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Petroleum and natural gas industries — Progressing cavity pump systems for artificial lift —

Part 1:
Pumps

Industries du pétrole et du gaz naturel — Pompes de fond à cavités progressantes pour activation des puits —

Partie 1: Pompes

Reference number
ISO 15136-1:2009(E)

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Foreword

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

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

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

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

ISO 15136-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

This second edition cancels and replaces the first edition (ISO 15136-1:2001), which has been technically revised.

ISO 15136 consists of the following parts, under the general title *Petroleum and natural gas industries — Progressing cavity pump systems for artificial lift*:

- *Part 1: Pumps*
- *Part 2: Surface-drive systems*

Introduction

This part of ISO 15136 has been developed by users/purchasers and suppliers/manufacturers of progressing cavity pumps and is intended for use in the petroleum and natural gas industry worldwide. This part of ISO 15136 provides requirements and information to both parties in the selection, manufacturing, testing, and using progressing cavity pumps as defined in the scope. Further, this part of ISO 15136 addresses supplier requirements, which set the minimum parameters with which it is necessary that suppliers comply to claim conformity with this part of ISO 15136.

This part of ISO 15136 provides grades of requirements for design validation, quality control and functional evaluations allowing the user/purchaser to select each for a specific application. There are three grades of design validation and quality control, and two grades of functional testing. Design validation grade V3 is restricted to legacy products, the basic grade is V2 and the highest grade is V1. Quality control grade 3 is the standard grade and grades 2 and 1 provide additional requirements. Functional evaluation grade F1 requires a hydraulic test of the PCP and grade F2 does not. The user/purchaser has the option of specifying requirements supplemental to these grades.

It is necessary that the users of this part of ISO 15136 be aware that requirements above those outlined in this part of ISO 15136 can be needed for individual applications. This part of ISO 15136 is not intended to inhibit a supplier/manufacturer from offering, or the user/purchaser from accepting, alternative equipment or engineering solutions. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the supplier/manufacturer to clearly and completely identify any variations from the requirements of this part of ISO 15136.

Petroleum and natural gas industries — Progressing cavity pump systems for artificial lift —

Part 1:
Pumps

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This part of ISO 15136 provides requirements for the design, design verification and validation, manufacturing and data control, performance ratings, functional evaluation, repair, handling and storage of progressing cavity pumps for use in the petroleum and natural gas industry. This part of ISO 15136 is applicable to those products meeting the definition of progressing cavity pumps (PCP) included herein. Connections to the drive string and tubulars are not covered by this part of ISO 15136.

This part of ISO 15136 includes normative annexes that establish requirements for characterization and testing of stator elastomer material, design validation and functional evaluation. Additionally, informative annexes provide information for PCP elastomer selection and testing, installation, start-up and operation guidelines, equipment selection and application guidelines, functional specification form, used pump evaluation, drive string selection and use, repair and reconditioning procedures and auxiliary equipment.

Equipment not covered by the requirements of this part of ISO 15136 includes bottom-drive systems except for the PCP components, drive-string components and auxiliary equipment such as tag bars, gas separators and torque anchors. These items might or might not be covered by other International Standards. Surface-drive systems are covered in ISO 15136-2.

2 Normative references

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

ISO 34-1, *Rubber, vulcanized or thermoplastic — Determination of tear strength — Part 1: Trouser, angle and crescent test pieces*

ISO 37, *Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties*

ISO 815-1:2008, *Rubber, vulcanized or thermoplastic — Determination of compression set — Part 1: At ambient or elevated temperatures*

ISO 2977, *Petroleum products and hydrocarbon solvents — Determination of aniline point and mixed aniline point*

ISO 4662, *Rubber, vulcanized or thermoplastic — Determination of rebound resilience*

ISO 4666 (all parts), *Rubber, vulcanized — Determination of temperature rise and resistance to fatigue in flexometer testing*

ISO 7619-1, *Rubber, vulcanized or thermoplastic — Determination of indentation hardness — Part 1: Durometer method (Shore hardness)*

ISO 7743, *Rubber, vulcanized or thermoplastic — Determination of compression stress-strain properties*

ISO 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO 11960, *Petroleum and natural gas industries — Steel pipes for use as tubing or casing for wells*

ISO 15136-2, *Petroleum and natural gas industries — Progressing cavity pump systems for artificial lift — Part 2: Surface-drive systems*

ISO 15156 (all parts), *Petroleum and natural gas industries — Materials for use in* H_2S*-containing environments in oil and gas production*

API Spec 11B, *Specification for Sucker Rods*[1)]

ASTM D412-06ae2, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers — Tension*[2)]

ASTM D471, *Standard Test Method for Rubber Property — Effect of Liquids*

ASTM D429-08, *Standard Test Methods for Rubber Property — Adhesion to Rigid Substrates*

ASTM D575, *Standard Test Methods for Rubber Properties in Compression*

ASTM D611-07, *Standard Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents*

ASTM D623, *Standard Test Methods for Rubber Property — Heat Generation and Flexing Fatigue in Compression*

ASTM D624, *Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers*

ASTM D2240-05, *Standard Test Method for Rubber Property — Durometer Hardness*

3 Terms and definitions

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

NOTE For quality system related terms used in this document and not defined below, reference can be made to ISO 9000.

3.1
actual capacity per rpm
volumetric capability determined through functional testing for a specific product

NOTE “rpm” has been retained in this term on the basis that it is part of an established industry terminology. However, it is deprecated by ISO as a unit, in which case it is rendered as the accepted form “r/min.”

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1) American Petroleum Institute, 1220 L Street North West, Washington, DC 20005, USA.

2) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohoken, PA 19428-2959, USA.

3.2
applied torque
torque that is applied to the top of the drive string by the surface drive system

3.3
artificial lift system
assembly of equipment used to transport fluid from a subsurface formation to surface, which may include pump, drive string, prime mover and production tubing

3.4
auxiliary equipment
equipment or components that are outside the scope of this part of ISO 15136 and that are typically selected and/or installed by the user/purchaser

EXAMPLES Tag bars, gas separators and torque anchors.

3.5
bottom-drive system
PCP drive system utilizing a downhole prime mover

3.6
casing
pipe extending from the surface and intended to line the walls of a drilled well

3.7
casing size
nominal casing OD as specified in ISO 11960

3.8
core deflection
radial offset of the stator cavity centre-line from the stator tube centre-line

3.9
corrosive environment
operating environment where the combination of temperature and chemical agents causes degradation of the equipment

3.10
design validation
process of proving a design by testing to demonstrate conformity of the product to design requirements

3.11
design verification
process of examining the premise of a given design by calculation, comparison or investigation, to substantiate conformity with specified requirements

3.12
dogleg severity
localized wellbore curvature

3.13
differential pressure
difference between pump intake and discharge pressures

3.14
downhole capacity per rpm
volumetric capability estimated through calculations and downhole conditions

NOTE “rpm” has been retained in this term on the basis that it is part of an established industry terminology. However, it is deprecated by ISO as a unit, in which case it is rendered as the accepted form “r/min.”

3.15
drive string
device transmitting power (usually sucker rods) between the surface drive system and the PCP

3.16
engaged cavities
number of full cavities created by the interaction between the rotor and stator

3.17
failed item
any item that has failed

3.18
failure
termination of the ability of an item to perform a required function

3.19
failure descriptor
apparent, observed effect of failure (of a failed item)

3.20
failure cause
circumstances during design, manufacture, or use which have led to a failure

3.21
flow rate
volume of fluid pumped per unit of time

3.22
friction torque
resistance to rotation of the drive string (inside the tubing) and the rotor (inside the stator) that is dependent upon factors including (but not exclusive to) well depth and trajectory, pump geometry and interference fit between rotor and stator, and stuffing box characteristics

3.23
function
operation of a product during service

3.24
functional specification
features, characteristics, process conditions, boundaries and exclusions defining the performance and use requirements of the equipment

3.25
functional test
test performed to confirm proper equipment operation

3.26
grade
category or rank given to different requirements for quality or design validation

3.27
head rating
pressure rating expressed in terms of equivalent water column

3.28
hydraulic torque
torque induced by the differential pressure across the pump

3.29
insertable pump
PCP where the stator is run into the well through the production tubing

3.30
item
any part, component, device, subsystem, functional unit, equipment or system that may be individually considered

3.31
manufacturing
process and action performed by an equipment supplier/manufacturer that are necessary to provide finished component(s), assembly(ies) and related documentation, that fulfil the requests of the user/purchaser and meet the standards of the supplier/manufacturer

NOTE Manufacturing begins when the supplier/manufacturer receives the order and is completed at the moment the component(s), assembly(ies) and related documentation are surrendered to a transportation provider.

3.32
maximum operating speed
maximum operating speed for the pump as specified by the supplier/manufacturer

3.33
maximum operating temperature
maximum operating temperature for the pump as specified by the supplier/manufacturer

3.34
model
equipment with unique components and operating characteristics which differentiate it from other equipment of the same type

3.35
no-turn tool
prevents the PCP stator and/or tubing from backing off due to rotational torque caused by the interference fit between the rotor and stator

3.36
nominal capacity per rpm
published volumetric capability based on theoretical calculations and adjusted for commercial purposes

NOTE “rpm” has been retained in this term on the basis that it is part of an established industry terminology. However, it is deprecated by ISO as a unit, in which case it is rendered as the accepted form “r/min.”

3.37
non-conformance
non-fulfilment of a specified requirement, such as the divergence of equipment, part, practice or procedure from an established standard

3.38
operator
user of the equipment

3.39
operator's manual
publication issued by the supplier/manufacturer that contains detailed data and instructions related to the design, installation, operation and maintenance of equipment

3.40
operating environment
set of conditions to which the product is exposed during its full life cycle

3.41
orbit tube
section of oversized production tubing installed immediately above the stator

3.42
PCP geometry
unique combination of pitch, eccentricity and diameter

3.43
performance ratings
ratings for the hydraulic performance of the pump

3.44
pressure rating
rated differential pressure capacity

3.45
primary failed item
failed item within the PCP responsible for initiating the failure of the PCP

3.46
prime mover
motor (typically hydraulic, electric or internal combustion) providing the torque to rotate the pump rotor

3.47
progressing cavity pump
PCP
pump installed in a well consisting of a stator and rotor whose geometry of assembly is such that it creates two or more series of lenticular, spiral, separated cavities

3.48
qualified part
part manufactured under an authorized quality assurance programme and in the case of replacement, produced to meet or exceed the performance of the original part

3.49
qualified person
individual with characteristics or abilities gained through training or experience or both as measured against established requirements, such as standards or tests that enable the individual to perform a required function

3.50
reason for pull
motive for the pump being pulled from the well

3.51
redress
any activity restricted to the replacement of qualified parts

3.52
repair
any activity beyond the scope of redress that includes disassembly, re-assembly and testing with or without the replacement of qualified parts and may include machining, welding, heat treating or other manufacturing operations that restore the equipment to its original performance

3.53
required function
function or a combination of functions of an item, which is considered necessary to provide a given service

3.54
rotor
helical, contoured shaft

3.55
rotor phasing alignment jig
short segment of material moulded to match the rotor profile

3.56
substantial design change
change to the design, identified by the supplier/manufacturer, that affects the performance of the product in the intended service condition

3.57
size
relevant dimensional characteristics of the equipment as defined by the supplier/manufacturer

3.58
slugging
well production characterized by non-homogeneous flow

3.59
stator
segment of tube with an internal helical contoured surface which meshes with a rotor to create a series of lenticular cavities along the length of the tube

3.60
stator phasing alignment jig
short segment of material moulded to match the stator core profile

3.61
swelling process
volume increase of an elastomer when a fluid diffuses into the material due to physical interactions between fluid and the elastomer

3.62
tag bar
assembly attached to the bottom of the stator that limits the distance the rotor may extend past the end of the stator

NOTE Also known as a “stop bushing.”

3.63
technical specification
requirements that shall be fulfilled by the equipment to comply with the functional specification

3.64
test pressure
pressure at which the equipment is tested based upon all relevant design criteria

3.65
test temperature
temperature at which the equipment is tested based upon all relevant design criteria

3.66
torque anchor
device that prevents the PCP stator and/or tubing from backing off due to rotational torque caused by the interference fit between the rotor and stator and that prevents axial movement of the pump relative to the well casing/liner

3.67
tubing
pipe placed within a well to serve as a production or injection conduit

3.68
tubing deployed
PCP system for which the stator is run into the well on the bottom of the tubing string

3.69
type
equipment with unique characteristics that differentiate it from other functionally similar equipment

3.70
unique identifier
unique combination of alphanumeric characters to identify a specific component

3.71
validated capacity per rpm
volumetric capability determined through design validation testing

NOTE “rpm” has been retained in this term on the basis that it is part of an established industry terminology. However, it is deprecated by ISO as a unit, in which case it is rendered as the accepted form “r/min.”

3.72
wellhead
composite of equipment used at the surface to maintain control of the well

NOTE Included in the wellhead equipment are casing heads (lowermost and intermediate), tubing heads, Christmas tree equipment with valves and fittings, casing and tubing hangers, and associated equipment.

