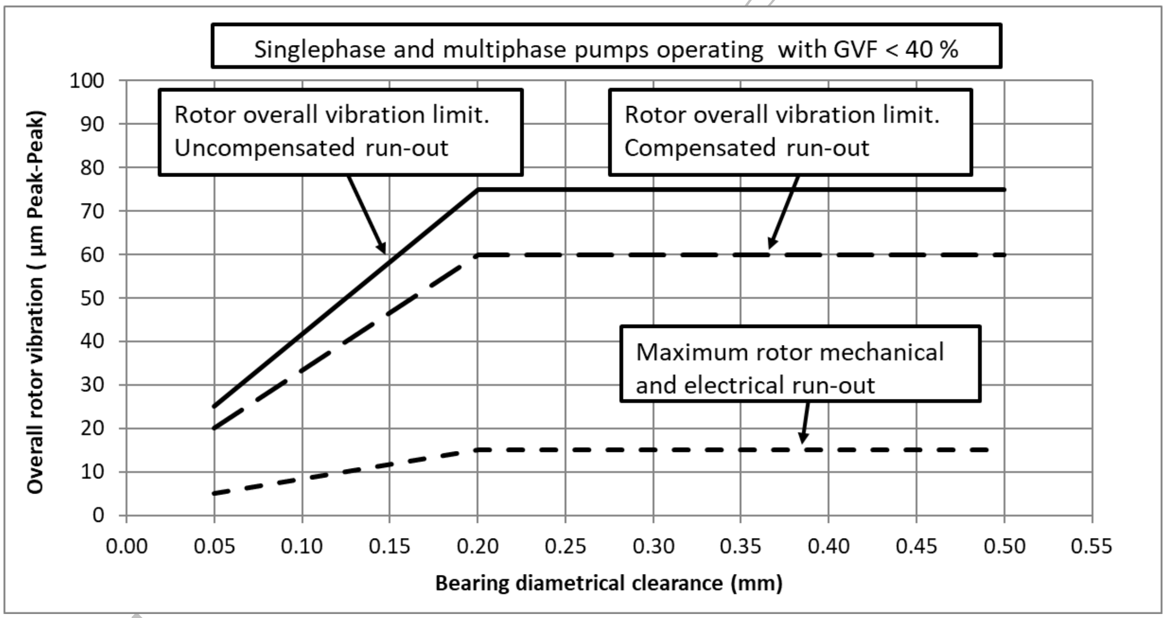


Figure 2—Vibration Limits for GVF < 40% in a Vertical Rotodynamic Pump with Hydrodynamic Bearings

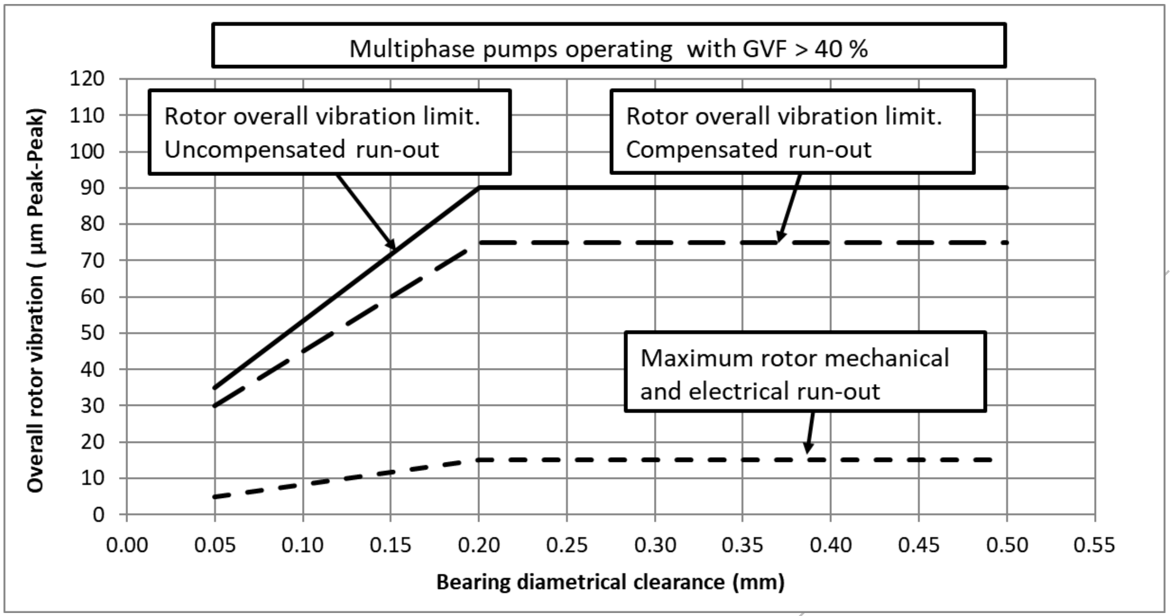


Figure 3—Vibration Limits for GVF > 40% in a Vertical Rotodynamic Pump with Hydrodynamic Bearings

For flexible coupled vertical liquid filled electric motors, the criteria shall be load independent. Overall shaft vibrations peak-peak at bearing locations shall not exceed 50% of the hydrodynamic support bearing diametral clearance.

For discrete frequencies below running frequency the vibration amplitude should not exceed 33% of the overall measured vibration amplitude. Amplitude values in excess of 33% shall be investigated and the effects may be accepted ~~if they are determined to not~~ if they are demonstrated to not be detrimental to pump performance.

For discrete frequencies above running frequency the vibration amplitude should not exceed 33% of the overall measured vibration amplitude. Amplitude values in excess of 33% shall be investigated and the effects may be accepted if they are determined to not be detrimental to neither pump nor motor performance.

~~When operating outside the preferred operating envelope, an increase in overall vibration by 30% is acceptable.~~ Outside the preferred operating envelope, overall vibration may be up to 130% of preferred operating envelope acceptance criteria.

Casing measurements shall be included during the test. Casing vibration sensors shall be located near the bearing housings. The vibration limit for casing vibration shall be 5 mm/s (RMS) for all operating points.

For this purpose, FFT spectra shall be measured using Hann windowing and a minimum frequency resolution of 400 lines.

During the performance test, overall vibration measurements over a range of 5 Hz to 1000 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:

1) on the bearing housing(s) or equivalent location(s) of all pumps, at the positions shown in Figure 4

2) on the shaft of pumps with hydrodynamic bearings and proximity probes.

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

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

NOTE 2: Because casing thicknesses and external dimensions are typically large, the devices are rigid and give significant inertial dampening of internal vibration. As a result, external measurements/results do not always provide true indications of internal vibration. Proximity probes (as applied during qualification testing) are preferred as the primary vibration detection system for subsea pumps.

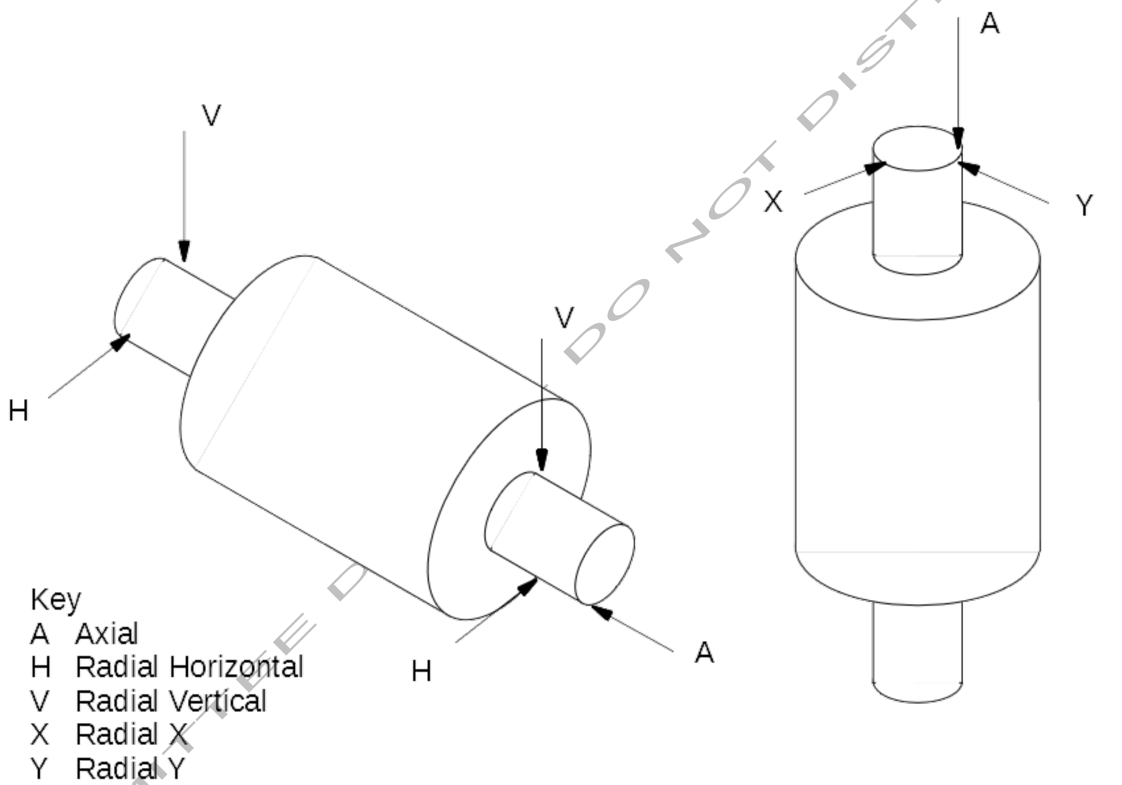


Figure 4—Illustration of Recommended Placement for Proximity Probes During Testing

8.2.2.3 Hydraulic Performance

The primary test should be conducted on water to prove the baseline hydraulic performance.

Where a multi-phase fluid system is used for testing, water and a common, safe immiscible gas such as compressed air or nitrogen should be used. If a hydrocarbon liquid is utilized the gas should be nonflammable.

~~The following acceptance criteria for pump performance on water shall be used~~:

- ~~API 610 section 6.9.3 acceptance criteria apply when testing with water.~~

- For a known suction pressure and GVF, the pressure rise for a given flow rate ~~will~~ shall be achieved within 150rpm of the predicted speed and the shaft power at this pressure rise point ~~will~~ shall be within 10% of the predicted power corresponding to the test condition.

- For rated operating point, suction pressure, GVF, pressure rise, and flow rate the speed shall be within 2% of predicted speed and 10% of the predicted electric power corresponding to the test condition.

NOTE : It is not uncommon to have multiple operating points for a subsea pump, single-phase or multi-phase, thus ~~requiring~~ expanding the pump operation "point" ~~to the pump to work throughout~~ to a range of values. As the pump performance will degrade closer to the extremes of the operating envelope~~.~~, acceptance ~~Acceptance~~ criteria typically drive the identification of the chosen rated operating point. The rated operating point drives the pump hydraulic arrangement, and it is to this point that these acceptance criteria apply.

8.3 Factory Acceptance Testing

8.3.1 General

A comprehensive acceptance test program shall be undertaken at the fabrication site to ensure that components have been manufactured in accordance with requirements. The testing shall be performed to a predefined and approved procedure.

Factory acceptance testing ~~is generally~~ should be conducted as a multi-tiered approach, involving individual component checks, subsystem checks (e.g. control system), interface checks and unitized system checks. Modifications and changes to the equipment during testing and manufacture shall be formally documented.

A typical format for a subsea equipment factory acceptance testi~~ng~~ procedure ~~can~~ should include the following:

a) purpose/objective

b) scope

c) requirements for fixtures/set-ups, facilities, equipment, safety, environment and personnel

d) performance data

e) acceptance criteria

f) reference information

Factory acceptance testing ~~typically covers~~ should include the following items:

1) individual component testing

2) assembly fit and function testing using actual subsea equipment and tools where possible

3) interface checks using actual subsea equipment and tools where possible

4) interchangeability testing

5) hydrostatic testing

6) includes valve seal checks at operating pressure

7) verifies piping code requirements

8) duration according to design code or 1 hour (recommended) if not specified

9) seal testing of end closures.

Unless otherwise specified ~~and per API 6A,~~ pumps ~~should~~ shall not be disassembled after successful completion of ~~passing~~ the final performance test(s).

8.3.2 Performance Testing

Unless otherwise specified, performance tests should be performed using single-phase water at a temperature not exceeding 55 °C (130 °F).

The duration of the test shall be defined in the test procedure and confirmed in ~~indicated on~~ the test report.

Pump and motor bearings shall operate within bearing temperature limits specified by the bearing manufacturer.

If bearing temperature sensors are installed, the bearing metal temperatures shall be recorded at the beginning, during and the end of the test.

If the system utilizes a lubricant or barrier fluid system, fluid temperatures shall be recorded at the beginning, during and at the end of the test.

~~Bearing metal temperatures or relevant lubricant/barrier fluid temperatures shall be recorded at the beginning and the end of the test.~~

If ~~relevant~~ the pump solution implements a barrier fluid or externally sourced lubricant:

a) All barrier fluid or lubricant, properties and temperatures shall be within the range of operating values recommended in the barrier fluid manufacturer's operating instructions for the unit being tested. ~~Maximum/minimum operating temperature during testing shall be communicated and agreed prior to testing.~~

b) Maximum/minimum operating temperatures during testing shall be communicated and agreed prior to testing and included in the test procedure.

c) Fluids from the barrier fluid circuit (if any) ~~should~~ shall be sampled and analyzed for contaminants (either process fluid or particulates) to confirm function and maintenance of overpressure.

Seal leakages above the agreed acceptance criteria shall be investigated, mitigated and shall lead to a rerun of the tests (to demonstrate satisfactory seal performance).

After the test has been completed and after barrier fluid circuit samples have been taken:

1) the pump internals exposed to the pumped fluid ~~should~~ shall be drained to the extent practical and displaced with a fluid which is both ~~suitable~~ intended for preservation and compatible with test and production fluids

2) the barrier fluid circuit ~~should~~ shall be flushed and closed,

Base-line vibration data values shall be recorded during FAT. ~~After deployment, installed base line values should be recorded for reference.~~

NOTE: After deployment, installed base line values can be recorded for reference

Performance data shall be recorded at each test point during testing (except shutoff) as per 8.2.1.

Pump performance curves shall be developed and reported in accordance with API 610. Disassembly of multistage pumps for any head adjustment (including less than 5 % diameter change) after test, shall be cause for retest.

If it is necessary to dismantle a pump for any other correction, such as hydraulic performance~~, NPSH or~~ mechanical operation, the performance test shall be performed again.

8.3.3 Hydraulic Performance

The acceptance criteria for pump performance as described in 8.2.2.3 apply.

8.4 Site Receival Testing

~~After transport and prior to commencement of installation, critical elements of the subsea pumping system should undergo inspection and testing to the extent possible for the purpose of verifying physical condition integrity and functional readiness for installation. Where applicable, the SRT scope may include necessary redressing and/or reconfiguration of equipment to effect the transition from preservation for transport to installation readiness status.~~

After transport and prior to commencement of installation, critical elements of the subsea pumping system shall be inspected and tested to verifying physical integrity and functional readiness for installation.

Any pump system redressing and/or reconfiguration to prepare for SRT shall be part of the SRT scope.

8.5 System Integration Testing

While the total system integration test is outside the scope of this document, the pump module and pump station should be part of the system integration test. The purpose of the test is to simulate all operations that can be done offshore, to the extent practical, and to verify all equipment/systems related to the permanent seabed installations.

A typical scope and guidance for system integration testing can be found in API 17P.

9 Transportation and Preservation

9.1 General

~~The design of transportation or shipping skids shall include limitations in the total height and handling loads of equipment for ease of transportation on land and for loadout to vessels.~~

Transportation and shipping packages shall conform to specified size and weight limitations.

NOTE Purchaser to consider transportation on land and loadout to vessels.

~~Safe transportation of the module of the boosting system shall be considered in the design of the handling and transport procedures. Personnel and equipment safety are paramount and should be documented in the handling instructions~~

Handling and transport procedures shall describe safe transportation all modules. Personnel and equipment safety practices shall be documented in the procedures.

~~The design of test stands and fixtures shall include assembly, transport, tests, and handling.~~ Storage containers and maintenance stands shall facilitate assembly, transportation, testing, and handling.

Skids used for storage or shipping shall be designed to simplify inspection of seal (and other) surfaces.

9.2 Lifting Arrangements

Lifting points shall:

a) be designed per Annex K of API 17D.

b) be ~~labeled~~ labelled per API 17D section 5.5.2.

9.3 Preservation

9.3.1 General

An inspection plan during preservation and storage periods including inspection requirements, scheduling of, and witnessing needs and procedures shall be defined.

9.3.2 Preservation Storage, and Transportation Procedures

Preservation and ~~Storage Procedures~~ Storage procedures shall meet the requirements of API 17P. The procedures shall include instructions describing the needs for:

a) Intermittent operation of the pump, motor, barrier fluids, and associated valving

b) Internal and external inspection, including in-situ methods for post-installation preservation.

c) EMF exposure prevention.

d) Protection of the equipment from environmental conditions during storage and transport.

e) The recommended storage environment, age control procedures, and protection of elastomer materials.

The following shall be included in the development of preservation and storage procedures.

1) Maximum and Minimum temperatures during transport from manufacturing site to installation site and including ~~transhipment~~ transshipment and storage sites

2) Shock logging devices shall be installed to record loads occurring during shipping or land transport

9.3.3 Corrosion Prevention

The individual requirements of all materials and the impact of transport and storage conditions shall be included in the evaluation and choice of preservation fluids. These requirements shall include compatibility, thermal exposure, sun tolerance, chemical stability, etc.

Rust preventatives shall be compatible with all pumped liquids

Exterior machined surfaces, which are not coated, shall be treated with a rust preventive.

Flanged openings shall be provided with metal closures at least 5 mm (0.19 in) thick, with elastomeric gaskets and at least four full-diameter bolts. For studded openings, all nuts required for the intended service shall be used to secure closures.

Threaded openings shall be provided with temporary steel caps or steel plugs.

9.3.4 Hydraulic and Barrier Fluid Systems

~~The following requirements shall be met to ensure that the hydraulic and barrier fluid systems are in a suitable state of cleanliness prior to shipment.~~

a) The total shipment including hydraulic and barrier fluid lines shall be flushed and filled.

b) Exposed end fittings shall be capped or covered.

c) All pressure shall be bled from equipment

d) A cleanliness certificate shall be submitted prior to shipment.

e) If appropriate, metal filter elements and screens are to be cleaned and reinstalled prior to shipment.

f) If appropriate Non-metallic filter elements should be shipped and installed in an unused condition

9.3.5 Loose Items and Cables

Loose seals, stab subs, and ring gaskets shall be individually boxed or wrapped for shipping and storage.

Instructions concerning proper storage and shipping of all electrical cables, connectors, and electronic packages shall be provided.

10 Installation and Intervention

10.1 General

Pump modules shall meet the installation and intervention requirements of API SPEC 17D, SPEC 17F, API RP 17H, API RP 17P, API RP 17R, and API RP 17S.

a) Retrievable modules shall be designed to enhance flexibility in the choice of installation/ maintenance vessels.

b) The pump module shall be designed for entry through the splash-zone – large closed surface-areas should be avoided.

c) Provisions shall be made for draining, flushing, and filling of structural steel during installation and/or retrieval.

10.2 ~~Design Requirements for~~ Retrieval

~~In addition to the requirements described of API SPEC 17D, SPEC 17F, API RP 17H, API RP 17P, API RP 17R, and API RP 17S, the design shall include.~~ Retrieval systems shall conform to API SPEC 17D, SPEC 17F, API RP 17H, API RP 17P, API RP 17R, and API RP 17S and provide:

a) An effective means for displacement of fluids from the module.

b) A method to minimize the release of hydrocarbon or other harmful fluids to the environment.

c) A recommended displacement procedure

d) A barrier philosophy that meets the requirements in API RP 17A

e) A method allowing for controlled depressurization.

f) Methodologies for controlled pump module pressure management during retrieval

11 Reliability, Operations and Maintenance

11.1 Reliability and Maintenance Data

Reliability data can be utilized for:

a) the assessment of overall field economics~~,~~

b) development of system specifications~~,~~

c) identification of qualification needs~~,~~

d) establishment of the performance targets~~,~~

e) identification design improvements~~, and~~ ¨

f) continuous improvement of operation and maintenance.

NOTE 1: ISO 14224 provides specific requirements and guidance on reliability data management, acquisition, and application for subsea processing system evaluations.

NOTE 2: API 17N provides general guidance on the use of reliability data for reliability assessment of subsea systems.

Overall system reliability assessment methods rely on and require uniform documentation and classification in the data input for their use in decision making.

11.2 Module Operations and Maintenance

API RP 17P provides guidance for operational principles which are relevant for the subsea equipment covered by this RP. The modules should be designed to simplify inspection and retrieval for maintenance.

NOTE: The addition of significant power loads (and potentially the addition of electric actuation) ~~may~~ can provide additional electrical influences which ~~may~~ can affect corrosion potentials. This ~~may~~ can impact cathodic protection systems or influence control equipment.

11.3 Module Retrieval

Procedures should be developed to displace hydrocarbon fluids from the module prior to retrieval.