4 Abbreviated terms and symbols

4.1 For the purposes of this part of ISO 15136, the following abbreviated terms apply.

—	BHT	bottomhole temperature
—	C30+	hydrocarbon fractions with more than 30 carbon atoms per molecule
—	CP	failure in the cover cement-prime cement (interfacial failure)
—	d	day (unit of time)
—	GOR	gas oil ratio
—	M	failure in the prime cement-metal interface (interfacial failure)
—	MD	measured depth
—	NDE	non-destructive examination
—	NPSH	net positive suction head
—	PCP	progressing cavity pump
—	PIP	pump intake pressure
—	R	failure of the rubber (substrate failure)
—	RC	failure in the rubber-cover cement (interfacial failure)

— rpm revolutions per minute

— TVD true vertical depth

4.2 For the purposes of this part of ISO 15136, the following symbols are used.

d_r	drive string diameter
Δp	differential pressure
D	minor diameter
e	eccentricity
F_r	drive string axial load
F_t	axial force on threads
F_s	axial force on torque shoulder
P	stator pitch; see Figure G.1
E_all	overall pump efficiency
Q	flow rate at a given differential pressure
Q_eff	volumetric efficiency
$Q_{\Delta\mathrm{p}}$	volumetric flow rate at a differential pressure
Q_o	volumetric flow rate at $\Delta p < 350$ kPa
q_TC	theoretical capacity; see Equation (G.1)
T_r	drive string torque
T_s	torsion on torque shoulder
T_t	torsion on threads
$\dot{W}_\mathrm{eff}$	mechanical pump efficiency at specified pressure and flow rate
$\dot{W}_\mathrm{fluid}$	fluid power
$\dot{W}_\mathrm{shaft}$	input power at the pump shaft
δ	phase or loss angle
σ_e	effective stress
τ	shaft torque
ω	shaft speed

5 Functional specification

5.1 General

The user/purchaser shall prepare a functional specification to order products that conform to this part of ISO 15136 and specify the following requirements and operating conditions as appropriate and/or identify the supplier/manufacturer's specific product. This information is used by the supplier/manufacturer to recommend the PCP and/or components for the application. These requirements and operating conditions may be conveyed by means of a user/purchaser functional-specification form (Annex H) and operational guidelines (Annex F). The user/purchaser shall specify the units of measurement for the data provided.

PCPs are designed for specific applications; their use in new/different applications requires a detailed evaluation by the user/purchaser to ensure that the system can operate properly in all aspects in that new application. Annexes E and F contain installation and operational guidelines that can be relevant in this consideration. The process used to evaluate the new application shall be no less stringent than that required for the initial application.

5.2 PCP type description

The user/purchaser shall select a PCP on the basis of the following conditions:

a) production requirements;

b) fluid characteristics;

c) surface equipment configuration;

d) stator conveyance method, such as drive string, tubing, wireline, coiled tubing.

5.3 Functional requirements

5.3.1 Application parameters

5.3.1.1 General

While installed, the PCP shall perform in accordance with its functional requirements, which are typically determined based on application parameters. These parameters include, but are not limited to, those listed in 5.3.1.2 to 5.3.3.4, as applicable.

5.3.1.2 Well information

The following well information shall be specified, as applicable:

a) operating environment, such as thermal recovery, abrasive conditions, corrosive environments, heavy and conventional oil production, and coal bed methane applications;

b) well type, such as vertical, slant, deviated or horizontal;

c) well directional survey, as applicable;

d) wellhead location, such as onshore, platform or subsea;

e) reservoir type, such as carbonate, consolidated sandstone, unconsolidated sandstone, coal, or shale;

f) reservoir recovery mechanism or process, such as aquifer drive, solution-gas drive, water flood, thermal, coal dewatering, enhanced oil recovery, such as CO_2 flood, water-alternating-gas, or polymer flood;

g) completion type, such as perforated casing, open hole, slotted liner, gravel pack, or sand screen;

h) previous production history using PCPs and other operating practices, such as other artificial lift methods and flowing well;

i) service-life expectation, such as total production volume, revolutions, days, years.

5.3.1.3 Completion information

The following completion information shall be specified, as applicable:

a) pump setting depth in terms of MD and TVD of the pump intake;

b) depth of producing interval in terms of MD and TVD;

c) current well total depth, such as plug-back depth in terms of MD and TVD;

d) in cases where no well deviation survey is provided:

  — inclination (hole angle) and wellbore curvature (if applicable) at pump seating depth,

  — maximum wellbore curvature (maximum dogleg severity) between wellhead and pump seating depth through which it is necessary for the PCP to pass through during installation;

e) casing size, including outside diameter and mass (weight), connection type and grade of production casing;

f) minimum drift diameter between wellhead and pump seating depth;

g) minimum drift diameter at pump seating depth;

h) production tubing size, including outside diameter, mass (weight), connection type and grade;

i) production tubing inner coating type and thickness;

j) pump intake type preference, such as slotted, selective, static gas separator, tail joint;

k) torque anchor type;

l) measured depth to the top of the torque anchor;

m) other well dimensions that can restrict pump installation or operation.

5.3.1.4 Operating and production information

The following operating and production information shall be specified, as applicable:

a) total liquid rate at standard conditions (15 °C, atmospheric pressure);

b) water cut by percentage volume of produced liquids or producing oil and water rates;

c) sand cut, expressed as percent by volume;

d) maximum and minimum operational speed, expressed in revolution per minute;

e) wellhead pressure;

f) wellhead fluid temperature;

g) casing-head pressure;

h) static or shut-in pressure at the pump intake;

i) static or shut-in reservoir pressure at a reference depth;

j) static or shut-in temperature at the pump intake;

k) static or shut-in reservoir temperature at a reference depth;

l) producing gas-oil ratio or measured gas rate at standard conditions (15 °C, atmospheric pressure);

m) ratio of casing-gas rate to tubing-gas rate at standard conditions (15 °C, atmospheric pressure) and/or downhole free-gas-separation efficiency;

n) PIP, expressed as one of the following:

  - producing pressure at the pump intake,
  - producing fluid level (metres to fluid), annular gradient/density and casing-head pressure,
  - reservoir static pressure and productivity index,
  - static fluid level and productivity index;

o) slugging tendency, such as gas, water, solids, steam.

5.3.2 Environmental compatibility

The user/purchaser shall specify the environmental compatibility requirements. The following parameters shall be supplied, as applicable:

a) for oil:

  - density at standard temperature and pressure (15 °C, atmospheric pressure);
  - compositional analysis, including, but not limited to
    - type and concentration of aromatic species,
    - aniline point;
  - viscosity at test conditions and/or operating conditions;
  - bubble-point pressure at reservoir temperature;

b) for water:

  - pH;
  - density;
  - chloride concentration;

c) for gas:

- composition, such as
  - CO_2 concentration, expressed as a mole percentage,
  - H_2S concentration, expressed as a mole percentage,
  - steam temperature, pressure and quality;
- specific gravity;

d) for solids:

- history of solids-related problems, such as erosion, plugging, wear;
- morphology, such as size, structure, angularity, composition;
- scale-deposition tendency;
- asphaltene and/or paraffin deposition tendency;

e) other:

- emulsion properties, such as
  - inversion point (percentage water cut),
  - emulsion viscosity at downhole operating conditions over predicted pump life,
  - emulsion forming tendency;
- foamy oil behaviour;
- other fluid types and concentrations, such as diluent, corrosion/scale inhibitor, completion fluid, dispersants and injection points in the wellbore.

5.3.3 Compatibility with related well equipment and services

5.3.3.1 General

The user/purchaser shall specify, where applicable, the interface connection designs and material requirements, and external dimensional limitations, required to assure that the product shall conform to the intended application.

5.3.3.2 Drive system

The following topics shall be considered for the application:

a) type: surface or bottom drive;

NOTE Surface-drive systems are covered in ISO 15136-2.

b) torque, speed and axial load limitations;

c) for bottom-drive systems:

- type of drive, such as electric, hydraulic,
- operational limitations, such as heat generation, flow restriction on intake or discharge,
- maximum outside diameter, length and position, above or below PCP,
- gearbox ratio.

5.3.3.3 Drive string

The following topics shall be considered for the application:

a) type, such as standard, continuous, hollow;

b) material grade;

c) diameter of body;

d) connection type and description;

e) torque and axial load rating;

f) rotating centralizer type, description and number installed;

g) guide type, description and number installed.

5.3.3.4 Accessory equipment and well operation

The following topics shall be considered for the application:

a) OD of injection tubing string and injection point, such as above pump, below pump, annulus, tubing string;

b) subsurface instrumentation OD, length and location, such as above or below pump, as applicable;

c) subsurface equipment OD, ID, length, location relative to the pump and attachment to the pump, such as interfaces with tag bars, no-turn tools, gas separators, tail pipes, backflow valves;

d) well intervention limitations, such as minimum polished rod length, pump length, maximum coiled tubing diameter.

5.4 Design validation

The user/purchaser shall specify one of the following three design-validation grades defined by this part of ISO 15136:

- V1: highest level of design validation;
- V2: basic design validation;
- V3: legacy.

The principal requirements for each design validation grade are presented in Annex B.

5.5 Product functional evaluation

The user/purchaser shall specify one of the following two product functional evaluation grades defined by this part of ISO 15136:

- F1: functional hydraulic test of the pump:

  The user/purchaser may specify the volumetric efficiency range, test fluid, pump speed, fluid temperature and pressures for use in the functional test.

- F2: functional evaluation without bench testing:

  The user/purchaser shall specify the volumetric efficiency range, fluid, pump speed, fluid temperature and pressures as applicable for use in the functional evaluation.

The principal requirements for each product functional evaluation grade are presented in Annex C.

5.6 Quality control grades

The user/purchaser shall specify one of the following three quality control grades defined in Clause 7.

- Q1: highest level of quality control;
- Q2: intermediate level of quality control;
- Q3: basic level of quality control.

5.7 Additional documentation

Additional documentation, such as operator's manuals, certificate of compliance and/or product data sheet, above that required for a specific quality grade may be requested by the user/purchaser.

5.8 Additional requirements

The user/purchaser may specify additional design verification, design validation testing and/or product functional evaluation that is deemed necessary for a specific application. These requirements shall be in addition to those specified in Annexes B and C.

Application-specific elastomer compatibility and bond testing, when requested, shall be performed in accordance with Annex D. These requirements shall be in addition to those specified in Annex A.

6 Technical specification

6.1 General

The supplier/manufacturer shall prepare the technical specification that responds to the requirements defined in the functional specification. The supplier/manufacturer shall also provide the user/purchaser with the product data defined in Clause 7.

6.2 Technical characteristics

The following criteria shall be met.

- The PCP shall move fluid from downhole to the surface against a differential pressure and shall do so until intentional intervention defines otherwise. Exceptions to this are service-life limitations associated with normal equipment wear or deterioration.
- While installed, the PCP shall perform in accordance with its functional specification.
- Where applicable, the PCP shall be compatible with related well equipment and services.

6.3 Design criteria

6.3.1 Materials

Metallic and non-metallic materials shall be specified by the supplier/manufacturer and shall be appropriate for the requirements in the functional specification. The supplier/manufacturer shall have written specifications for all materials and all materials used shall comply with these specifications.

Materials substitutions in validated equipment designs are allowed without validation testing provided that the supplier/manufacturer's materials-selection criteria are documented and approved by a qualified person and meet all other requirements of this part of ISO 15136.

6.3.2 Metals

6.3.2.1 General

In a PCP, the primary metal components are the stator tube and associated connecting assemblies and the rotor, which is normally coated or plated.

The supplier/manufacturer's specifications shall define the materials for the stator tube and rotor bar that are appropriate for the application, taking into account the following:

a) chemical-composition limits;

b) mechanical-property limits:
  - tensile strength,
  - yield strength,
  - elongation,
  - hardness.

The rotor bar shall be of sufficient strength that the profile and connection can withstand the combined torsional and axial loads within the specified operational range for the pump model. When bending loads and alternating combined loads are anticipated, the rotor-strength evaluation shall consider the effect of fatigue. High-temperature applications shall also de-rate material strength as appropriate for the application. The resulting design verification shall be approved by a qualified person.

Material test reports provided by the material supplier or the manufacturer may be used to verify compliance of the material to the specifications.

6.3.2.2 Welds

Welds in rotor and stator components shall be in accordance with the supplier/manufacturer's specifications as defined in 7.6.3. Weld identification and examination shall be in accordance with the specified quality grade.

6.3.3 Rotor coating or surface treatments

Rotor coating or surface-treatment type and thickness (if applicable) shall take into consideration the fluid characteristics of the operating environment specified in the functional requirements, in particular the abrasiveness, as well as any special chemical treatments that are anticipated. The supplier/manufacturer's specifications shall define the characteristics and acceptance criteria of the rotor coating or treatment, including

a) the basic coating or surface treatment composition;

b) the effective surface hardness;

c) the minimum and maximum coating thickness on rotor peak and valley, if applicable;

d) the surface roughness.

6.3.4 Stator elastomer and bond system

The stator elastomer and bond system shall comply with Annex A, which contains detailed information on elastomer classifications, characteristics and test procedures.

The supplier/manufacturer shall have documented procedures and evaluations, the results of which shall verify that the stator elastomer material and bond system used are suitable for use in the specific PCP configuration, environment and application as defined in the functional specification. These evaluations shall be performed and the results approved by a qualified person and shall consider test data and the historical performance of the elastomer and bond system in combinations of pressure, temperature and fluids similar to those in the functional specification.