Retrieval procedures may include requirements for additional tooling and equipment for use in the retrieval process.

Displacement of hydrocarbons may be either to a subsea facility or to a dedicated tool.

Annex A
(Normative)

Pump Design Data Sheets Minimum Requirements

This annex contains the minimum pump design data required to execute and deliver a pump system capable of meeting the defined performance targets. Responsibilities for the data reporting shall be per contract requirements or manufacturer procedures.

NOTE: In a traditional project with an operator representing a field specific application, the majority of the data in the **input** data sheets lie within the scope of the field operatorship. ~~Similarly, the~~ The data in the **output** data sheets represents the results of design work or design specifications from the manufacturer. Sheets described as both **input** and **output** illustrate the requirement / proposed solution relationship where the input (such as “communication bandwidth” can be on one side “this is the existing infrastructure capacity” and the response sheet represents “the net capacity requirement from the integrator”.

Datasheet Table A-1: Design Basis (Input)

Date:	**Project:**	**Page: ___ of ___**
General Design Inputs		
Description	**Value**	**Reference Number**
Application Description		
Application Site		
Geographic Location		
Application Service		
Application Type		
Pump Count		
Design Life		
Reliability or Availability Performance Objective		
Design Conditions		
MAWP, bara (psia)		
~~MADP, bara~~ Static Sealing Pressure, barg(psig)		
Flowline Rated Pressure, bara (psia9		
Pump Maximum ~~Deadhead~~ Blocked Discharge Operating Pressure, bara (psia)		
Rated Pressure, bara (psia)		
Rated Temperature, ºC (ºF)		
Ambient Conditions		
Water Depth, m (Mean Sea Level reference)		
Water Temperature, ºC (ºF)		
Seawater Salinity, kg/kg (lb/lb)		
Minimum Current, m/s (ft/s)		
Cooler Design		
Design Case Seawater Current, m/s, (ft/s)		
Seawater Salinity, kg/kg (lb_m/lb_m)		
Design Case Fouling Factor, $m^2 \cdot K/kW$ ($\mu H\ ft^2\ ^oF$ /BTU)		
System Documents		
P&ID		
Layout		
Cause and Effect		
HMI Requirements		
Operability / Transient Analysis Data		
Upstream /Downstream valve closure times, sec		
Shutdown time, sec		

Table A-1, Continued.

Date:	**Project:**	**Page: ___ of ___**
General Design Inputs (SI Units)		
Description	**Value**	**Reference Number**
Material Standard		
Material Class (AA-HH)		
Forging Specification Level (FSL-2, -3 or -4)		
Product Specification Level (PSL -3, -3G or -4)		
Bolt Specification Level (BSL-2 or -3)		
Piping Geometry		
Inlet Diameter, mm (in)		
Inlet Elevation, m (ft)		
Inlet Orientation		
Inlet Connector		
Discharge Diameter, mm (in)		
Discharge Elevation, m (ft)		
Discharge Orientation		
Discharge Connector		
Coating Requirements		
Relevant Standard		
Weight/Size Limitations		
Weight, metric tons (short tons)		
Envelope Dimensions, WxLxH , m (ft)		
Testing Requirements		
Application/Contract Specific Performance Testing		
Factory Acceptance Testing		
Site Integration Testing		
Motor Specific Requirements		
Full Speed/Full Load		
Full Speed/No Load		
Locked Rotor		
Others		
Hydro-Test with Internals		
Gas Test if Relevant		
Inspection Points		
Acceptance Criteria Vibration (specify one of)		
RMS Velocity, mm/s		
Shaft Vibration Displacement (peak to peak), μm (thou)		
Shaft Acceleration, mm/s^2		
Acceptance Criteria Barrier Fluid, Bearing and Motor Coolant Data		
Barrier Fluid Consumption Rate, l/h (gpd)		
Temperature rise motor inlet to outlet, ºC (ºF)		
Temperature rise bearing inlet to bearing outlet, ºC (ºF)		

Datasheet Table A-2 Production Data

Date:	**Project:**		**Page: ___ of ___**	
Operating Data Inputs (SI Units)				
Description	**Minimum Flow**	**Rated Point**	**Maximum Flow**	**Attachment**
Capacity Requirement				
Oil Rate (Standard Conditions), Sm^3/d (stbd)				
Oil Rate (Pump Inlet Conditions), m^3/d (bpd)				
Gas Rate (Standard Conditions), MSm^3/d (mmscfd)				
Gas Rate (Pump Inlet Conditions), m^3/d (cfd)				
Water Rate (Standard Conditions), Sm^3/d (stbd)				
Water Rate (Pump Inlet Conditions), m^3/d (bpd)				
Production Profile (attach data)				
Operating Inlet Pressure, bara (psia)				
Operating Discharge Pressure, bara (psia)				
Operating Inlet Temperature, °C (°F)				
Phase Data at Pump Inlet				
Oil Density, kg/m^3 (°API)				
Oil Viscosity, cP				
Oil Heat Capacity, kJ/kg K (BTU/lb_m °F)				
Gas Density, kg/m^3 (lb_m/ft^3)				
Gas Viscosity, cP				
Gas Heat Capacity, kJ/kg K (BTU/lb_m °F)				
Produced Water Density, kg/m^3 (lb_m/ft^3)				
Produced Water Viscosity, cP				
Produced Water Heat Capacity, kJ/kg K (BTU/lb_m °F)				
Produced Water Salinity, kg/kg (lb_m/lb_m)				
Emulsion Viscosity, cP				
Sand Data				
Sand Rate at Steady-State, kg/d (lb_m/d)				
Sand Size at Steady-State, μm (thou)				
Sand Rate at Upset Conditions, kg/d (lb_m/d)				
Sand Size at Upset Conditions, μm (thou)				
Period for Upset Condition, hours				
Sand Hardness, Vickers				
Hydrate Potential				
Attach Curve				
Wax Behavior				
Wax Appearance Temperature, °C (°F)				
Pour Point, °C (°F)				
Trace Components				
Mercury, mg/l (lb/gal)				
Other, mg/l (lb/gal)				
Production Chemicals				
Hydrate Inhibitor(s), l/d (gpd)				
Scale Inhibitor(s), l/d (gpd)				
Asphaltene Inhibitor(s), l/d (gpd)				
Wax Inhibitor(s), l/d (gpd)				

Table A-2, Continued

Date:		**Project:**		**Page: ___ of ___**	
Fluid Description Inputs					
Description				**Input Value**	**Reference Number**
Stock Tank Oil Properties, (Single Stage Flash)					
Density, kg/m^3 (ºAPI)					
Viscosity, cP					
Gas Properties (Single Stage Flash)					
Molecular weight or specific gravity					
Viscosity, cP					
Saturation Point					
Pressure, bara (psia)					
Temperature, ºC (ºF)					
Phase Envelope (attach)					
Single Stage Flash Results					
Gas-Oil-Ratio/Condensate Gas Ratio, Sm^3/Sm^3 (scf/stb)					
Recombined Fluid, Gas, Oil Compositions					
Separator Reference Temperature, ºC (ºF)					
Separator Reference Pressure, bara (psia)					
Separator Gas-Oil Ratio, Sm^3/Sm^3 (scf/stb)					
	Gas	**Oil**	**Recombined**		
Component	**Mol Percent**	**Mol Percent**	**Mol Percent**		
H_2S					
N_2					
CO_2					
CH_4					
C_2H_6					
C_3H_8					
i-C_4H_{10}					
n-C_4H_{10}					
i-C_5H_{10}					
n-C_5H_{10}				**Molecular wt.**	**Specific Gravity**
Hexanes					
Heptanes					
Octanes					
Nonanes					
Decanes					
Decanes +					
Undecanes					
Dodecanes					
Tridecanes					
Tetradecanes					
Pentadecanes					
Hexadecanes					
Heptadecanes					
Octadecanes					
Nonadecanes					
Eicosanes +					

Table A-2, Continued

Date:	**Project:**		**Page: ___ of ___**
Formation Water Composition Inputs			
Description	**Input Value**		**Reference Number**
Total Dissolved Solids, kg/kg (lb_m/lb_m)			
pH			
Ion	**Ion mol wt.**	**Charge Range**	**mg/*l***
H^+	1.00798	+1	
Na^+	22.9898	+1	
K^+	39.0983	+1	
Mg^{++}	24.305	+1 to +2	
Ca^{++}	39.0983	+1 to +2	
Ba^{++}	137.327	+1 to +2	
Mn^{n+}	54.9381	+1 to +7	
Si^{n+}	28.085	+4 to +4	
Sr^{n+}	87.62	+1 to +2	
Cr^{n+}	51.9961	+4 to +6	
Fe^{n+}	55.845	+4 to +6	
Zn^{n+}	65.38	+2 to +2	
OH^-	17.007	-1	
Cl^-	35.453	-1	
HCO_3^-	61.106	-1	
SO_4^{2-}	96.0618	-2	
CO_3^{2-}	76.0972	-2	
		sum	
Scale Squeeze philosophy, attach			

Datasheet Table A-3 Umbilical Requirements (Input and Output)

Date:	**Project:**	**Page: ___ of ___**
Motor Design Details (SI Units)		
Description	**Value**	**Appendix Number**
Power System		
Umbilical Length, m (ft)		
Line Frequency at Source, Hz		
Short-Circuit Capacity at Source, MVA		
Phase Current at Source, A		
Line Voltage at Source, kV		
Interface Requirements		
Power Connection		
Start-up Procedures		

Datasheet Table A-4 Control Requirements (Input and Output)

Date:	**Project:**	**Page: ___ of ___**
Pump Instrumentation Details		
Description	**Value**	**Reference Number**
Communication System		
Umbilical Length, m (ft)		
Communication and Control Interface		
Communication Bandwidth		
Communication Standard		
SEM Interface		
Instrumentation Requirements		
Accelerometer, count		
Acoustic Sensors, count		
Leakage Detection, count		
Bearing Temperature, count		
Radial Proximity Probes, count		
Axial Proximity Probes, count		
Pump Inlet Pressure, count		
Pump Inlet Temperature, count		
Pump Discharge Pressure, count		
Pump Discharge Temperature, count		
Motor Torque, count		
Key Phasor, count		
Cooler Inlet Pressure, count		
Cooler Inlet Temperature, count		
Cooler Outlet Pressure, count		
Cooler Outlet Temperature, count		
Coolant Flowmeter, count		