6.4 Dimensional information

6.4.1 Rotor-stator fit

The supplier/manufacturer shall have documented procedures performed by qualified personnel to select the appropriate rotor-stator fit to meet the requirements of the functional specification. Annex G provides information on considerations for selecting rotor-stator fit.

6.4.2 Dimensional limits

PCP components shall be dimensioned such that they can be run through and, where required, operated in the specified well curvatures. For tubing-deployed configurations, the stator shall provide adequate annular space for gas separation and, in instances where the PCP is landed below the perforations, provide for fluid passage without excessive pressure drops. In the event that the functional specification includes equipment such as secondary tubing strings for injection/flushing or instrumentation cables, the stator assembly shall allow the required annular space.

The supplier/manufacturer shall specify the following:

a) stator OD and maximum OD of the stator assembly; the stator assembly shall pass through the casing for a tubing-deployed pump and through the tubing for insertable pumps and all other devices that are part of these strings;

b) major diameter of the rotor and maximum diameter of the rotor assembly; the rotor assembly shall pass through the production tubing and all other devices that are part of the tubing string;

c) orbit diameter of the rotor profile and rotor connection; the eccentric motion of the rotor and the rotor connection shall be less than the inside diameter of the production tubing or orbit tube immediately above the stator;

d) total assembly lengths and masses (weights) of the rotor and stator.

6.5 Performance ratings

6.5.1 Volume capability

The supplier/manufacturer shall provide the nominal capacity per rpm and validated capacity per rpm for each basic pump geometry. These parameters shall be expressed in terms of a fluid rate at a given speed as $(m^3/d)/(100\ r/min)$.

The validated capacity per rpm shall be determined through validation testing as outlined in 6.7 and detailed in Annex B. Additional discussion on volume capability is provided in Annex G.

6.5.2 Pressure and head rating

The supplier/manufacturer shall provide the PCP pressure rating, head rating, pressure per cavity and number of engaged cavities.

Pressure ratings shall be confirmed through validation testing as outlined in 6.7 and detailed in Annex B. Additional discussion on pressure rating is provided in G.5.

6.5.3 Design performance curves

The supplier/manufacturer shall prepare the design performance curves for each model that displays fluid rates as a function of differential pressure and pump speed. At a minimum, these curves shall present calculated data from zero pressure to the pump pressure rating, at speeds of 100 r/min, 200 r/min and 300 r/min with a nominal rotor and stator fit.

6.5.4 Volumetric efficiency

The supplier/manufacturer shall prepare design performance curves representing predicted performance under conditions specified in the functional specification.

NOTE Actual volumetric efficiencies can vary significantly over the wide range of potential downhole and operating conditions. Volumetric efficiency represents a combination of the pump volumetric efficiency and the inefficiency implied by the differences between the multiphase fluid rate at the pump intake and the surface liquid rate. See Annex G for more information.

6.5.5 Design pump speed, torque and power

The supplier/manufacturer shall prepare the design hydraulic and total torque and power values for the PCP design as a function of differential pressure and speed. Where appropriate, the supplier/manufacturer shall specify maximum torque and minimum and maximum rotational speed values.

NOTE Additional discussion on pump speed, torque and speed is provided in Annex G. It is necessary that the design hydraulic and total torque and power values be used cautiously since they might not be representative of downhole conditions. Experience is used to translate these values to expected performance under downhole conditions.

6.5.6 Maximum pump intake gas volume fraction

The supplier/manufacturer shall provide the maximum pump intake gas volume fraction that can be handled by the pump. The supplier/manufacturer shall have a documented process that supports the reported maximum pump-intake gas-volume fraction.

NOTE While PCPs are capable of pumping gas, it results in non-uniform pressure loading within the pump and a reduced ability to remove internal frictional heat. The resulting mechanical loads and temperatures within the pump can have a detrimental impact on pump service life.

6.6 Design verification

Design verification shall be performed by the supplier/manufacturer to verify that the product design meets the technical specifications. Design verification includes documented activities such as review of design calculations, product testing and comparison with similar designs and historical records of defined operating conditions. Empirical methods and/or physical testing used in design verification shall be fully documented and supported with drawings and material specifications.

The results of design verification shall be documented and include a review of the fundamental geometry and its ability to meet the volume and pressure capacity requirements, dimensional limits, strength characteristics and tolerances to ensure that it meets the technical specifications. All design verification documentation shall be included in the product design file and be approved by a qualified person other than the design's originator.

6.7 Design validation

Design validation testing shall be performed on each PCP basic design of rotor/stator and elastomer combination to ensure that its design meets the supplier/manufacturer's technical specifications. The design validation grade specifies the design validation process(es), procedure(s) and test(s) required for each validation grade. Annex B provides a detailed description of the three validation grades (V1, V2 and V3) in this part of ISO 15136. Supplemental design validation may be required by the user/purchaser.

NOTE Some applications can require supplemental design validation testing. Examples include pump performance or durability testing with alternative test media and multiphase fluids; minimum pump intake pressure; maximum gas fraction; or advanced elastomer evaluation, such as explosive decompression resistance, compression set, heat resistance, dynamic characterization or H_2S resistance.

6.8 Functional evaluation requirements

Functional evaluation shall be performed in accordance with Annex C and approved by a qualified person to verify that each PCP manufactured meets the supplier/manufacturer's documented requirements, technical specification and the functional specification. The results of these evaluations shall be recorded and become a portion of the quality documentation for that product.

6.9 Allowable design changes

All design changes shall be documented and reviewed by the supplier/manufacturer against the design verification and design validation documents to determine if the change is a substantial change. A substantial design change is a change to the design identified by the supplier/manufacturer that affects the performance of the product in the intended service condition. A design that undergoes a substantial change becomes a new design, requiring design verification in accordance with 6.6 and design validation in accordance with 6.7.

All design changes and modifications shall be identified, documented, reviewed and approved before their implementation and meet the applicable validation test requirements of this part of ISO 15136. Justifications for design changes that are identified as non-substantial shall be documented. The supplier/manufacturer shall, at a minimum, consider the following for each design change:

a) stress levels in the modified or changed components;

b) material changes;

c) functional changes.

6.10 Scaling of design validation

Scaling may be used to validate new designs and design variations based on previously validated designs with the following limitations.

a) Scaling applies only to designs validated to V1 or V2.

b) Elastomer and bond validation in accordance with Annex A shall apply only to the specific elastomer compound tested. Scaling of this validation is not allowed for other elastomer compounds. Scaling of this validation is allowed for any designs that utilize the tested elastomer compound.

c) Durability validation in accordance with Annex B can be scaled to design variations, including elastomer compounds that utilize the same stator geometry as the tested product, as long as the elastomer compound used in the design variation has been previously validated in a durability test on any stator geometry.

d) Hydraulic validation in accordance with Annex B shall apply only to the specific elastomer compound and stator geometry combination tested. Hydraulic validation may be scaled to any design variations that utilize the same elastomer compound and stator geometry as the tested product.

7 Supplier/manufacturer requirements

7.1 General

The detailed requirements to verify that each product manufactured meets the requirements of the functional and technical specifications for each specific product are contained in Clause 7.

7.2 Documentation and data control

7.2.1 General

The supplier/manufacturer shall establish and maintain documented procedures to control all documents and data that relate to the requirements of this part of ISO 15136. These documents and data shall be maintained to demonstrate conformance to specified requirements. All documents and data shall be legible and shall be sorted and retained in such a way that they are readily retrievable in facilities that provide suitable environments to prevent damage or deterioration and to prevent loss.

Documents and data may be in any type of media, such as hard copy or electronic media. All documents and data shall be available and auditable by the user/purchaser. Design documents and data shall be maintained for five years after date of last manufacture of that product.

7.2.2 Design documentation

Documentation of the design process for each type, size and model of pump shall include the following as a minimum:

a) design criteria;

b) functional and technical specifications;

c) engineering drawings and bill of materials;

d) applicable specifications and standards;

e) validation testing procedures, acceptance criteria and approved results;

f) functional evaluation procedures and acceptance criteria;

g) design changes and design change justifications, if applicable.

7.2.3 Delivery documentation

Documentation supplied at the time of delivery of a product to the user/purchaser shall include the following as a minimum:

a) name and address of supplier/manufacturer;

b) supplier/manufacturer product identification;

c) functional evaluation documentation according to specified functional grade;

d) quality documentation according to specified quality grade.

7.2.4 Operator's manual

When required by the quality grade or the user/purchaser, an operator's manual shall be supplied and shall contain the following information as a minimum:

a) name and address of supplier/manufacturer;

b) supplier/manufacturer product identification;

c) representative illustration(s) identifying major components, significant dimensions and configurations and details of the interface connections;

d) handling and storage guidelines;

e) pre-installation inspection and pre-service procedures;

f) installation guidelines, including make-up procedures for all pump components and rotor space-out (see Annex E);

g) operating and troubleshooting guidelines, including precautions for safe and environmentally acceptable operation.

7.2.5 Certificate of compliance

When required by the quality grade or the user/purchaser, certificates of compliance shall be supplied and shall state that the product meets the following requirements, as a minimum:

a) quality grade;

b) functional grade;

c) validation grade.

The statement shall include the product identification and shall be approved by the supplier/manufacturer's designated qualified person.

7.2.6 Product data sheet

When required by the quality grade or the user/purchaser, a product data sheet shall be supplied and shall contain the following, as a minimum:

a) product identification;

b) name and address of supplier/manufacturer;

c) conveyance method;

d) nominal capacity per rpm;

e) validated capacity per rpm;

f) pressure rating;

g) pressure per cavity;

h) number of engaged cavities;

i) design performance curves;

j) torque and power curves;

k) maximum pump-intake free-gas volume fraction;

l) minimum and maximum speed;

m) rotor length and mass (weight);

n) stator assembly length and mass (weight);

o) rotor major, minor and orbit diameter;

p) stator outside diameter and maximum outside diameter of stator assembly;

q) end connections for rotor and stator;

r) rotor coating type and thickness;

s) operator's manual identification.

7.2.7 Elastomer data sheet

When required by the quality grade or the user/purchaser, an elastomer data sheet shall be provided and shall contain, as a minimum, the following items as defined in Annex A:

a) stator elastomer classification;

b) fluid resistance;

c) mechanical properties;

d) maximum operating temperature;

e) unaged bond properties.

7.3 Product identification

Each furnished rotor and stator shall be permanently identified according to the supplier/manufacturer's specifications, which shall include the type and method of application. The following information is the minimum that shall be marked on each product:

a) supplier/manufacturer's identifier;

b) unique identifier;

c) each stator shall be identified with month and year of manufacturer stated as mm-yyyy;

d) each stator shall be identified with “ISO-vvv-hhhh-eee” no more than 1 m from the end of the stator where

- vvv is the nominal capacity per rpm, expressed in units of $m^3/(100\ r/min)$,
- hhhh is the nominal head rating, expressed in units of metres of water,
- eee is the elastomer code;

e) each rotor shall be identified with a minimum of ISO-vvv-hhhh-rrr on the rotor head where

- vvv is the nominal capacity per rpm, expressed in units of $m^3/(100\ r/min)$,
- hhhh is the nominal head rating, expressed in units of metres of water,
- rrr is the rotor size code;

f) repaired equipment shall be identified following the supplier/manufacturer unique identifier to identify each major repair where

- T indicates rethreading,
- R indicates recoating,
- S indicates straightening.

7.4 Quality

7.4.1 General

The supplier/manufacturer shall have documented quality control procedures implemented by qualified personnel to ensure that each product manufactured conforms to the applicable specifications and drawing standards.

The quality control grades apply to the final product unless otherwise specified.

Table 1 specifies the percentage of products that shall be inspected per purchase order with a minimum of 1. Where the percentage of products inspected is less than 100 %, the supplier/manufacturer and user/purchaser shall agree on the process for selecting representative specimens.

Testing methods specified in Table 1 are considered as the minimum requirements to meet the quality grade. Conformance to the requirements of a higher quality grade automatically qualifies the final product for lower grades. These procedures include acceptance criteria for all manufactured products furnished to this part of ISO 15136.

The requirements defined in Table 1 shall be implemented in accordance with the referenced subclauses.

Table 1 — Inspections required for each quality grade

Inspection	Reference	Inspection requirements for quality grades		
		Q3	Q2	Q1
Material certificate (metals and non-metals)	7.5.1	as per supplier/ manufacturer specification	100 % rotors 100 % stators	100 % rotors 100 % stators
Stator elastomer hardness testing	7.9.2	as per supplier/ manufacturer specification	20 %	100 %
Stator elastomer bond testing	7.9.3	as per supplier/ manufacturer specification	20 %	100 %
Stator phasing alignment	7.9.4	as per supplier/ manufacturer specification	as per supplier/ manufacturer specification	100 %
Rotor coating testing	7.9.5 and 7.9.6	as per supplier/ manufacturer specification	thickness, 20 %	thickness, 100 % surface finish, 100 % coupon hardness, 100 %
Rotor phasing alignment	7.9.7	as per supplier/ manufacturer specification	as per supplier/ manufacturer specification	100 %
Stator visual surface defect inspection	7.9.8	as per supplier/ manufacturer specification	basic, 100 %	detailed,100 %
Rotor visual surface defect inspection	7.9.8	as per supplier/ manufacturer specification	100 %	100 %
Core deflection inspection	7.9.10	as per supplier/ manufacturer specification	pass/fail, 100%	quantitative, 100 %
Stator non-destructive weld examination	Q3: 7.9.9.2 Q2: 7.9.9.5 or 7.9.9.6 Q1: 7.9.9.3 or 7.9.9.4	visual	magnetic particle or liquid penetrant, 100 %	radiographic or ultrasonic, 100 %
Rotor non-destructive weld examination	Q3: 7.9.9.2 Q2: 7.9.9.5 or 7.9.9.6 Q1: 7.9.9.3 or 7.9.9.4	visual	magnetic particle or liquid penetrant, 100 %	radiographic or ultrasonic, 100 %
Component dimensional inspection	7.9.11	as per supplier/ manufacturer specification	general dimensions rotor and stator, 100 % rotor profile dimensions, 50 %	general dimensions rotor and stator, 100 % rotor profile dimension, 100 % stator profile dimensions, 100 %
Documentation	7.2.4 to 7.2.7	as per supplier/ manufacturer specification	certificate of compliance product data sheet elastomer data sheet	certificate of compliance operator's manual product data sheet elastomer data sheet

7.5 Raw materials certification

When required by the quality grade or requested by the user/purchaser, raw material used in the manufacture of components shall have a material test report to verify conformance to the properties defined in the supplier/manufacturer's documented material specifications.

7.6 Additional processes applied to components

7.6.1 Documentation

Documentation of the processes described in 7.6.2, 7.6.3 and 7.6.4 shall conform to at least one of the following requirements when approved by a qualified person:

a) certificate of conformance stating that the material and processes applied comply with the supplier/manufacturer's documented specifications and acceptance criteria; or

b) material test report verifying that the materials and processes conform to the supplier/manufacturer's documented specifications and acceptance criteria.

7.6.2 Coatings

The application of coatings and overlays shall be performed according to documented procedures that provide a product that meets the supplier/manufacturer's acceptance criteria.

When required by the quality grade, the rotor surface hardness shall be measured using coupons based on the supplier/manufacturer's sampling programme or in accordance with ISO 2859. Hardness testing and hardness conversion to other measurement units shall be in accordance with a national standard or International Standard, such as ISO 6506-1, ISO 6507-1, ISO 6508-1 or ISO 18265, with the exceptions noted in ISO 15156 for materials that are intended for use in wells where corrosive agents can induce stress corrosion cracking.

7.6.3 Welding

Welding and brazing procedures and personnel qualifications shall be in accordance with a national standard such as ASME BPVC, Section IX, or ANSI/AWS D1.1/D1.1M or an International Standard. Material and practices not listed in the ASME BPVC, Section IX, or ANSI/AWS D1.1/D1.1M shall be applied using weld procedures qualified in accordance with a national standard such as the methods of ASME BPVC, Section IX, or ANSI/AWS B2.1/B2.1M, or an International Standard.

The supplier/manufacturer shall ensure that welding and brazing procedures are appropriate for the specific well application, considering issues such as corrosion susceptibility and hydrogen embrittlement.

The supplier/manufacturer shall have documented acceptance criteria.

7.6.4 Heat treating

Heat treating shall be performed according to documented procedures that provide a product that meets the supplier/manufacturer's acceptance criteria.

7.7 Traceability

Traceability shall be in accordance with the supplier/manufacturer's documented procedures. All components shall be traceable to their raw material heat(s) or batch lot(s) and material test report using a unique identifier. Traceability of equipment is considered sufficient if the equipment meets the requirements of this part of ISO 15136 when it leaves the supplier/manufacturer's inventory.

7.8 Calibration systems

Inspection, measuring and testing equipment used for acceptance shall be identified, inspected, calibrated and adjusted at specific intervals in accordance with documented specifications, such as ISO/IEC 17025 and this part of ISO 15136 and traceable to the applicable national standards agency or International Standard that is no less stringent than the requirements included herein. Inspection, measuring and testing equipment shall be used only within the calibrated range.

Technologies for inspection, measuring and testing with verifiable accuracies equal to or better than those listed in this part of ISO 15136 may be applied with appropriate documentation and when approved by qualified personnel.

Calibration intervals shall be established based on repeatability and degree of usage. Calibration intervals shall be a maximum of three months until a recorded calibration history can be established. Intervals may be lengthened or shortened based on documented repeatability, amount of usage and calibration history. The calibration interval may not be increased by more than twice the previous interval, which shall not exceed one year.

Calibration standards used to calibrate measuring equipment shall be checked and approved by an independent outside agency in accordance with the applicable national or international standards.

7.9 Examination and inspection

7.9.1 General

When specified by the supplier/manufacturer or user/purchaser, NDEs and inspections shall be performed and accepted according to the supplier/manufacturer's documented specifications, which shall include the requirements defined in 7.9 and acceptance criteria.

NDE instructions shall be detailed in the supplier/manufacturer's documented procedures and comply with this part of ISO 15136. All NDE instructions shall be approved by a qualified ISO 9712 level III examiner and performed by a qualified person. Personnel performing and accepting NDEs shall be qualified in accordance with the supplier/manufacturer's procedures as a minimum for evaluation and interpretation. Personnel performing visual examinations shall have an annual eye examination in accordance with ISO 9712, as applicable to the discipline being performed. As an alternative, the quality manager shall be authorized to qualify inspector's reading/observation capabilities based on pre-specified criteria (e.g. eye examination chart readings from a specified distance).

NOTE For the purposes of this requirement, ASNT SNT-TC-1A is equivalent to ISO 9712.

7.9.2 Stator elastomer hardness

The stator elastomer hardness shall be measured in accordance with Annex A using at least one representative elastomer specimen cut from the stator and shall be within the range of elastomer hardness in the elastomer material specifications.

7.9.3 Stator-elastomer bond

The stator-elastomer bond shall be tested in accordance with A.4.5.1 using at least one representative elastomer specimen cut from the stator and shall exhibit 100 % rubber failure based upon a visual inspection by a qualified person.

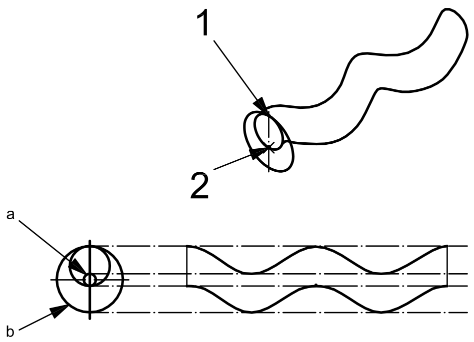
7.9.4 Stator phasing alignment

As a minimum, the phase alignment of stator sections shall be verified by inserting a stator phasing-alignment jig into the phased area of the assembled stator. The stator shall be rejected if the jig does not pass through the phased area unimpeded.

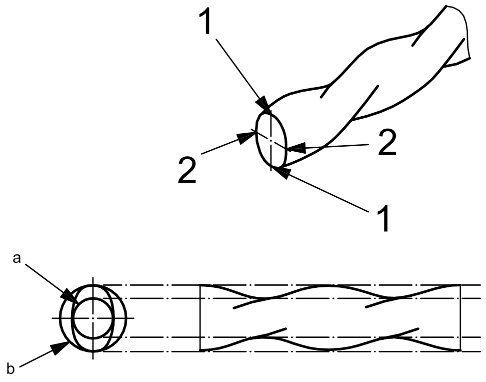
7.9.5 Rotor coating thickness

The rotor coating thickness shall be measured by direct measurement or by calculation using measurements made before and after the coating process. These measurements shall include, as a minimum, measurements approximately 1 m from each end of the rotor and at the middle. At each measurement location, at least two measurements shall be made at the rotor peak and rotor valley, as shown in Figure 1.

All measurements shall be within the range of peak and valley thicknesses in the product technical specifications.



a) **Single lobe** (1:2 configuration)



b) **Multi-lobe** (2:3 configuration)

Key

1 peak

2 valley

[a] Projected path of the valley on a plane normal to the rotor centre-line.

[b] Projected path of the peak on a plane normal to the rotor centre-line.

Figure 1 — Definition of valley and peak for rotor-coating measurement specification

7.9.6 Rotor surface finish

The rotor surface finish shall be visually inspected using a visual-comparator method or other methods with proven history of accurate evaluation.

NOTE For these inspections, ISO 1302 is an example of an International Standard and ANSI B46.1 is an example of a national standard.

7.9.7 Rotor phasing

As a minimum, the phase alignment of rotor sections shall be verified by placing the assembled rotor in a rotor phasing-alignment jig. The welded rotor shall pass through the phasing jig using a force no greater than is required for passing non-welded sections.

7.9.8 Visual inspection

7.9.8.1 Rotor

Visual inspections of rotors shall include a comparison of the following features with the supplier/manufacturer's documented specifications:

a) coating cracks (except for heat checking near weld zones) and blisters;

b) pin holes in the rotor coating;

c) mechanical damage to the surface finish;

d) bends.

7.9.8.2 Stator

Two types of stator visual inspection shall be specified in accordance with the product quality grade.

a) The basic visual inspection of the stator is limited to viewing the exterior of the stator and the internal surface from the stator ends.

b) The detailed visual inspection includes the basic visual inspection plus a boroscope or other technique for viewing the full length of the internal surface of the stator.

The following shall be considered unacceptable in the visual inspection of a stator:

- elastomer cracks, blisters and other surface irregularities;
- elastomer separation from the stator tube;
- mechanical damage to stator housing or plug screws, if applicable;
- bending.

7.9.9 Weld

7.9.9.1 General

Weld inspections shall be performed in accordance with the quality grade and according to the requirements of 7.9.9. Base-metal welds (such as in rotor stock material) are not included in the weld inspections in this part of ISO 15136. All other welds performed on the rotor or stator are included.

7.9.9.2 Visual inspection

All visible welds shall be visually inspected and reported in accordance with the quality grade. The following features shall be considered unacceptable in the visual inspection of a weld:

- cracks in base or filler metal;
- inclusions;
- surface defects.

7.9.9.3 Radiographic inspection

Radiographic inspections shall meet the requirements of a national standard such as ASTM E94 or an International Standard. Acceptance criteria shall be in accordance with a national standard such as ASME BPVC, Section VIII, Division I, UW-51, or ASME B31.3, or an International Standard.

7.9.9.4 Ultrasonic inspection

Ultrasonic inspections shall meet the requirements of a national standard such as ASME BPVC, Section V, Article 5, or an International Standard. Acceptance criteria shall be in accordance with a national standard such as ASME BPVC, Section VIII, Division 1, Appendix 12, or an International Standard.

7.9.9.5 Magnetic particle inspection

Magnetic particle inspection shall be in accordance with a national standard such as ASTM E709 or an International Standard such as ISO 13665.

7.9.9.6 Liquid-penetrant inspection

Liquid-penetrant inspection shall be in accordance with a national standard such as ASTM E165 or an International Standard such as ISO 12095.

7.9.10 Core deflection

The supplier/manufacturer shall inspect each stator for core deflection in accordance with the quality grade. For quantitative core deflection inspections, the core deflection shall be expressed in terms of the maximum radial offset of the stator cavity centre-line from the stator tube centre-line.

7.9.11 Component dimensional inspection

Components shall be dimensionally inspected in accordance with the quality grade to assure compliance with the supplier/manufacturer's design criteria and specifications. Inspections shall be performed during or after the manufacture of the component but prior to assembly, unless assembly is required to complete a measurement. All stator-elastomer measurements shall be corrected to 15 °C and reported in accordance with the supplier/manufacturer's documented procedures. The inspection results shall be documented.

Inspected component dimensions shall include the following:

a) general dimensions:

   1) rotor:

      — total length,

      — contour length (see Figure 2),

      — top threaded connection type and size;

   2) stator:

      — total length,

      — elastomer cut-back length at each end (see Figure 3),

      — tube outside and inside diameter,

      — top threaded connection type and size,

  - bottom threaded connection type and size;

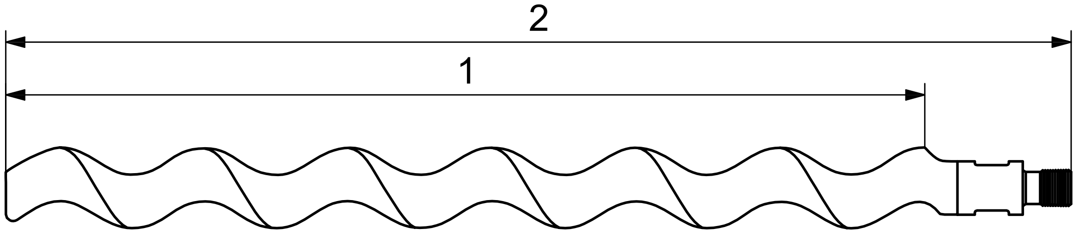
b) profile dimensions, to be reported to the precision specified for each measurement:

  1) rotor:

    - major and minor diameter at a minimum of five locations spaced evenly along the rotor length; measurement locations shall not be more than 1 m apart along the rotor length,
    - dimensions shall be reported to the nearest 0,02 mm;

  2) stator:

    - minor diameter of the stator profile at a minimum of five locations spaced evenly along the stator length; measurement locations shall not be more than 1 m apart along the stator length,
    - dimensions shall be reported to the nearest 0,2 mm,
    - ambient temperature.