Datasheet Table A-5 Pump Data

Date:	**Project:**	**Page: ___ of ___**
Pump and Motor Mechanical Design Outputs		
Description	**Value**	**Reference Number**
Pump Ratings		
Pump Type		
Rated Pressure, bara (psia)		
Maximum Differential Pressure, barg (psig)		
Maximum ~~Deadhead~~ Blocked Discharge Operating Pressure, bara (psia)		
Rated Temperature, ºC (ºF)		
Rated Capacity at BEP, m^3/d (bpd)		
~~Rated Volumetric Efficiency at BEP, %~~		
Required Power at Rated Condition, MW (HP)		
Required Power at Pressure Limiting Rate, MW (HP)		
Maximum Allowable Speed, rpm		
Performance Curves		
Coupling		
Type		
Piping Geometry		
Materials		
Inlet Diameter, mm (in)		
Inlet Interface/Connector		
Discharge Diameter, mm (in)		
Discharge Interface/Connector		
System Dimensions		
Weight, metric tons (tons)		
Envelope Dimensions, WxLxH, m (ft)		

Datasheet Table A-6 Barrier Fluid System

Date:	**Project:**	**Page: ___ of ___**
Barrier Fluid/Lubrication System Design Outputs (SI Units)		
Description	**Value**	**Reference Number**
Lubricant/Barrier Fluid		
Expected Normal Rate, l/d (gpd)		
Maximum Allowed Rate, l/d (gpd)		
Fluid Type		
Fluid Density, kg/m^3 (lb_m/ft^3)		
Fluid Viscosity, cP		
Fluid Classification/MSDS		
Barrier Fluid/Lubricant System		
Rated Pressure, bara		
Instrumentation		
Controls Interface		
Piping/Tubing Materials		
Piping/Tubing Interface Details		
Piping/Tubing Coating Requirements		
Piping/Tubing Coating Details		

Datasheet Table A-7 Pump Rating and Material Details

Date:	**Project:**	**Page: ___ of ___**
Pump Detail Design Outputs (SI Units)		
Description	**Value**	**Reference Number**
Pump Casing		
Rated Pressure, bara		
Rated Temperature, ºC (ºF)		
Hydrostatic Test Pressure, barg (psig)		
Casing Materials		
Bolting Materials		
Coating Materials		
Motor Casing		
Rated Pressure, bara		
Rated Temperature, ºC (ºF)		
Hydrostatic Test Pressure, barg (psig)		
Casing Materials		
Bolting Materials		
Coating Materials		
Piping		
Coating Materials		
Inner Barrel/Liner		
Material		
Coating Description		
Hydrostatic Test Pressure, barg (psig)		
Casing Materials		
Bolting Materials		
Rotor/Impeller/Bearing/Gears/Shaft		
Rotor/Impeller Description		
Rotor/Impeller Material		
Rotor/Impeller Coating		
Rotor/Impeller Mounting		
Rotor/Impeller Diameter, mm (in)		
Rotor/Impeller Length, mm (in)		
Rotor/Impeller Clearance, mm (in)		
Shaft Diameter at Rotor/Impeller, mm (in)		
Shaft Diameter at Coupling/Drive-End, mm (in)		
Shaft Diameter at non-Drive-End, mm (in)		
Shaft Material		
Timing Gear Standard		
Timing Gear Pitch/Line Diameter, mm (in)		
Timing Gear Material		
Radial Bearing Count		
Radial Bearing Type		
Thrust Bearing Type		
Thrust Bearing Material		
Mechanical Seals		

Datasheet Table A-8 Motor Design

Date:	**Project:**	**Page: ___ of ___**
Motor Design Outputs (SI Units)		
Description	**Output Value**	**Reference Number**
Motor		
Type		
Rated Power, MW (HP)		
Rated Speed, rpm		
Maximum Allowable Speed, rpm		
Rated Voltage, kV		
Voltage Range, kV		
Insulation Class		
Frequency Range, Hz		
Number of Poles		
Number of Phases		
Minimum Starting Voltage, V		
Full Load Current, A		
Locked Rotor Current, A		
Motor Efficiency, %		
Motor Cooler		
Coolant Circulation Rate, l/h (gpm)		
Duty, MW (BTU/hr)		
Area, m^2 (ft^2)		
Materials		
U-Value Used in Design, $W/m^2 \cdot K$ ($BTU/hr\ ft^2\ ^oF$)		
Coating Requirements		
Coating Details		
Interface		
Power Connection		
Start-up procedures		
Instrumentation		
Motor Temperature		
Motor Torque		
Motor Bearing Temperature		
Key Phasor		
Proximity Probes		
Cooler Inlet Pressure		
Cooler Inlet Temperature		
Cooler Outlet Pressure		
Cooler Outlet Temperature		
Coolant Flowmeter		

Datasheet Table A-9 Equivalent Rated Operating Point (Input and Output)

Date:	Project:	Page: ___ of ___	
Equivalent Rated Operating Point and Test Acceptance Criteria (SI Units)			
Capacity Requirement	**Rated Operating Point**	**Equivalent Test Point**	**Value**
Oil Rate (Standard Conditions), Sm^3/d (stbd)		Chosen Gas	
Oil Rate (Pump Inlet Conditions), m^3/d (bpd)		Chosen Liquid	
Gas Rate (Standard Conditions), MSm^3/d (mmscfd)		~~Suction~~ Pressure, bar	
Gas Rate (Pump Inlet Conditions), m^3/d (mmcfd)		~~Suction~~ Temperature, °C	
Water Rate (Standard Conditions), Sm^3/d (stbd)		Fluid Density Ratio, -	
Water Rate (Pump Inlet Conditions), m^3/d (bpd)		Chosen GVF, -	
Operating Inlet Pressure, bara (psia)		Chosen ΔP, barg	
Required □P, barg (psig)		Equivalent Power, MW	
Operating Inlet Temperature, °C (°F)		Equivalent Rate, m^3/d	
		Equivalent Speed, RPM	
Phase Data at Pump Inlet (Reservoir Fluid)			
Oil Density, kg/m^3 (lb_m/ft^3)			
Oil Viscosity, cP			
Oil Heat Capacity, kJ/(kg K) (BTU/(lbm °F))			
Gas Density, kg/m^3 (lb_m/ft^3)			
Gas Viscosity, cP			
Gas Heat Capacity, kJ/(kg K) (BTU/(lbm °F))			
Aqueous Phase Density, kg/m^3 (lb_m/ft^3)			
Aqueous Phase Viscosity, cP			
Aqueous Phase Heat Capacity, kJ/(kg K) (BTU/(lbm °F))			
Aqueous Phase Salinity, kg/kg, (lb_m/lb_m)			
Emulsion Viscosity, cP			
~~Required Power at Equivalent Test Point (with Chosen Fluid)~~ Equivalent Test Point Specifications			
Topic	**Expected Value**	**Tolerance**	
Test Fluids and Properties		Requires attachment	
Phase Rate Tolerance			
GVF Tolerance			
Shaft Power, MW (HP)		10% of prediction	
Chosen ΔP, barg (psig)			
Speed, rpm		+/- 150 of predicted	
Chosen Suction Pressure, bara (psia)			
Expected Discharge Temperature, °C (°F)			
Chosen Suction Temperature, °C (°F)			
Acceptance Criteria Vibration (specify one of)			
RMS Velocity, mm/s (in/s)			
Shaft Vibration Displacement (peak to peak), μm (thou)			
Shaft Acceleration, mm/s^2			
Acceptance Criteria Barrier Fluid, Bearing and Motor Coolant Data			
Barrier Fluid Consumption Rate, l/h			
Temperature rise motor inlet to outlet, °C (°F)			
~~If feasible and specified~~, ~~temperature rise bearing~~ Bearing coolant ~~a~~ temperature rise ~~circuit inlet to bearing coolant circuit outlet~~, °C (°F)			

Datasheet Table A-10 Test Data Collection Requirement

Date:	**Project:**	**Page: ___ of ___**
Data Collection Requirements		Sensing Method and Redundancy Solution
GVF, GVFi		
Motor current		
Motor voltage		
Motor input power		
Motor winding temperature (measured directly or via barrier fluid temperature)		
Process fluid density (at pump inlet)		
Pump inlet and discharge pressure		
Pump inlet and discharge temperature		
Pump and/or motor speed		
Pump and/or motor torque		
Pump and motor casing vibration data (accelerometer data)[1]		
Pump and motor rotor vibration data if feasible (rotor radial and axial displacements)[2]		
Recycle valve position and recycle flowrates		
Recycle coolant rates and temperatures		
Balance line pressure[3]		
Barrier fluid dielectric properties (conductivity and relative permittivity at a given frequency[3]		
Barrier fluid flow rate within the cooling loop[3]		
Barrier fluid leakage rate (bulk leakage rate and for steady state operation only[3]		
Barrier fluid pressures[3]		
Barrier fluid temperatures[3]		
Barrier fluid temperature within motor[3]		
Barrier fluid cleanliness measurement (e.g. by sample and analysis) [3]		
Barrier fluid inlet temperature[3]		
Balance line pressure[3]		
Barrier fluid dielectric properties (conductivity and relative permittivity at a given frequency[3]		
Barrier fluid flow rate within the cooling loop[3]		
Barrier fluid leakage rate (bulk leakage rate and for steady state operation only[3]		

NOTE 1: The casing vibration data are obtained and used for long term surveillance.

NOTE 2: After the prototype phase, rotor and motor vibration data acquisition ~~may not~~ might not be feasible.

NOTE 3: Only ~~required~~ if relevant for pump/motor unit design (ie if the system has a barrier fluid system)

Annex B
(Informative)
Qualification Testing

B.1 General Procedure for Qualification Testing

The testing procedure starts with the development of a test objective from the pump specification; then continues with the development of an experimental design within the capabilities of the test facility and test object. Four different sets of tests are then executed within the chosen experimental design. Each of these tests generates data which are used to develop the outputs in the test report.

B.2 General Procedure for the Start-up and Shut-down Tests

The primary objectives of this test are to:

a) Identify any damaging oscillatory torque that occurs during start-up

b) Confirm that motor can meet necessary start-up torque for the pump, and

c) Confirm the dynamic response of the barrier fluid system and mechanical seals to process fluid GVF fluctuations and temperature changes

Additional start-up and shutdown tests should be conducted to discover and verify resonant or high vibration conditions and to confirm functionality for expected start-up transient operations.

- Cold start (all systems at ambient conditions)
- Hot fluids, cold pump (start of a parallel pump, start-up of a system capable of natural flow)
- Hot pump, hot fluids (re-start immediately after a system shutdown)
- Hot pump, cold fluids (re-start after a partial cooldown)

This is a dynamic test without a defined steady-state test point. In this transient test, the pump begins at rest, ramps up to the maximum ~~operating~~ continuous speed, and ramps down to rest.

NOTE: Barrier fluid temperatures will be affected by variations in ambient, storage and pit temperature during the test period and will, likely, ~~may~~ not reflect the actual operating conditions for a subsea installed pump.