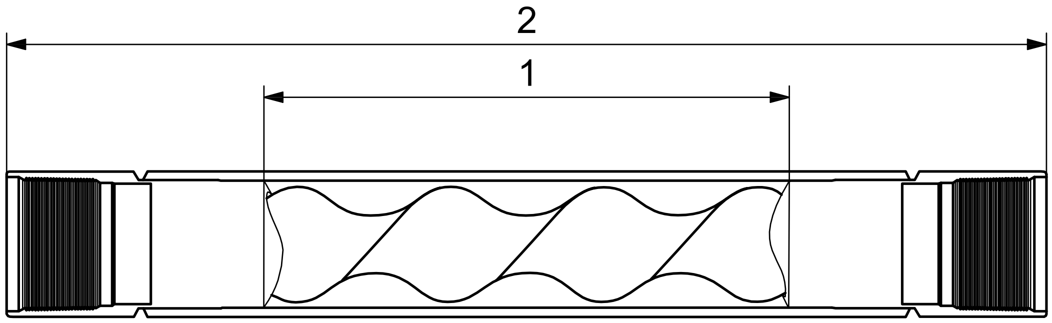


Key

1 contour length

2 total length

Figure 2 — Illustration of a rotor



Key

1 elastomer length

2 total length

Figure 3 — Illustration of a stator

7.10 Manufacturing non-conformance

The supplier/manufacturer shall establish and maintain documented procedures to ensure that an assembly or component that does not conform to specified requirements is prevented from being delivered or installed. This control shall provide for the identification, segregation, evaluation, documentation and disposition of non-conforming products. Non-conforming assemblies or components dispositioned for re-work shall be re-inspected to the same requirements as the original component or assembly. Responsibility for review and authority for the disposition of non-conforming products shall be defined by the supplier/manufacturer.

7.11 User/purchaser complaint returns

In the event that a product fails to meet the functional specification, the supplier/manufacturer shall be responsible for issuing a complaint number to the user/purchaser for tracking and reporting purposes. The user/purchaser shall provide appropriate well and operational data and make the failed product available for inspection in order to address the complaint.

7.12 Product functional testing

Product functional testing shall be performed by the supplier/manufacturer on each product manufactured in accordance with this part of ISO 15136. Product functional test results shall be recorded, dated and signed by qualified personnel performing the test. The testing details and acceptance criteria shall be defined by the supplier/manufacturer's documented procedures. Product functional testing shall include, as a minimum, the items listed in Annex C.

8 Repair

Repairs to PCPs shall return the product to a condition meeting or exceeding the requirements stated in this part of ISO 15136 or the edition in effect at the time of its original manufacture. The repaired product shall meet or exceed the requirements of the product functional evaluation grade specified by the user/purchaser.

Major repairs that can affect the performance of the product include recoating, rethreading and straightening. In instances where a major repair is performed, the product shall be permanently identified to indicate each repair, as defined in 7.3, such that the full repair history of the product can be tracked.

The supplier/manufacturer shall have a documented process for recording and tracking such repair details. The documentation of the repair shall include, as a minimum, the repair-centre identification, date and type of repair, inspection and test records.

Annex K provides guidelines for repairing and reconditioning rotors, stators and tag bars.

9 Shipping, handling and storage

9.1 General

PCPs shall be prepared for shipment, handled and stored in accordance with the written specifications of the supplier/manufacturer to prevent contamination of the equipment and damage from normally anticipated loads.

9.2 Preparation for shipment

PCP stators shall be drained of all fluids in preparation for shipment or storage.

PCP rotors and stators shall be prepared for shipment with support points located a maximum of 3 m apart.

Protection for threaded connections shall include, but not be limited to, protective caps for male-thread connections or protective plugs for female-thread connections. Protective devices shall be firmly connected to the threaded connection to avoid damaging the thread itself or accidental removal during transit.

Protection of rotor-coating integrity shall include, but not be limited to, covering the length of the rotor contour with a protective covering, such as nylon mesh. The protective covering shall be attached to the rotor to avoid accidental removal during rotor transit.

9.3 Handling

9.3.1 Rotor

A thread protector shall be installed prior to handling the rotor.

Non-marring lifting straps and supports shall be used when handling the rotor. The use of steel chains, wrenches and racks directly on the rotor can damage the surface.

The rotor shall be supported at a spacing not to exceed 3 m when being moved in the horizontal position.

Transition to vertical lift should be conducted with caution to prevent a permanent bend from forming in the rotor. This normally requires supporting the rotor during transition from horizontal to vertical.

The rotor shall not be allowed to strike, or be struck by, other objects during handling.

NOTE Threads and the rotor tip are the most easily damaged.

9.3.2 Stator

A thread protector shall be installed prior to handling a stator.

The stator shall be supported at a spacing not to exceed 3 m when being moved in the horizontal position.

Transition to vertical lift shall be conducted with caution to prevent a permanent bend from forming in the stator.

The stator shall not be allowed to strike, or be struck by, other objects during handling.

Do not strike, drop, or otherwise impact a stator near or below the elastomer brittle point. This can fracture the stator elastomer and result in rapid failure of the pump.

NOTE The elastomer brittle point is compound-dependent and can be reached at temperatures ranging from as high as –4 °C to as low as –50 °C.

9.4 Storage

PCP products shall be stored in compliance with the guidelines provided in the product operator's manual to prevent damage to the product.

Ferrous elements not previously coated shall be coated upon receipt with a rust inhibitor approved by the supplier/manufacturer. Exposed rotor threaded connections shall be properly coated with a rust inhibitor prior to installing protective caps for male-thread rotor connections and protective plugs for female-thread rotor connections. Protection devices shall be firmly connected to the threaded connection to ensure that the thread itself is not damaged and that the protective device is not accidentally removed during storage.

Precautions shall be taken to minimize elastomer exposure to the environment (e.g. sunlight, high humidity, salt water, temperature variations) and to avoid contamination of the stator cavity. Stator ends shall be fitted with protective plugs for female-thread stator connections and caps for male-thread stator connections.

PCP rotors and stators shall be stored on a flat surface or rack system with support points being a maximum of 3 m apart. Rotors shall not be stored inside stators.

The supplier/manufacturer shall make available, upon request, storage recommendations pertaining to storage life under specific environmental conditions.

If the stator is stored at a low temperature, the rotor and stator shall be warmed to at least 0 °C prior to inserting the rotor in the stator. Special care should be taken to ensure that a stator is warmed sufficiently prior to performing pump hydraulic tests.

For products that have been stored for prolonged periods, or that could have been damaged during storage, the user/purchaser shall consult with the supplier/manufacturer to determine the inspections that it is necessary to perform prior to installing the product.

Annex A
(normative)

Requirements for progressing cavity pump elastomers

A.1 General

This annex provides requirements to user/purchasers and supplier/manufacturers for the classification and testing of PCP elastomers for artificial-lift use in the petroleum and natural gas industries. Elastomeric materials shall be in compliance with the requirements of this annex. These requirements are defined for each combination of elastomer, bonding agent and tube material. All testing shall be performed on equipment meeting the requirements of 7.8 and to documented procedures that include acceptance criteria with the results approved by a qualified person.

This part of ISO 15136 is not intended to inhibit a supplier/manufacturer from offering, or the user/purchaser from accepting, alternative materials (materials not specifically defined herein). Where an alternative material is offered, the supplier/manufacturer shall identify any variations from this part of ISO 15136 and provide those details on the elastomer data sheet.

A.2 Elastomer classifications

A.2.1 General

PCP elastomer classification shall be in compliance with a national standard such as ASTM D1418 or an International Standard. These classifications address only the base polymer of the elastomers and do not classify the elastomers by specific properties, since these properties are dependent on proprietary formulations and processes. The main classifications of elastomers used by the suppliers/manufacturers in this application are listed in A.2.2 to A.2.4. Alternative material types and additional classification are provided in A.2.5 and A.2.6, respectively.

A.2.2 Nitrile elastomer

Nitrile elastomers (NBR) are copolymers of butadiene and acrylonitrile (ACN). The incorporation of acrylonitrile in the polymer structure imparts resistance to hydrocarbons and oils. Butadiene imparts flexibility and rubber-like behaviour; see A.2.6.

A.2.3 Hydrogenated nitrile elastomer

Hydrogenated nitrile elastomers (HNBR) are nitrile elastomers that have been subjected to a hydrogenation process to increase the degree of saturation of hydrogen in the elastomer structure. This process reduces the total number of carbon double bonds, which are susceptible to degradation, resulting in a polymer more resistant to certain environments (e.g. H_2S) and elevated temperatures; see A.2.6.

A.2.4 Fluoro elastomer

Fluoro elastomers (FKM) are fluorine-containing elastomers that are more resistant to oil, certain chemicals and temperature degradation than are nitrile-based elastomers.

A.2.5 Alternative material types

Suppliers/manufacturers may specify elastomer types other than the three specified in A.2.3 to A.2.5. The requirements of A.3 and A.4 apply for alternative material types.

A.2.6 Additional classification

The ACN content of NBR and HNBR elastomers contributes to the resistance of the elastomers to hydrocarbons. In the case of nitriles, compound characteristics in addition to ACN content determine elastomer performance. The supplier/manufacturer shall supply the approximate ACN value upon agreement with the user/purchaser.

A.3 Elastomer characteristics

When required by the quality grade or as requested by the user/purchaser, the following elastomer characteristics shall be provided by the supplier/manufacturer on the elastomer data sheet:

a) fluid resistance:

   1) elastomer immersion tests, which shall be performed and reported in accordance with A.4.3 for the conditions shown in Table A.1,

   2) elastomer bond-retention tests, which shall be performed and reported in accordance with A.4.5.2 for the conditions shown in Table A.1;

b) mechanical properties:

   1) hardness, which shall be performed and reported in accordance with A.4.4.1,

   2) tensile properties, which shall be performed and reported in accordance with A.4.4.2;

c) maximum operating temperature, which shall be reported in accordance with A.4.6;

d) bond-properties testing, which shall be performed on an unaged specimen and reported in accordance with A.4.5.1 or A.4.5.2.

Table A.1 — Immersion test parameters

Test fluid	**Reference**	**Nominal test temperature**[a] °C				
		30	**60**	**100**	**150**	**175**
Distilled water	—	NBR HNBR FKM	NBR HNBR FKM	NBR HNBR FKM	—	—
IRM 903	ASTM D471	NBR HNBR FKM	NBR HNBR FKM	NBR HNBR FKM	HNBR FKM	FKM
Fuel B (ASTM)	ASTM D471	NBR HNBR FKM	—	—	—	—

[a] At atmospheric pressure with 168 h of exposure.

A.4 Testing requirements and procedures

A.4.1 General

The supplier/manufacturer shall perform tests in accordance with the requirements listed in A.4.2 to A.4.6 and record all testing results.

A.4.2 Elastomer specimen preparation

Elastomer specimens shall be prepared from slabs moulded under conditions representative of those used for moulding PCP stators.

A.4.3 Fluid resistance

Fluid resistance of elastomeric materials shall be measured in accordance with an internationally recognized standard such as ASTM D471 or ISO 1817 with the following requirements:

a) specimens: 2 mm thick dumbbells (ASTM D412-06ae2 — Tensile die C);

b) test conditions in accordance with Table A.1;

c) immersion test conditions reporting:

  - test fluid,
  - temperature,
  - pressure,
  - exposure time;

d) reporting of initial value, final value and change in the following elastomer properties:

  - volume,
  - mass (weight),
  - hardness, performed and reported in accordance with A.4.4.1,
  - ultimate tensile strength, performed and reported in accordance with A.4.4.2,
  - ultimate elongation, performed and reported in accordance with A.4.4.2.

A.4.4 Mechanical properties

A.4.4.1 Hardness

Hardness shall be tested in accordance with ISO 7619-1. In all cases, 3 s delay hardness measurements shall be reported.

A.4.4.2 Tensile properties

Tensile properties (ultimate strength and ultimate elongation) shall be tested and reported in accordance with ISO 37 or ASTM D412.

A.4.5 Elastomer bond retention

A.4.5.1 Bond-retention piston test

This test shall be performed with the following conditions.

a) Specimens shall be 9,5 mm (3/8 in) or 15,9 mm (5/8 in) thick stator rings.

b) The testing system shall consist of a mechanical or hydraulic device to push a piston through the stator ring at a rate of between 5 cm/min and 10 cm/min. The piston shall have the following characteristics.

   - The outer diameter of the piston shall be 4 mm smaller than the nominal ID of the stator housing.
   - The piston shall be longer than 20 mm.
   - The leading edge of the piston shall be rounded to at least a 5 mm radius to avoid cutting the elastomer.

c) After testing the specimen, the interface between the rubber and the housing shall be visually inspected in accordance with A.4.5.3.

A.4.5.2 Bond-retention peel test

The adhesive force between the elastomer and housing shall be quantified in a bond-retention peel test in accordance with ASTM D429-08, method B, 90° stripping test-rubber part assembled to one metal plate, or modified method B, 180° stripping test-rubber part assembled to one metal plate. In all cases, lab specimens shall reproduce, as closely as possible, the bond properties and characteristics of the PCP stators.

The results shall include

- the adhesive peeling force;
- the failure mode in accordance with A.4.5.3.

A.4.5.3 Bond-retention test inspection

Inspection of the bond-retention test specimens following testing shall be performed by a qualified person in accordance with ASTM D429. Bond retention shall be reported in terms of percentage of elastomer failure with respect to the total area of the interface. The test results shall be expressed by one or more of the following letters or groups of letters:

- R, which indicates a failure of the rubber (substrate failure);
- RC, which indicates a failure in the rubber-cover cement (interfacial failure);
- CP, which indicates a failure in the cover cement-prime cement (interfacial failure);
- M, which indicates a failure in the prime cement-metal interface (interfacial failure).

EXAMPLE R-60, RC-40 means that 60 % of the bonded area showed failure in the rubber and the other 40 % showed failure at the rubber-cover cement interface.

A.4.6 Maximum operating temperature

The supplier/manufacturer shall have documented procedures for defining and specifying the maximum operating temperature of the elastomer and bond system.

Annex B
(normative)

Design validation

B.1 General

Each validation grade requires a number of individual validation procedures, processes and tests. The supplier/manufacturer shall document the validation test procedures and results in a design validation file that is legible and retrievable. The file shall contain test results that validate the design and shall be reviewed and approved by a qualified person other than the originator. This review shall confirm that, as a minimum, all of the design validation requirements of this part of ISO 15136 have been met. Test equipment shall meet the requirements of 7.8 and supplier/manufacturer's documented procedures.

B.2 Design validation grades

B.2.1 General

This part of ISO 15136 provides three grades of design validation for the product, as outlined below. Previous documentation or testing applicable to existing products shall be accepted for the relevant grade. Products qualified to higher grades of design validation shall be considered qualified for lower grades of design validation.

- V3 Legacy grade: applies to products that satisfy all applicable functional, technical and manufacturing requirements of this part of ISO 15136, except for validation testing, and includes systems or products tested under previous standards and/or procedures;

- V2 Basic grade: applies to products that satisfy all applicable functional, technical and manufacturing requirements of this part of ISO 15136, except for durability validation testing;

- V1 Highest grade: applies to products that satisfy all applicable functional, technical and manufacturing requirements of this part of ISO 15136.

The specific requirements for each design validation grade are summarized in Table B.1.

Table B.1 — Design validation grades

Element	Requirements and references for design validation grade		
	V3	V2	V1
Documentation	Historical record (B.2.2.2)	Required (B.2.3.1)	Required (B.2.3.1)
Hydraulic validation	Not required	Required (B.2.3.2)	Required (B.2.3.2)
Elastomer and bond validation	Not required	Required (B.2.3.3)	Required (B.2.3.3)
Durability validation	Not required	Not required	Required (B.2.4.2)

B.2.2 V3 — Legacy grade

B.2.2.1 General

Validation grade V3 is a designation provided to accommodate experience gained from existing PCP installations through documentation of historical performance to ensure that the product satisfies all requirements of this part of ISO 15136, as summarized in Table B.1. Grade V3 shall be applicable only to geometries, elastomers and bonding systems in existence prior to the publication of the second edition of this part of ISO 15136.

B.2.2.2 Documentation

The supplier/manufacturer shall demonstrate by use of historical records that the PCP product design has been deployed successfully in the range of operating conditions for which it is designed. The documentation shall show that a minimum of 20 pumps have met the functional requirements for

- volumetric capacity;
- pressure capacity;
- fluid compatibility;
- torque and power;
- service life expectations.

B.2.2.3 Other validations

Hydraulic validation, elastomer and bond validation, and durability validation are not required for grade V3.

B.2.3 V2 — Basic grade

B.2.3.1 Documentation

The design validation file shall include all of the design validation assumptions, calculations, evaluations, test results and any other supporting documentation that is used to validate the design.

B.2.3.2 Hydraulic validation

Hydraulic validation testing shall be performed to determine the PCP's validated capacity per rpm, pressure capability and performance characteristics (e.g. torque and power consumption). The objective of this testing is to validate a specific PCP geometry. The testing requirements in this part of ISO 15136 are not meant to be representative of downhole well conditions.

A specific pump geometry shall be considered to pass the hydraulic validation only for the specific elastomer compound and bonding system tested.

Hydraulic validation tests shall be performed in accordance with Annex C, grade F1, with the following exceptions.

a) Rotational speeds shall cover the specified operational range for the pump model. A minimum of three speeds is required and the separation between adjacent speeds shall not exceed 200 r/min.

b) Differential pressures shall range from zero to the pump pressure rating with a minimum of ten test points.

NOTE When testing at temperatures above 100 °C, the minimum pump pressure can be the pressure required to keep the water from flashing.

c) The test fluid shall be water.

d) The test temperatures shall range from ambient up to the pump's maximum operating temperature with a maximum 30 °C increment between test temperatures. Test data shall be collected only when the maximum temperature differential between the fluid and stator exterior is less than 10 °C.

NOTE Shrouds around the stator with test fluid circulation can be required to meet this criterion when testing at moderate to high temperatures.

e) Pumps shall be tested using test rotors that have been sized based on the supplier/manufacturer's internal design criteria. In cases where there is a wide range of rotational speeds and test temperatures, more than one rotor size may be used to achieve the required performance. However, for a specific combination of rotation speed and test temperature, the same rotor shall be used for determining the capacity per rpm, pressure and torque performance.

f) The hydraulic performance measured in the hydraulic validation test shall be compared to the theoretical performance derived from the technical specifications as follows.

- All hydraulic validation testing shall be performed with a rotor fit that achieves between 70 % and 90 % volumetric efficiency at 300 r/min at the specified test temperature.
- The maximum pressure measured at ambient temperature shall meet or exceed the specified pressure rating.
- The capacity per rpm measured at ambient temperature shall be ±5 % of the specification for validated capacity per rpm.
- The torque measured at the test speeds, and throughout the pressure range, shall be within ±10 % of the specification for total design torque.

g) At the conclusion of the hydraulic testing, the rotor and stator shall be visually inspected in accordance with 7.9.8 and measured in accordance with 7.9.11 and shall not show any signs of wear or damage.

B.2.3.3 Elastomer and bond validation

The elastomer and bond validation shall be performed in accordance with Annex A and shall include, as a minimum, the following:

a) fluid resistance in accordance with A.4.3;

b) mechanical properties in accordance with A.4.4;

c) elastomer bond retention in accordance with A.4.5.

B.2.3.4 Durability validation

Durability validation is not required for grade V2.

B.2.4 V1 — Highest grade

B.2.4.1 General

Grade V1 is the highest level of design validation. PCPs selected for grade V1 shall conform to the requirements specified in Table B.1.

Documentation, design validation, hydraulic validation and elastomer and bond validation shall conform to the requirements of validation grade V2.

B.2.4.2 Durability validation

The durability validation test is intended for applications where all practical measures are justified to avoid premature failures of the PCP. It involves extended duration, full-scale testing to validate the ability of the PCP to maintain performance over time. This test simultaneously validates multiple aspects of the pump, including the pump geometry, rotor fit, elastomer and bonding system. The testing conditions are not necessarily meant to be representative of downhole well conditions, but rather to subject the pump to the mechanical load cycles it is anticipated to see in service. Durability validation is normally selected to gain confidence in the use of new geometries, elastomers or bonding systems or in the use of an existing product outside its historical service range.

The choice of the pump used in the testing shall depend on the validation purpose as follows:

- The specific pump configuration shall be used to validate a geometry or selected rotor fit.
- Any geometric configuration that encompasses the materials in a manner that is representative of the final manufactured product may be used to assess an elastomer or bond system.

As a minimum, the test shall be tested under the following combined conditions.

a) The pump shall be tested under the combined conditions of
   - 100 % of maximum rated speed,
   - 125 % of pressure rating,
   - rated temperature.

b) The pump shall contain at least three stator pitches.

c) The initial volumetric pump efficiency shall be at least 70 %.

d) The test bench shall maintain the following parameters within 5 % of the specification:
   - rotational speed,
   - discharge pressure,
   - fluid temperature over the test duration.

e) Pump fluid rates, torque and external stator temperature shall be recorded at least daily.

f) The test fluid shall be water. Other test fluids, such as oils, high-temperature fluids and abrasive slurries, may be used to validate specific service conditions in addition to the standard durability test.

g) Tests shall be run for a minimum of 25×10^6 revolutions or to pump failure. Pump failure in the durability test is defined as the inability of the pump to maintain volumetric efficiency of more than 50 %. In special circumstances, the user/purchaser may specify alternative acceptance criteria.

h) At the conclusion of the durability testing, the rotor and stator shall be visually inspected in accordance with 7.9.8 and measured in accordance with 7.9.11. The elastomer and bond systems shall be evaluated in accordance with Annex A.

i) Documentation shall include a summary of the test product, test conditions, performance measured over the test period and final inspection details. This documentation shall be included in the product design file.

Annex C
(normative)

Functional evaluation

C.1 General

This annex contains requirements for the functional evaluation procedures that verify the ability of a PCP or its components to satisfy specific performance criteria under application conditions specified by the user/purchaser. For each application, the users/purchasers require information that allows them to

a) verify the functionality of the pumps delivered by suppliers/manufacturers;

b) determine the suitability of each pump for each specific application.

NOTE Several factors make it very difficult to establish a single evaluation procedure that satisfies the second objective. These factors include: effect of fluid-elastomer interaction on the rotor-stator fit; and the effect of the characteristics (viscosity, gas, etc.) of the produced fluid on pump performance. Due to chemical swell and the thermal expansion of the elastomer once the PCP is exposed to the well environment, the actual pump performance in terms of volumetric efficiency and actual capacity per rpm can differ from the results of the functional tests. For more information see Annex G.

The functional evaluation procedures have been arranged into two grades:

- F1: functional hydraulic test;
- F2: functional evaluation without bench testing.

All testing shall be performed in accordance with the supplier/manufacturer's documented procedures that meet, or exceed, the requirements of this part of ISO 15136.

The supplier/manufacturer shall document the functional evaluation procedures and results in a functional evaluation file that is legible and retrievable. The file shall be reviewed and approved by a qualified person.

C.2 Grade F2 — Functional evaluation without bench testing

C.2.1 General

A functional grade F2 evaluation shall consist of a dimensional measurement of the rotor and stator in accordance with documented procedures and approved by a qualified person. This includes, as a minimum

a) measurement of the stator profile in accordance with 7.9.11;

b) measurement of the rotor profile in accordance with 7.9.11.

The supplier/manufacturer shall have documented methodologies to use the rotor and stator measurements to estimate pump-performance characteristics.

C.2.2 Documentation requirements

The following shall, as a minimum, be recorded in the PCP functional evaluation report:

a) location of evaluation;

b) date of evaluation;

c) qualified person performing evaluation;

d) user/purchaser, as applicable;

e) PCP description:

  - pump model, stator unique identifier, rotor unique identifier and elastomer code,
  - pump stator, length stator and rotor average minor and major diameters (from data points in accordance with C.2);

f) ambient temperature;

g) estimated pump performance characteristics in accordance with 6.5.

C.3 Grade F1 — Functional hydraulic test

C.3.1 General

The following procedure applies to both a complete pump (the combination of the actual stator and rotor) and to a single stator, in which case, a rotor with reference dimensions agreed upon by the user/purchaser and the supplier/manufacturer shall be used.

The objective of the hydraulic test is to measure pump flow rate and torque at specific conditions of rotational speed, temperature and differential pressure with a fluid of known characteristics.

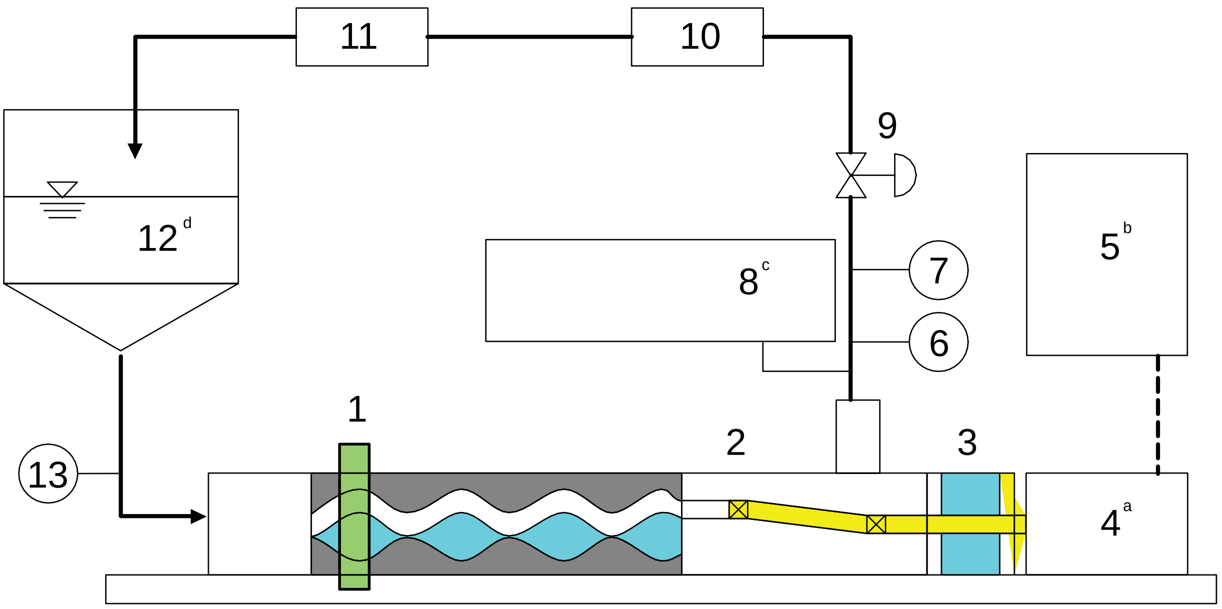
The type of application and its parameters shall be considered in determining the best way to perform the hydraulic test. Therefore, the intention of this part of ISO 15136 is not to provide a single procedure for application in all cases, but rather provide a set of requirements for a procedure.