The tests are detailed below but are set up to give combinations based on the following example in Table B.1:

Table B. 1—Suggested Start-up and Shut-down Test Process for Qualification Testing

Scenario	Data Points
Start-stop cycles Minimum Flowrate @ minimum GVF Minimum Flowrate @ maximum GVF Maximum Flowrate @ minimum GVF Maximum Flowrate @ maximum GVF	20 total 5 Cycles 5 Cycles 5 Cycles 5 Cycles
Allowable start up ramp rate	10 cycles at minimum ramp-up rate 10 cycles at maximum ramp-up rate
Shutdown rate	4 ESD simulations 8 cycles at maximum ramp-down rate 8 cycles minimum ramp-down rate
Minimum test suction pressure	10 ~~each~~cycles
Maximum test suction pressure	10 ~~each~~cycles

Table B.2 lists each parameter for each test where the cycles are intentionally randomized.

NOTE: Minimum test suction pressure and maximum test suction pressure do not need to correspond to minimum and maximum design suction pressures. These are solely used for test purposes and are based upon the limits of the test loop.

Table B. 2 —Suggested Start-up and Shut-down Test Order for Qualification Testing

Cycle #	GVF	Flow Rate	Starting Ramp Rate	Shut Down Rate	Suction Pressure
~~6~~1	min	max	max	ESD	max
~~11~~2	max	min	min	ESD	max
~~16~~3	max	max	max	ESD	max
~~5~~4	min	min	min	max	max
~~4~~5	min	min	max	min	max
~~10~~6	min	max	max	max	max
~~12~~7	max	min	max	min	max
~~17~~8	max	max	min	min	max
~~18~~9	max	max	max	max	min
~~20~~10	max	max	max	max	max
~~1~~11	min	min	min	ESD	min
~~3~~12	min	min	min	max	min
~~2~~13	min	min	max	min	min
~~9~~14	min	max	min	min	min
~~7~~15	min	max	min	min	max
~~8~~16	min	max	max	max	min
~~15~~17	max	min	min	max	max
~~13~~18	max	min	min	max	min

Cycle #	GVF	Flow Rate	Starting Ramp Rate	Shut Down Rate	Suction Pressure
~~14~~19	max	min	max	min	min
~~19~~20	max	max	min	min	min

Monitor all variables specified in 8.2.1. This test will create variations in torque, speed, barrier fluid pressure, process fluid pressure, and vibration levels that should be analyzed for signs of system damage. Produce Bode plots for each cycle.

B.3 Normal Performance Qualification

The primary goals of this test are to determine the performance map and vibration behavior of a new design:

a) Determine the system performance at steady-state

b) Confirm the predicted performance map at steady-state, and

c) Confirm the operating region (if single-phase) or envelope (if multi-phase) with respect to pre-defined vibration limits

Qualification tests are performed at multiple combinations of the key variables for pump performance:

1) set speed

2) flowrate

3) suction pressure

4) differential pressure, and

5) GVF

In the case of application specific tests, the choice of data points near the ~~Best Efficiency Point(s) (BEP) or~~ design point(s), may be specified in the contract between Manufacturer and Purchaser.

NOTE: Barrier fluid temperatures will be affected by variations in ambient, storage and pit temperatures during the test period and can not be relied on to reflect the actual operating conditions for a subsea installed pump.

Set temperature and GVF at design point(s) within the range agreed for qualification of system.

Operate the system at the specified set point(s) until the following conditions are met:

- Inlet and discharge pressure variations achieve steady state and are less than +/- 5 bar or 5 % (whichever is smaller)

- Process and barrier fluid temperatures reach their steady state values and vary by no more than +/- 5%

- Flowrate stabilized at a steady state value within 5% of desired value

- GVFi within 5 % of desired value for GVF ~~(if not in intermittent flow regime)~~
- ~~GVFi within 5 % of desired value for GVF (if in intermittent flow regime)~~

Qualification Test Duration: No less than 15 minutes of additional operation after thermal and pressure equilibria are established by the criteria above in 8.2.2.

Monitor all variables specified in 8.2.1.

B.4 Liquid Slugging Tolerance

The Liquid Slugging Tolerance test is aimed at the minimum scope pump system and is aimed at evaluating its tolerance to GVFi variations. This test is aimed at verifying the slug tolerance of the pump sub-system. The dynamics of the responses will also qualify the dynamic response of the barrier fluid system to process pressure changes. The test qualifies the combination of the following:

a) the pump control system

b) the barrier fluid system

c) the capacity of (any) pump sumps

d) any other directly associated equipment

NOTE: The liquid slugging tolerance test is applicable to any pump that is designed for > 0% inlet GVFi.

The test is therefore aimed at confirming that the test system responds in a controlled manner to liquid slugs and gas pockets. Because extensive field modelling and dynamic simulation results are required to predict a worst-case scenario for the size of GVFi fluctuations and the duration of time in which these changes can occur, this qualification test may be generic. Because of the test infrastructure needs, distinctions between application specific and qualification testing will be defined by each application project and the chosen “system-of-systems” level slug mitigation technologies.

This dynamic test does not have a fixed test point. The pump system should begin operating near the BEP Δp and flowrate for a given GVF and remain within the operational envelope while responding to changing process conditions.

For this test, the barrier fluid should be uncontrolled at the ambient and pit temperatures as they vary during the test.

Process fluid conditions vary, as specified by the agreed test conditions. The GVF is chosen near the design point and varies to simulate liquid slugs and gas pockets per worst-case scenario predictions or agreed criteria.

B.5 Extended Performance Qualification

This test demonstrates design robustness and simulates an extended duration of operation by going through several cycles and operating near the edge of the envelope with barrier fluid at maximum temperature.

This set of test points should be repeated for the entire range of process variables claimed by the pump manufacturer. For example, if a pump can run with GVF from 40 % to 60 %, the test points should be run at the upper and lower GVF values. Continuing with that example, the number of GVF values to be run between the upper and lower limits should be agreed on by all parties prior to testing.

Table_B. 3 Test points and their locations on operational envelope

Test Point	Speed	Flowrate	ΔP
1	Midpoint	At surge limit for speed	Maximum ΔP for flow and speed
2	Midpoint	Near choke/stall limit for speed	Maximum ΔP for flow and speed
3	Maximum	Near choke/stall limit for speed	Minimum ΔP for flow and speed
4	Minimum	At surge limit for speed	Maximum ΔP for flow and speed
5	Minimum	Near choke/stall limit for speed	Minimum ΔP for flow and speed
6	Maximum	At surge limit for speed	Maximum ΔP for flow and speed
7	Maximum (at maximum power)	Midpoint (furthest point from surge and stonewall)	Maximum (at maximum power)

Figure B. 1 indicates where each test point lands on the operational envelope. The seven test points should be repeated over the entire range of GVF values for multi-phase pumps.

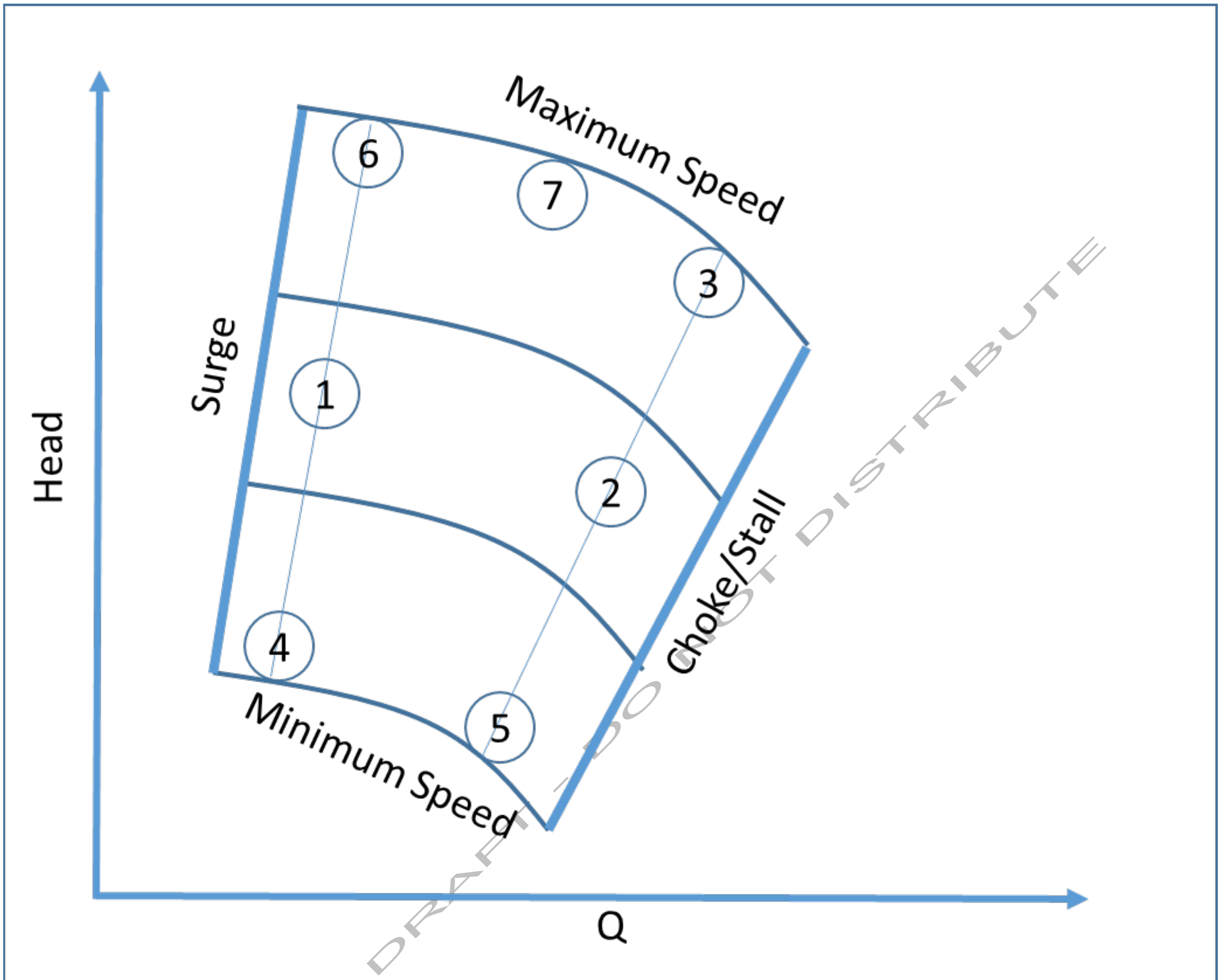


Figure B. 1— Location of Test Points on the Operational Envelope

For this test, the barrier fluid should be uncontrolled at the ambient and pit temperatures as they vary during the test.