The test shall be performed in a controlled environment where key input parameters (pump speed, pump differential pressure, fluid characteristics and temperature) are controlled and output parameters (flow rate, torque and power consumption) are measured to a certain level of accuracy.

Test equipment and procedures shall provide documented, repeatable results within ±10 % of the required fluid rate and torque at a given fluid temperature and speed.

C.3.2 Test bench requirements

Figure C.1 shows a schematic of the test bench with the minimum set of required components designated.



Key

1 means for fixing the stator to the bench to prevent excessive vibration

2 universal joint or flexible shaft to absorb the eccentric motion of the rotor

3 seal section to minimize leakage around the drive shaft

4 drive system to supply mechanical energy to the drive shaft

5 torque measurement device

6 pressure-measurement device to measure the discharge pressure

7 temperature-measurement device to measure the discharge temperature

8 safety relief valve and/or a pressure switch set below the maximum design pressure of the bench

9 control valve or choke to regulate the discharge pressure thereby creating a differential pressure across the PCP

10 flow measurement device based on direct (e.g. inline) or indirect (e.g. measuring tank) measurement

11 temperature control device to restrict the fluid temperature changes during the test

12 fluid supply tank

13 pressure-measurement device to measure the pump intake pressure

[a] This system may be composed of an electric motor and driver, a hydraulic motor and a hydraulic power unit, or any other drive system that allows control of the rotational speed and measurement of the power consumption as required by this procedure.

[b] Where a seal with considerable frictional torque is used to seal the drive shaft (e.g. a stuffing box), the supplier/manufacturer shall determine experimentally the value of this additional torque and subtract it from the torque and power consumption values in the final report.

[c] The safety device is designed to be "fail safe", i.e. "fail open" for the valve and "fail off" for the switch. At least one of the safety triggering devices is activated directly by the line pressure.

[d] The tank provides enough available net pump suction head to prevent cavitation at test conditions.

Figure C.1 — Schematic of test bench

C.3.3 Instrumentation accuracy

Instrumentation shall be located, installed and operated by qualified persons. Test equipment shall meet the requirements of 7.8 and supplier/manufacturer's documented procedures.

The supplier/manufacturer shall ensure that the level of accuracy meets the requirements in Table C.1 for the pump being tested.

NOTE To ensure sufficient resolution and control of all test parameters, caution is recommended when a small pump is tested using a large test bench.

Table C.1 — Measurement resolution required for test parameters

Measured parameter	Measurement accuracy % of maximum expected value
Pressure	±5
Temperature	±5
Speed	±3
Flow rate	±5
Pump torque	±5
Pump power consumption	±5

C.3.4 PCP bench test procedure

The supplier/manufacturer shall develop and document procedures for each step of the PCP bench test, which shall include, as a minimum, the requirements presented in Table C.2. The test sequence shall be in accordance with any requirements included in the functional specification provided by the user/purchaser.

Table C.2 — Steps required to prepare for and complete a pump bench test

Step		Requirements
1	Inspection of the test bench and test fluid	As a minimum, inspect and verify visual fluid of fluid contamination level monthly. Prepare a procedure for operational inspection of test bench.
2	Inspection and measurements	Verify model and rotor and stator unique identifiers. Perform basic visual inspection of the rotor and stator in accordance with 7.9.8. Measure rotor: minor and major diameter, and total length.
3	Installation	Install the PCP according the to supplier/manufacturer's documented procedures.
4	Start-up and warm-up	Warm up the pump with the fluid at test temperature until the stator tube external temperature does not vary by more than 5 °C in 5 min.
5	Data gathering	Start each test at the lowest differential pressure. Increase the differential pressure while maintaining a constant speed. Stabilize all variables at each pressure point in accordance with Table C.3. Record flow rates at a minimum of five differential pressure points per speed curve. Repeat the test at other speeds as required.
6	Approval/rejection of test data	Compare data collected to the criteria in Tables C.2 and C.3 and have them approved by a qualified person.
7	Approval/rejection of the pump based on performance	Compare test results to the technical specification and approved by a qualified person. It is required, as a minimum, that — the test results be within ±10 % of specified values of actual capacity per rpm and torque at minimum pressure and test temperature; — the allowable variations from the required volumetric efficiency at a given pump differential pressure and PIP be agreed upon between user/purchaser and supplier/manufacturer; see 5.8.
8	Post-test pump examination	Perform basic visual inspection of the rotor and stator in accordance with 7.9.8.

Requirements and recommended values for test parameters are summarized in Table C.3

Table C.3 — Pump bench test parameter requirements

Parameter	Requirements	Recommended values
Pump speed, r/min	Maximum allowable variation of ±2%[a]	100, 150, 200, 250, 300, 500
Fluid type	Test fluid meets the functional requirements Test fluid shall be benign to the stator and rotor during the test and storage period.	water oil, SAE 140 mixture of oil and water
Fluid contamination	Documented criteria for contamination acceptance available from supplier/manufacturer	
Fluid temperature, °C	Maximum allowable variation of less than ±5 °C within a given test Temperature shall be measured within the flow path.	30, 40, 50, 60, 90
Stator tube external temperature	Measure and record the temperature in the middle of a stator section at the start and conclusion of testing.	
Pump intake pressure	Maximum allowable variation during testing of ±70 kPa	
Pump differential pressure	Minimum time at each point of 2 min	minimum, pump pressure rating and three intermediate values

[a] Based on actual instrument reading. This requirement is related to process controllability and not linked to instrument accuracy.

C.3.5 Test data reporting

Actual capacity per rpm shall be measured as the fluid volume associated with one rotation of the pump derived from flow rate at less than 350 kPa pressure at a specific speed and reported as cubic metres per day per revolution per minute.

Differential pressure shall be calculated as the difference between the pump discharge pressure and the pump intake pressure.

Volumetric efficiency, Q_{eff}, expressed as a percent, shall be calculated as per Equation (C.1):

$$Q_{\mathrm{eff}} = \left(\frac{Q_{\Delta \mathrm{p}}}{Q_{\mathrm{o}}} \right) \times 100 \qquad \text{(C.1)}$$

where

$Q_{\Delta \mathrm{p}}$ is the volumetric flow rate at a differential pressure;

Q_{o} is the volumetric flow rate at $\Delta p < 350$ kPa.

Input power at the pump shaft, $\dot{W}_{\mathrm{shaft}}$, shall be calculated as per Equation (C.2):

$$\dot{W}_{\mathrm{shaft}} = \tau \times \omega \qquad \text{(C.2)}$$

where

τ is the shaft torque;

ω is the shaft speed.

The fluid power, $\dot{W}_{\text{fluid}}$, shall be calculated as per Equation (C.3):

$$\dot{W}_{\text{fluid}} = Q \times \Delta p \tag{C.3}$$

where

Q is the flow rate at a given Δp;

Δp is the differential pressure.

Mechanical pump efficiency at a specified differential pressure and flow rate, $\dot{W}_{\text{eff}}$, expressed as a percent, shall be calculated as per Equation (C.4).

$$\dot{W}_{\text{eff}} = \left(\frac{\dot{W}_{\text{fluid}}}{\dot{W}_{\text{shaft}}} \right) \times 100 \tag{C.4}$$

C.3.6 Testing documentation

The following test information shall be recorded in the PCP bench test report:

a) location of test;

b) date of test;

c) qualified person performing testing;

d) test fluid and viscosity at standard conditions (if the fluid is other than water);

e) user/purchaser, if applicable;

f) PCP description:

- pump model, stator unique identifier, rotor unique identifier and elastomer code,
- rotor measurements in accordance with Table C.2;

g) test fluid temperature (initial and final);

h) stator external temperature (initial and final);

i) ambient test temperature;

j) intake pressure;

k) acceptance criteria and result of the test and inspection;

l) actual capacity per rpm;

m) data points and curves to present: flow rate, volumetric efficiency, torque and mechanical pump efficiency as a function of differential pressure and speed.

Annex D
(informative)

Optional information for PCP elastomer testing and selection

D.1 General

This annex provides information to users/purchasers and suppliers/manufacturers in the selection and testing of PCP elastomers. This information is prepared to complement the requirements of Annex A and offers optional testing and selection guidelines that can be useful for specific applications. All testing shall be performed on equipment meeting the requirements of 7.8 and to documented procedures with the results approved by a qualified person. When requested in the functional specification, the requirements of each subclause become normative.

D.2 Additional requirements

The supplier/manufacturer and user/purchaser shall agree on determining or disclosing any additional elastomer property that can be relevant for specific applications. Those additional properties can include, but are not limited to, the following:

a) custom elastomer compatibility;

b) bond retention under specified aging conditions;

c) mechanical properties:

- tear strength,
- abrasion resistance,
- compressive modulus;

d) compression set;

e) explosive decompression resistance;

f) H_2S resistance;

g) dynamic properties:

- dynamic mechanical analysis,
- heat build-up,
- resilience.

D.3 Optional testing procedures

D.3.1 General

Unless otherwise specified, elastomer coupons (specimens) shall be prepared from slabs moulded at a laboratory scale when it is assured that the characteristics, properties and state of curing represent as closely as possible those of the designated PCP stators.

Specific test requirements for optional tests include the following.

a) The user/purchaser shall specify the fluid composition, which may consist of either modified standard fluids or user-/purchaser-supplied fluid samples. The supplier/manufacturer shall specify the fluid sample volume required for the test programme. Typically, a minimum well-fluid sample volume of approximately 2 l is required.

b) In the case of multi-component test fluids (e.g. oil and water), the test equipment shall provide sufficient agitation to ensure that the elastomer samples experience representative fluid exposure.

c) Pressure vessels used in aging tests shall meet local statutory requirements for pressure-containment equipment and be capable of being purged to remove oxygen before the test is initiated.

d) Test temperature, pressure, duration and other relevant conditions shall be agreed upon by the user/purchaser and the supplier/manufacturer and shall be selected to be representative of downhole conditions.

All testing shall have documented procedures, acceptance criteria and be performed and recorded by a qualified person. Testing shall be conducted in compliance with the procedures in D.3.2 to D.3.9. Acceptance of the results of the optional testing shall be at the discretion of the user/purchaser.

D.3.2 Fluid sampling and shipping

Samples shall be collected and shipped in accordance with national or international statutory requirements and with agreements between the user/purchaser and supplier/manufacturer. This includes ensuring that the sample container is inert with respect to the sampled fluid and properly sealed to provide safe containment of the fluid during transport.

D.3.3 Application specific elastomer compatibility testing

D.3.3.1 General

This test validates the elastomer suitability for service in a particular class of application using test fluids and conditions specified by the user/purchaser. Results from this test are intended to provide general guidelines about elastomer performance and not direct correlation with service performance.

D.3.3.2 Test programme design

D.3.3.2.1 Data requirements

It is desirable to evaluate elastomer samples under conditions that simulate the specific environments to which they will be exposed in service.

NOTE The observed performance of elastomeric materials in service is highly dependent upon the particular physical nature and chemical composition of the service environments. Any change in water, hydrocarbon and/or gas composition can significantly affect the test results.

The following information, as a minimum, shall be provided by the user/purchaser to conduct the testing:

a) fluid composition in accordance with D.3.3.2.6;

b) BHT;

c) current producing GOR;

d) gas composition;

e) pump intake pressure.

D.3.3.2.2 Specimens

Specimens with similar thicknesses shall be selected when comparing elastomer performance. Different specimens are recommended for use depending on each particular case and the availability of specimens. While other specimen geometries may be agreed between the user/purchaser and supplier/manufacturer, the following geometries are recommended:

— ASTM D412-06ae2:	2 mm thick, tensile die C or trouser;
— ISO 815-1:2008, type A:	12,7 mm thick compression-set coupons;
— ISO 815-1:2008, type B:	6,1 mm thick compression-set coupons.

NOTE The recommended 2 mm specimen thickness is to accelerate the swelling process, thus minimizing the affect of permeation rate. Thicker specimens provide closer correlation to aging in PCP applications, however, much longer exposure times are required to achieve equilibrium swelling values.

Thicker specimens may be acceptable by agreement between the supplier/manufacturer and user/purchaser.

D.3.3.2.3 Exposure time

The recommended exposure times for use in aging elastomer specimens are given below; other times may be agreed upon between the supplier/manufacturer and the user/purchaser:

a) 168 h (7 d);

b) 336 h (14 d).

NOTE Swelling kinetics is a function of fluid type and temperature and it is necessary that it be considered when selecting a test exposure time. Lighter oils and higher temperatures usually lead to faster swelling processes. Equilibrium swelling can be achieved with exposure times ranging from a few days to months, depending on conditions.

D.3.3.2.4 Temperature

The recommended test temperature is equal to the reservoir temperature. The test temperature shall be maintained within ±2°C throughout the duration of the test.

NOTE Elevated temperatures usually increase fluid-elastomer interactions leading to faster and a greater degree of swelling and changes in elastomer properties. Other factors, such as plasticizer extraction or additional cross-linking promoted by elevated temperature, can affect the expected elastomer behaviour.