For this test, the process fluids should be at maximum temperature and GVF.

Table B-4 provides durations for each of the tests.

Table B. 4—Suggested Extended Performance Test Process for Qualification Testing

Scenario	Procedure	Duration/Cumulative Running time
1. Hot/Cold Start:	Start up the pump at ambient temperature and the process fluid at maximum temperature.	
2. 10 Cycles Set I	Start up and shutdown the pump ten times including a minimum of five emergency stops.	Run each test point for equal amounts of time for 10 hours qualification giving 100 hours cumulative test time
3. Test Point Extended Performance Set I	Run each of the 7 chosen test points for equal amounts of time	~15 hours per point 100 hours cumulative

Scenario	Procedure	Duration/Cumulative Running time
4. Hot/Cold Start Repetition	Start up the pump at ambient temperature and the process fluid at maximum temperature.	
5. 10 Cycles Set II	Start up and shutdown the pump ten times including a minimum of five emergency stops.	
6. Test Point Extended Performance Set II	Run each of the 7 chosen test points for equal amounts of time	~15 hours per point 100 hours cumulative
7. 30 Cycles:	Start up and shutdown the pump 30 times including a minimum of five emergency stops.	
8. Test Point Extended Performance Set III	Run each of the 7 chosen test points for equal amounts of time	~30 hours per point 200 hours cumulative
For items 3, 6, and 8, operate the system at the specified set points until the steady-state conditions are met as described in 8.2.2 above: No less than fifteen minutes of additional operation are required once the temperatures and pressures are constant.		

Annex C
(Informative)
Application Specific Testing

C.1 Start-Up and Shutdown Test

The primary objectives of the test steps listed in Table C.1 are to:

a) Identify any damaging oscillatory torque that occurs during start-up

b) Confirm that motor can provide the necessary start-up torque for the pump, and

c) Confirm the dynamic response of the barrier fluid system and mechanical seals to process fluid GVF fluctuations and temperature changes

Additional start-up and shutdown tests should be conducted to discover and verify resonant or high vibration conditions and to confirm functionality for expected start-up transient operations.

– Cold start (all systems at ambient conditions)

– Hot fluids, cold pump (start of a parallel pump, start-up of a system capable of natural flow)

– Hot pump, hot fluids (re-start immediately after a system shutdown)

– Hot pump, cold fluids (re-start after a partial cooldown)

Table C.1—Suggested Start-up and Shut-down Test Process for Application Specific Testing

Scenario	Data Points
Start cycles at Minimum Settle-out Pressure Minimum Flowrate @ maximum GVF Maximum Flowrate @ minimum GVF Start cycles at Maximum Settle-out Pressure Minimum Flowrate @ maximum GVF Maximum Flowrate @ minimum GVF One Stop cycle at Maximum Suction Pressure Maximum Flowrate @ minimum	10 total cycles 2 sets of cycles at each pressure
Allowable start up ramp rate	4 cycles at standard speed ramp-up rate
Shutdown rate	2 ESD simulations, 3 cycles at PSD ramp-down rate
Minimum settle-out pressure	4 ~~each~~ cycles
Maximum settle-out pressure	4 ~~each~~ cycles

This is a dynamic test without a defined steady-state test point. In this transient test, the pump begins at rest, ramps up to the maximum ~~operating~~ continuous speed, and ramps down to rest.

Ambient temperature for test environment as varies during the test.

Table C.2 lists each parameter for each test.

Table C.2—Suggested Start-up and Shut-down Test Order for Application Specific Testing

Cycle #	GVF	Flow Rate	Starting Ramp Rate	Shut Down Rate	Suction Pressure
1	max	min	std	PSD	min
2	min	max	std	PSD	min
3	max	min	std	PSD	max
4	min	max	std	PSD	max
5	min	max	std	ESD	max
6	max	min	std	PSD	min
7	min	max	std	PSD	min
8	max	min	std	PSD	max
9	min	max	std	PSD	max
10	min	max	std	ESD	max

Monitor all variables specified in 8.2.1. This test creates variations in torque, speed, barrier fluid pressure, process fluid pressure, and vibration levels that should be analyzed for signs of system damage. Produce Bode plots for each cycle.

C.2 Test of Normal Performance

The primary goals of the application specific tests at normal operating conditions test are the confirmation that the desired performance is met by the design:

a) confirm that the system meets the required performance objective;

b) confirm the predicted performance map at steady-state; and,

c) confirm that the desired performance is within pre-defined vibration limits

Application specific tests are performed at multiple combinations of the key variables for pump performance:

1) set speed

2) flowrate

3) suction pressure

4) differential pressure, and

5) GVF

In the case of application specific tests, the choice of data points near the BEP or design point(s), may be specified in the contract between Manufacturer and Purchaser.

Operate the system at the specified set point(s) until the following conditions are met:

- inlet and discharge pressure variations achieve steady state and are less than +/- 5 bar or 5 % (whichever is smaller);
- process and barrier fluid temperatures reach their steady state values and vary by no more than
  +/-5 %;
- GVFi within 5 % of desired GVF value (if not in intermittent flow regime)
- GVF within 5 % of desired GVF value (if in intermittent flow regime)

Test Duration: No less than 15 minutes of additional operation after thermal and pressure equilibria are established by the criteria above.

Monitor all variables specified in 8.2.1.

C.3 Liquid Slugging Mitigation

Confirm that the system responds in a controlled manner to liquid slugs and gas pockets. Extensive field modelling and dynamic simulation results are required to predict a worst-case scenario for the size of GVFi fluctuations and the duration of time in which these changes can occur. The qualification test is aimed at the minimum scope pump system and is aimed at evaluating its tolerance to GVFi variations. The dynamics of the responses are also required to qualify the dynamic response of the barrier fluid system to process pressure changes. Because of the infrastructure needs, distinctions between application specific and qualification testing should be determined by each project and the chosen “system-of-systems” level slug mitigation technologies.

The test may include equipment that is designed to mitigate any effects of slugs or other flow variations. This can be simulated, if agreed between Manufacturer and Purchaser. This test does not include the qualification or application specific testing of process or flow conditioning equipment.

This dynamic test does not have a fixed test point. The pump system should begin operating near the BEP Δp and flowrate for a given GVF and remain within the operational envelope while responding to changing process conditions.

For this test, the barrier fluid should be uncontrolled at the ambient and pit temperatures as they vary during the test.

Process fluid conditions vary, as specified by the operator, for specific field conditions. The chosen GVF begins near the design point and varies to simulate liquid slugs and gas pockets per worst-case scenario predictions or agreed criteria.

Operate the system near BEP at a GVF near the design point. Vary the process conditions and allow the pump system to respond to keep operation within the allowable operating envelope.

As with the qualification test, the parameters of this test are highly reservoir and field dependent. Distinctions between application specific testing and the acceptance of this qualification test will be determined by each project and the chosen system level slug mitigation technologies.

C.4 Extended Performance (Optional)

This test demonstrates design robustness and simulates an extended duration of operation by going through several cycles and operating near the edge of the envelope with barrier fluid at test environment temperature.

This set of test points should be repeated for the entire range of GVF values claimed by the pump manufacturer. For example, if a pump can run with GVF from 40 % to 60 %, the test points should be run at the upper and lower GVF values. The number of GVF values to be run between the upper and lower limits should be agreed on by all parties prior to testing.

Table_C.3

Test Point	Speed	Flowrate	ΔP
1	Midpoint	At surge limit for speed	Maximum ΔP for flow and speed
2	Midpoint	Near choke/stall limit for speed	Maximum ΔP for flow and speed
3	Maximum	Near choke/stall limit for speed	Minimum ΔP for flow and speed
4	Minimum	At surge limit for speed	Maximum ΔP for flow and speed
5	Minimum	Near choke/stall limit for speed	Minimum ΔP for flow and speed
6	Maximum	At surge limit for speed	Maximum ΔP for flow and speed
7	Maximum (at maximum power)	Midpoint (furthest point from surge and stonewall)	Maximum (at maximum power)

Figure C.1 indicates where each test point lands on the operational envelope. The seven test points should be repeated over the entire range of GVF values for multi-phase pumps.

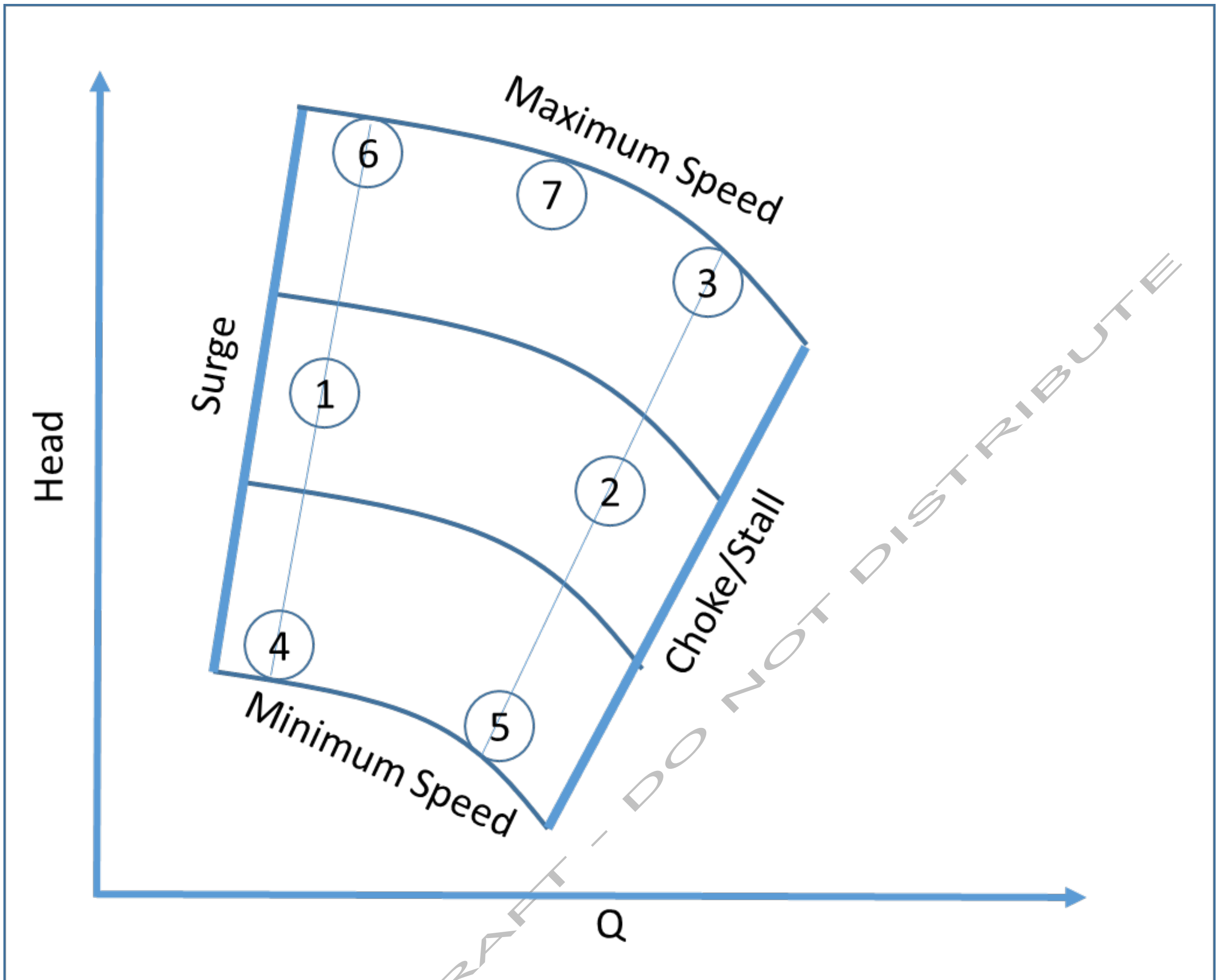


Figure C.1—Location of Test Points on the Operational Envelope

For this test, the barrier fluid should be uncontrolled at the ambient and pit temperatures as they vary during the test.

For this test, the process fluids should be at maximum temperature and GVF.

Table C.4 provides a sequential suggestion for steps and times for execution of the extended performance test procedures when conducted for application specific testing.

Table C.4—Suggested Extended Performance Test Process for Application Specific Testing

	Scenario	Procedure	Duration/Cumulative Running time
1.	Hot/Cold Start:	Start up the pump at ambient temperature and the process fluid at maximum temperature.	
2.	10 Cycles Set I	Start up and shutdown the pump ten times including a minimum of five emergency stops.	Run each test point for equal amounts of time for ~7 hours testing giving 50 hours cumulative test time

3. Test Point Extended Performance Set I	Run each of the 7 chosen test points for equal amounts of time	~7 hours per point 50 hours cumulative
4. Hot/Cold Start Repetition	Start up the pump at ambient temperature and the process fluid at maximum temperature.	
5. 10 Cycles Set II	Start up and shutdown the pump ten times including a minimum of five emergency stops.	
6. Test Point Extended Performance Set II	Run each of the 7 chosen test points for equal amounts of time	~7 hours per point 50 hours cumulative
7. 30 Cycles:	Start up and shutdown the pump 30 times including a minimum of five emergency stops.	
8. Test Point Extended Performance Set III	Run each of the 7 chosen test points for equal amounts of time	~15 hours per point 100 hours cumulative
For items 3, 6, and 8, operate the system at the specified set points until the steady-state conditions are met as described in Section 8.2.2 above: No less than fifteen minutes of additional operation are required once the temperatures and pressures are constant.		

Annex D
(Informative)
Pump Manufacturing Data Check List and Schedule

The documents should be marked to identify

a) the equipment item number and service name;

b) any other identification specified in the inquiry or purchase order;

Table D.1 is, in general, structured by typical order of appearance and alphabetically.

Note that the columns to the left of the description provide an option to ~~chose~~choose a document during various phases of the project: proposal, execution, reviews and describe content for the user documentation and other volumes.

The columns following the text provide an option for due dates.

Engineering Documentation shall be stored by Manufacturer for time periods relevant to the product line.

User Manual and MRB Documentation shall be stored by both Purchaser and Manufacturer for time periods relevant to the delivered product.

Documentation shall be provided by the specified delivery milestone dates listed in Table D.1

Items chosen under the row heading of “General” shall be supplied during the proposal phase and are updated as the project matures.

Items chosen under the row heading of “Verification” shall be supplied in the manufacturing phase and are updated as the project matures.

Items chosen under the row heading of “Manufacturing Record Book” shall be with the delivered product and are updated only if the item is modified prior to commercial operation

Items chosen under the row heading of “FAT Specific” are outputs of the testing of the manufactured product and may be included in both the MRB and User Manual.

Items chosen under the row heading of “User Manual” shall be delivered to Purchaser and describe installation, use, storage and operation of the pump and ancillary equipment.

Table D.1 - Manufacturer Drawing and Data Requirement List

SUBSEA PUMPS DRAWING &	JOB		ITEM
	PURCHASE ORDER		DATE
DATA REQUIREMENTS	REQUISITION		DATE
	INQUIRY		DATE
	PAGE	OF	BY
API 17X	REVISION		
	UNIT		
FOR SITE SERVICE	NUMBER REQUIRED		

Proposal	Engineering Documentation	System Engineering Design Review/Freeze	Manufacturing Record Book	User Manual	VDDR Note Reference Number		Proposal Acceptance	System Engineering Design Review/Freeze	FAT/EFAT	Final Supply
						General				
					GEN.1	Barrier fluid/cooling system GA & component drawings				
					GEN.2	Barrier philosophy document				
					GEN.3	Cause and effect report				
					GEN.4	Control system and GUI description				
					GEN.5	Data sheets				
					GEN.6	Electrical and instrumentation arrangement drawing and list of connections				
					GEN.7	Export Control Tagging (If required)				
					GEN.8	Displacement system design				
					GEN.9	Inspection Plan				
					GEN.10	List of handling and maintenance tools				
					GEN.11	List of special tools furnished				
					GEN.12	Materials specifications and welding procedures				
					GEN.13	MSDS information on all lubricants, preservatives, and chemicals				
					GEN.14	MDR: List of documents, drawings, and other submittals				
					GEN.15	Nondestructive testing procedures				
					GEN.16	Performance and current/speed/torque curves				
					GEN.17	Performance and optional test procedures				
					GEN.18	Plan, schedule, and progress reports				
					GEN.19	Scope of supply drawing				
					GEN.20	Shipping List				
					GEN.21	Spare parts recommendations				
					GEN.21	Tabulation of utility requirements				
					GEN.23	Technology readiness level self-assessment				
					GEN.24	Vibration Analyses and Data				
					GEN.25	Weight report				

SUBSEA PUMPS DRAWING & DATA REQUIREMENTS API 17X FOR SITE SERVICE	JOB PURCHASE ORDER REQUISITION INQUIRY PAGE REVISION UNIT NUMBER REQUIRED	 OF	ITEM DATE DATE DATE BY

Proposal	Engineering Documentation	System Engineering Design Review/Freeze	Manufacturing Record Book	User Manual	VDDR Note Reference Number		Proposal Acceptance	System Engineering Design Review/Freeze	FAT/EFAT	Final Supply
						Verification				
					VER.1	Barrier fluid and cooling system dynamic studies				
					VER.2	Control system dynamic studies				
					VER.3	Damped unbalanced response analyses				
					VER.4	Electrical system response analyses				
					VER.5	Thermal expansion				
					VER.6	Torsional critical speed analysis				
						MRB				
					MRB.1	As-built clearances				
					MRB.2	Barrier Fluid / Sealing Fluid drawings, manufacturing data, and bills of materials				
					MRB.3	Bearing Assembly drawings, manufacturing data, and bills of materials				
					MRB.4	Certified dimensional outline drawing				
					MRB.5	Certified hydrostatic test data				
					MRB.6	Certified rotor balance data				
					MRB.7	Cooler assembly drawing, manufacturing data, and bills of materials				
					MRB.8	Coupling assembly drawing, manufacturing data, and bills of materials				
					MRB.9	Electrical and instrumentation schematics, wiring diagrams, and bills of materials				
					MRB.10	Lubricating oil schematic, manufacturing data, and bills of materials				
					MRB.11	Material certificates				
					MRB.12	Mechanical / Shaft seal drawing and bills of materials				
					MRB.13	Primary and auxiliary flushing system schematics and bills of materials				
					MRB.14	Rotor assembly drawing, manufacturing data, and bills of materials				
					MRB.15	General and Sub assembly dimensional verification				
						FAT Specific				
					FAT.1	Noise and vibration data				
					FAT.2	Residual unbalance check				

SUBSEA PUMPS DRAWING & DATA REQUIREMENTS API 17X FOR SITE SERVICE	JOB PURCHASE ORDER REQUISITION INQUIRY PAGE OF REVISION UNIT NUMBER REQUIRED	ITEM DATE DATE DATE BY

Proposal	Engineering Documentation	System Engineering Design Review/Freeze	Manufacturing Record Book	User Manual	VDDR Note Reference Number		Proposal Acceptance	System Engineering Design Review/Freeze	FAT/EFAT	Final Supply
					FAT.3	Rotor mechanical & electrical runout for pumps with non-contacting vibration probes				
						User Manual				
					USE.1	Allowable flange loadings (can be part of certified outline drawing)				
					USE.2	Cross-sectional drawings and bills of materials				
					USE.3	Installation, inspection, and retrieval manual				
					USE.4	Lifting / running procedures, and relevant data				
					USE.5	List of handling and maintenance tools				
					USE.6	Operation and maintenance manual				
					USE.7	Preservation, packaging, and shipping procedures				
					USE.8	ROV Panel images and drawings				

D.1 Details

The entries above are described in more detail in Table , which provides guidelines as to the intended content of each entry.

Table D.2—Details and Comments to Table D.1

Manufacturer Drawing and Data Requirement Reference	Description
General	
GEN.1	**Barrier fluid/cooling system GA and component drawings**
	Document should describe – pumps – reservoirs and accumulators – valves – tubing – coolers
GEN.2	**Barrier philosophy report**
	Document should describe physical safety barriers as implemented in design – isolation valves – caps Document and illustrations should describe barriers for items as installed as well as barriers on the retrieved and unretrieved portions of the pump module and subsea facility
GEN.3	**Cause and effect report**
	Document should describe: – alarms – shutdown limits – operational setpoints – operational sequencing.

Manufacturer Drawing and Data Requirement Reference	Description
GEN.4	**Control system and GUI description**
	Control system and GUI description – instrumentation, safety devices, control schemes – control, alarm, and trip settings (pressure and recommended temperatures), – vibration alarm and shutdown limits, – bearing temperature alarm and shutdown limits, – lubricating oil temperature alarm and shutdown limits. – system interlocks
GEN.5	**Data sheets**
	Data sheets applicable to proposals, purchase and as-built Including auxiliary systems, single line, and wiring diagrams
GEN.6	**Electrical and instrumentation arrangement drawing and list of connections**
GEN.7	**Export control tagging document**
GEN.8	**Displacement system design**
GEN.9	**Inspection Plan**
GEN.10	**List of handling and maintenance tools**
GEN.11	**List of special tools furnished**
GEN.12	**Materials specifications and welding procedures**
GEN.13	**MSDS information on all lubricants, preservatives, and chemicals**
GEN.14	**MDR: List of documents drawings and submittals**

Manufacturer Drawing and Data Requirement Reference	Description
GEN.15	**Nondestructive testing procedures**
GEN.16	**Performance and current/speed/torque curves**
	For proposal: preliminary or simulated data, – Average torque versus speed during starting at rated voltage and minimum starting conditions (voltage and short circuit MVA). – Current versus speed during starting at rated voltage and minimum starting conditions (voltage and short circuit MVA). – The expected moment of inertia of the rotor. – Estimated times for acceleration at rated voltage and minimum starting conditions (voltage and short circuit MVA) s. – The locked-rotor (stalled) withstand time with the motor at ambient temperature and at its maximum rated operating temperature for rated voltage and minimum starting conditions (voltage and short circuit MVA). – Expected and rated operating point efficiencies. For final supply, – Performance test data for both motor alone and pump/motor assembly including: – certified shop logs of the performance test, – record of shop test data For induction motors, less than 150 kW (200 hp), certified test reports for all test run and performance curves as follows: – speed-torque curves – efficiency and power factor curves at one-half, three-quarter, and full load. For induction motors, larger than 150 kW (200 hp) and larger, certified test reports for all test run and performance curves as follows: – Time current heating curve – speed-torque curves at 70%, 80%, 90%, and 100% of rated voltage – efficiency and power factor curves from 0 to rated service factor – current vs load curves from 0 to rated service – current vs speed curves from 0 to 100% of rated speed For Pump/motor assembly,

Manufacturer Drawing and Data Requirement Reference	Description
	– total rotor moment of inertia, See also separate sections for application specific testing, qualification, or FAT/EFAT
GEN.17	**Performance and optional test procedures**
GEN.18	**Plan, schedule, and progress reports**
	Progress reports and delivery schedules, including manufacturer buy-outs and milestones, progress reports detailing the cause of any delays: the reports should include engineering, purchasing, manufacturing and testing schedules for all major components. Planned and actual dates, and the percentage completed, should be indicated for each milestone in the schedule.
GEN.19	**Scope of supply drawing**
	The drawings should indicate the extent of the system to be supplied by Manufacturer and the extent to be supplied by others.
GEN.20	**Shipping List**
	Shipping list, including all major components that will ship separately.
GEN.21	**Spare parts recommendations**
GEN.22	**Tabulation of utility requirements**
	Tabulation of utility requirements including power, coolant, lubricant, chemicals, and heat loads
GEN.23	**Technology readiness level self-assessment**

Manufacturer Drawing and Data Requirement Reference	Description
GEN.24	**Vibration Analyses and Data**
	For proposal stage: relevant vibration results from previous supply/qualification For final supply: data from FAT/EFAT/Application Specific Testing The FAT results report includes vibration data from steady state and transient (startup and/or shutdown) operation. The transient data to include: Bode plots, Waterfall plots, and Centerline plots. These are over the speed range where the machine can be operated continuously. The steady state data to include: Shaft Unfiltered and Synchronous Orbits; FFT's. These are over the speed range where the machine can be operated continuously.
GEN.25	**Weight report**
	The document should describe the total mass of each item of equipment (motor and auxiliary equipment) plus loading diagrams, heaviest mass, and name of part
Verification	
VER.1	**Barrier fluid and cooling system dynamic studies**
	The document to cover agreed application specific scenarios: – steady-state – transient Each to include system-wide flow and pressure responses at each use point and agreed operational transients. These analyses should also include steady-state and thermal transient details of the cooler design.
VER.2	**Control system dynamic studies**
	The document to cover agreed application specific scenarios: – steady-state – transient Each to include system-wide flow and pressure responses at each use point and agreed operational transients

Manufacturer Drawing and Data Requirement Reference	Description
VER.3	**Damped unbalanced response and Lateral Critical Speed analyses**
	The analysis reports should be supplied prior to systems engineering review, no later than 3 months after the date of order. Lateral critical speed analysis The lateral critical speed analysis results that need to be reported shall include: - Damped natural frequencies and damping ratios; - Shaft vibration predictions from unbalance response analysis for the unbalance distributions that excite different rotor mode shapes. These are for four times the rotor balance grade as is typical in other machinery API standards.
VER.4	**Electrical system response analyses**
	The document to cover agreed application specific scenarios: – steady-state – transient Each to include system-wide responses at each use point and agreed operational transients
VER.5	**Pressure casing, piping and thermal expansion evaluations**
	The document to cover agreed application specific scenarios: – steady-state pressure containment – transient pressure responses – erosion evaluations – surge, slug, and water-hammer – piping vibration including hydraulic and chemical tubing
VER.6	**Torsional critical speed analysis**
	The analysis reports should be supplied prior to systems engineering review, no later than 3 months after the date of order.
Manufacturing Record Book	

Manufacturer Drawing and Data Requirement Reference	Description
MRB.1	**As-built clearances**
MRB.2	**Barrier Fluid / Sealing Fluid drawings, manufacturing data, and bills of materials**
	The document to include: – primary and auxiliary seal drawings and bills of materials – seal/barrier fluid, fluid flows, pressure, pipe and valve sizes, instrumentation, and orifice sizes.
MRB.3	**Bearing Assembly drawings, manufacturing data, and bills of materials**
MRB.4	**Certified dimensional outline drawing**
	Certified dimensional outline drawing – size, location, and purpose of all Purchaser connections, including conduit, instrumentation, and any piping or ducting; – ASME rating and facing for any flanged connections; – size and location of bolt holes and thicknesses of sections through which bolts should pass; – total mass of each item of equipment (motor and auxiliary equipment) plus loading diagrams, heaviest mass, and name of the part; – overall dimensions and all horizontal and vertical clearances necessary for dismantling, and the approximate location of lifting lugs; – shaft centerline height; – shaft end dimensions, plus tolerances for the coupling; – direction of rotation. – size and locations of external alignment devices (guideposts, pins, etc.)
MRB.5	**Certified hydrostatic test data**
	Including pressure plots from body tests
MRB.6	**Certified rotor balance data**
MRB.7	**Cooler assembly drawing, manufacturing data, and bills of materials**

Manufacturer Drawing and Data Requirement Reference	Description
MRB.8	**Coupling assembly drawing, manufacturing data, and bills of materials**
MRB.9	**Electrical and instrumentation schematics, wiring diagrams, and bills of materials**
MRB.10	**Lubricating oil schematic, manufacturing data, and bills of materials**
MRB.11	**Material certificates**
MRB.12	**Mechanical / Shaft seal drawing and bills of materials**
MRB.13	**Primary and auxiliary flushing system schematics and bills of materials**
MRB.14	**Rotor assembly drawing, manufacturing data, and bills of materials**
MRB.15	**General and sub -assembly dimensional verification**
	General and Sub assembly dimensional verification of – Rotors/impellers, etc. – Shafts – Gears – Seals and seal surfaces – Bearings and mating surfaces – Overall dimensions including interfaces
FAT Specific	
FAT.1	**Noise and vibration data**
FAT.2	**Residual unbalance check**
FAT.3	**Rotor mechanical & electrical runout for pumps with noncontacting vibration probes**
User Manual	

Manufacturer Drawing and Data Requirement Reference	Description
USE.1	**Allowable flange loadings (can be part of certified outline drawing)**
USE.2	**Cross-sectional drawings and bills of materials**
USE.3	**Installation, inspection, and retrieval manual**
USE.4	**Lifting / running procedures, and relevant data**
	Lifting and handling drawings and data including baskets and slings and including weights, dimensioned general assembly drawings, centers of gravity and details of lifting lugs
USE.5	**List of handling and maintenance tools**
USE.6	**Operation and maintenance manual**
	Operation and maintenance manual should include – start-up, including tests and checks before start-up, – operating limits including number of successive attempts to start – planned and emergency shutdown – routine operations – barrier fluid / lubricant recommendations
USE.7	**Preservation, packaging, and shipping procedures**
USE.8	**ROV Panel images and drawings**

Bibliography

[1] API Specification 17E, *Specification for Subsea Umbilicals*.

[2] API Recommended Practice 17N, *Recommended Practice for Subsea Production System Reliability and Technical Risk Management*

[3] API RP 17Q, *Subsea Equipment Qualification—Standardized Process for Documentation*

[4] API Recommended Practice 17R, *Recommended Practice for Flowline Connectors and Jumpers*

[5] API Recommended Practice 17S, *Recommended Practice for the Design, Testing, and Operation of Subsea Multi-phase Flow Meters*

[6] API Specification 20B, *Open Die Shaped Forgings for Use in the Petroleum and Natural Gas Industry*

[7] API Specification 20C, *Closed Die Shaped Forgings for Use in the Petroleum and Natural Gas Industry*

[8] API Standard 674, *Positive Displacement Pumps—Reciprocating*

[9] API Standard 675, *Positive Displacement Pumps - Controlled Volume for Petroleum, Chemical, and Gas Industry Services*

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

[11] API Standard 685, *Sealless Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Process Services*

[12] API Technical Report 17TR8 *High-pressure, High-Temperature Design Guidelines*

[13] API Technical Report 17TR9 *Subsea Umbilical Termination (SUT) Selection and Sizing Recommendations*

[14] API Technical Report 17TR10 *Subsea Umbilical Termination (SUT) Design Recommendations*

[15] API Specification Q1 *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

[16] ASME, Boiler and Pressure Vessel Code, Section VIII Div.2: *Rules for Construction of Pressure Vessels, Alternative Rules*

[17] ASME, Boiler and Pressure Vessel Code, Section VIII Div.3: *Rules for Construction of Pressure Vessels, Alternative Rules for Construction of High Pressure Vessels*

[18] DNVGL RP-0034, *Steel forgings for subsea applications*

[19] DNVGL RP_O101, *Technical documentation for subsea projects*

[20] ISO 9712, *Non-destructive testing -- Qualification and certification of personnel*

[21] ISO 14224, *Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment*

[22] ISO 17782, *Petroleum, petrochemical and natural gas industries -- Qualification of manufacturers of special materials*

[23] ISO 23936-2:2011 *Preview Petroleum, petrochemical and natural gas industries -- Non-metallic materials in contact with media related to oil and gas production -- Part 2: Elastomers*

[24] ISO 20815:2018 *Petroleum, petrochemical and natural gas industries — Production assurance and reliability management*

[25] NORSOK M-001[7]: *Materials selection*

[26] NORSOK M-650: *Qualification of manufacturers of special materials*

[27] NORSOK M 710: *Qualification of non-metallic sealing materials and manufacturers*

[7] Norsk Sokkels Konkuranseposisjon, Standards Norway, Strandveien 18, Postboks 252, 1326 Lysaker, Norway, www.standard.no