D.3.3.2.5 Pressure

Test pressure shall correspond to the field application or a defined standard reflecting an average field condition. In cases where the application pressure is not available, a standard of 6 900 kPa at 77 °C

(1 000 psi at 170 °F) is recommended. The test pressure shall be maintained within ±70 kPa throughout the duration of the test.

To conduct the testing, the test vessel may be pressurized with nitrogen (recommended), water or any gas mixture representing the gas composition of the well, such as CO_2 and hydrocarbons.

NOTE Since swelling is a thermodynamic process, pressure also affects the rate of swell. Usually, higher pressure results in a higher degree of swelling with faster kinetics as pressure drives the permeation of chemical species into the elastomer matrix.

D.3.3.2.6 Fluids

The following fluids may be considered for the elastomer compatibility test:

a) crude oil sample;

b) water-oil mixtures;

c) chemical additives;

d) brine;

e) any other fluid that may come in contact with the pump.

To avoid redundancy, conduct compatibility tests only using those fluids or conditions that differ from each other significantly to produce a difference in elastomer performance.

NOTE Well fluids can include dead fluid collected from the tank after separation, live fluid collected at the wellhead, pressurized fluid with entrained gas collected at surface or live fluid collected downhole. When dealing with dead fluids, samples can be recombined with gases at a lab scale to a specific GOR representative of conditions found in the application. Special testing and fluid handling procedures are required in this case.

WARNING — Transferring of pressurized fluid samples to a pressure vessel for testing requires special consideration and procedures.

D.3.3.3 Test procedure

The test procedure is carried out as follows.

a) Perform the following measurements on a minimum of three unaged elastomer specimens:

- mass (weight) in accordance with ASTM D471;
- hardness in accordance with ASTM D2240;
- tensile properties in accordance with ASTM D412.

b) Place each specimen in the vessel such that the specimens are completely immersed in the test fluid and that there is no contact between specimens or between a specimen and the vessel interior.

c) Purge the air from the test vessel using nitrogen.

d) After purging, seal the test vessel.

e) Fill the test vessel with a sufficient volume of the test fluid to cover the specimens completely. If a pressurized fluid sample is being used, the sample shall be transferred to the test vessel under pressure to minimize segregation of the fluid sample.

f) Pressurize the vessel to the required test pressure by either using the pressure from the sample container or injecting a fluid such as dead oil, chemicals, water, nitrogen or a gas mixture.

g) Heat the test vessel to the required temperature.

h) Control the pressure and temperature during the test to maintain specified conditions.

i) Begin to depressurize the test vessel at the completion of the exposure period. If the test fluid contains gas, it is necessary that the vessel pressure be released slowly to prevent explosive-decompression damage to the test specimen. The test-vessel pressure shall be released using one of the following two methods:

- at a constant rate, not to exceed 138 kPa/min (20 psig/min);
- stepwise, in 690 kPa (100 psig) decrements, with each step lasting a minimum of 5 min.

j) After depressurization, cool the test vessel to a maximum temperature of 38 °C within 6 h. The test specimens shall not be removed from the test vessel until the vessel has cooled down to a temperature of no more than 38 °C.

k) Remove the specimens from the test vessel and wipe it clean of test fluid. Do not use any form of solvent to clean the specimens.

l) Perform the measurements from D.3.3.3 a) on aged specimens at room temperature within 2 h of the time they are removed from the test vessel.

m) Report the following differences in properties between aged and unaged specimen, as a minimum:

- mass (weight) and volume change in accordance with ASTM D471;
- hardness change in accordance with ASTM D2240;
- tensile properties change in accordance with ASTM D412.

D.3.3.4 Test report

Test reports shall include the following information as a minimum:

a) elastomer compounds tested;

b) test fluid description;

c) compatibility test conditions:

- date of test,
- test temperature,
- test pressure and pressurizing media,
- exposure time,
- depressurization rate,
- elapsed time between depressurization and measurements;

d) test results.

The test report shall also include all pertinent observations and recorded data. Each sample elastomer shall be visually inspected by a qualified person to identify indications of micro-cracks, bubbles or blisters and a cross-section of each specimen shall also be inspected. The report shall include interpretation of the test results in accordance with supplier/manufacturer's or third party documented procedures.

D.3.4 Bond-retention testing under specified aging conditions

The purpose of this test is to qualify the stator bond by exposing representative samples to aging conditions that simulate downhole environments.

Test conditions including fluid, pressure, temperature and exposure time shall be defined in agreement between users/purchasers and suppliers/manufacturers.

NOTE Aging conditions can be similar, but not limited, to those considered in this annex for custom elastomer compatibility testing.

Typically bond specimens, either stator ring or peeling samples, are exposed to the specified environment and bond retention is evaluated in accordance with A.4.5.1 or A.4.5.2.

D.3.5 Mechanical properties

D.3.5.1 General

The following mechanical properties of the elastomer shall be supplied by the supplier/manufacturer when requested by the user/purchaser. Where applicable, testing shall be conducted in accordance with the procedures given in D.3.5.1 to D.3.5.4.

D.3.5.2 Tear strength

Tear strength shall be tested in accordance with ISO 34-1 or ASTM D624. Two different types of specimens may be used, type C or trouser, and the specimen type shall be specified in the test results.

D.3.5.3 Abrasion resistance

This testing compares the measured abrasion resistance of a test sample to that of a known reference sample subjected to the same abrasive testing procedures. Due to the wide range of variables, actual operational conditions might not be reproduced in these tests. Testing shall be performed in accordance with an internationally recognized standard such as ASTM D5963 or ISO 4649.

The test report shall include the type of abrader, test conditions and standard of conformance.

D.3.5.4 Compressive modulus

Compressive modulus shall be tested and reported in accordance with ISO 7743 or ASTM D575.

D.3.6 Compression set

Compression set shall be tested in accordance with ISO 815-1 with the following modifications.

a) Specimen size shall be type 1 (recommended) or type II.

b) Environment shall be air or fluid at specific conditions of temperature and pressure upon agreement between user/purchaser and supplier/manufacturer.

c) Exposure time and temperature shall be 72 h at 100 °C for NBR and 72 h at 100 °C and 150 °C for HNBR. Other times and temperatures may be used upon agreement between user/purchaser and supplier/manufacturer.

d) If the test environment is other than air, the reporting shall include a description of the test fluid, the temperature and the exposure time(s).

D.3.7 Explosive decompression

Elastomer explosive decompression shall be tested in accordance with a national standard such as NORSOK M-710 or NACE TM0192 or an International Standard, with the following modifications in test conditions.

a) Specimens shall be approximately 6 mm thick and consist of approximately square coupons with an area of 16 cm^2.

b) The test temperature shall be maintained between 20 °C and 30 °C.

c) Exposure time shall be 3 days.

d) Gas shall be CO_2 or other gas agreed upon between user/purchaser and supplier/manufacturer.

e) The test pressure shall be 5 170 kPa for CO_2; for other gases, test pressure shall be agreed upon between user/purchaser and supplier/manufacturer.

f) The depressurization rate shall be no greater than 2 070 kPa/min and shall be maintained within ±20%.

g) The results shall include the following:

- visual inspection of surface and cross-section for physical damage (blistering, cracks) 10 min, 1 h and 24 h after depressurization. Explosive decompression damage shall be evaluated in accordance with a national standard such as NORSOK M-710 or NACE TM0192 or an International Standard as agreed upon between the user/purchaser and supplier/manufacturer;
- photographs of the specimen at intervals following decompression according to a documented procedure.

D.3.8 H_2S resistance

H_2S resistance shall be tested in compliance with A.4.3 with the following modifications.

a) Initial value, final value and change in the following elastomer properties shall be reported:

- hardness performed and reported in accordance with A.4.4.1;
- ultimate tensile strength performed and reported in accordance with A.4.4.2;
- ultimate elongation performed and reported in accordance with A.4.4.2.

b) For comparison purposes or for ranking elastomers, the following test parameters are proposed:

- specimens conforming to ASTM D412-06ae2, type C tensile specimens or ISO 815-1:2008, type A compression set buttons;
- minimum exposure time of 5 days;
- gas concentration of (10 ± 1) % mole fraction;
- test temperature maintained at (50 ± 5) °C;
- total N_2 applied pressure of (5 170 ± 100) kPa.

c) The concentration of H_2S in the autoclave at the conclusion of the test shall be measured at the gas outlet to verify that the target H_2S concentration was maintained throughout the test.

d) A duplicate test using similar elastomer specimens exposed to N_2 at the same temperature and pressure conditions is recommended to differentiate the effect of H_2S from the effects of temperature and pressure alone on the changes in the elastomer properties.

NOTE Laboratory testing might not represent actual elastomer performance conditions. In real applications, H_2S as a free gas or in solution can cause degradation problems not defined in this testing. The extent of degradation and kinetics is a function of temperature and gas concentration. More rigorous testing is time consuming and can include many variables.

D.3.9 Dynamic properties

D.3.9.1 Background information

Under cyclic or dynamic oscillations, the viscoelastic properties of elastomers play an important role. The energy required to deform a perfectly elastic material is completely recovered when the force is removed, but the viscous losses, which are caused by internal molecular friction, retard elastic deformation and energy is lost. This lost energy is dissipated in the form of heat and the consequent temperature rise in the elastomer is called heat build-up. The percentage of energy loss per cycle of deformation is known as hysteresis. If force is plotted against deflection for one cycle of deformation, a hysteresis loop is obtained.

Resilience is the ratio of the energy returned on recovery from deformation to the energy required to produce deformation. It follows that hysteresis is 1 minus the resilience.

Hysteresis and heat build-up can be important failure modes in PCP stators, especially under conditions of high speed or high rotor-stator interference. The viscoelastic properties of each specific elastomeric compound dictates the performance of stators under dynamic cycling. Typically, rigid elastomers exhibit high hysteresis and consequently poor dynamic performance.

The dynamic properties of elastomers may be visualized in terms of a specimen undergoing uniform sinusoidal deformation. The in-phase stress is due to the elastic component and the out-of-phase stress is due to the viscous component. Because of the hysteresis losses, the strain lags behind the resultant of the two stresses by an amount that is usually known as the phase or loss angle, δ. The more viscous the material, the greater the loss angle and the higher the hysteresis. The tangent of the loss angle, $\tan\delta$, in the simplest terms, is the viscous modulus divided by the elastic modulus.

D.3.9.2 Testing

D.3.9.2.1 The recommended method to test dynamic properties of PCP elastomers is dynamic mechanical analysis following a standard test procedure such as ASTM D5992.

NOTE The results of dynamic tests on elastomers are dependent on the specimen shape, mode of deformation, strain amplitude, strain history, frequency and temperature. The data collected can be complex in nature and difficult to interpret.

To standardize dynamic testing, it is recommended that elastomer moduli be measured under the following conditions:

- frequency: 20 Hz;
- temperature: 30 °C;
- strain amplitude: 2 % to 5 %.

D.3.9.2.2 Various dynamic properties of PCP elastomers may be characterized directly or indirectly using other testing procedures such as

- heat build-up performed and reported in accordance with ISO 4666 (all parts) or ASTM D623;
- rebound resilience test performed and reported in accordance with ISO 4662.

D.4 Application guidelines

D.4.1 General

Background information is provided in D.4 about common environmental conditions and general guidelines that typically define the elastomer selection for a range of PCP applications. This is not intended to dictate or limit product selection. Establishing the limits of specific products is the responsibility of the supplier/manufacturer.

Consideration of the environmental parameters given in D.4.2 to D.4.4 in elastomer selection and how they can interact with each other is recommended.

D.4.2 Chemical environment

D.4.2.1 Crude-oil specific gravity and aromatics content

Light oils are usually more aggressive than heavy oils since they typically contain low-molecular-mass aromatics. These aromatics show chemical affinity with nitrile elastomers, causing swelling. However, API gravity by itself may not be used as an absolute guideline, since some heavy crude oils contain high concentrations of aromatic species and, in contrast, some light oils can contain smaller amounts.

Characterization of the type and concentration of aromatic species in the crude oil is critical for elastomer selection, since these species are responsible for causing nitrile rubbers to swell.

The use of gas chromatograph and mass spectrometer methods, such as ASTM D3239 to determine aromatic content, and ASTM D5790 to determine volatiles, helps to establish a correlation to elastomer swell that can assist in the selection of the correct elastomer for the required service.

Another approach to assessing aromatic content is to determine the aniline point in accordance with ISO 2977 or ASTM D611-08, method B. Although not as robust as the tests listed in the preceding paragraph, it is much less expensive and can be done in even the more basic laboratories. The lower the anile point of a hydrocarbon fluid, the higher its aromatic content and, consequently, the more aggressive it is in causing elastomer swell.

The distribution of hydrocarbon components in the crude oil is typically termed a C30+ analysis and shall be performed using a gas chromatograph in accordance with a national standard such as ASTM D2887 or an International Standard.

NOTE 1 Light aromatics are typically composed of compounds with 6 to 11 carbon atoms such as benzene, toluene, xylene, short-chain alkyl aromatics and non-substituted diaromatics (for example naphthalene). These species possess a high swelling potential since they are highly soluble in the nitrile elastomer matrices. Oils typically contain light aromatics at absolute concentrations varying from 0 % to 5 %.

NOTE 2 Aromatic species typically found in heavy oil are mixtures of higher-molecular-mass mono-, di- and poly-aromatics, highly substituted with long alkyl chains. These species tend to have a lower swelling potential since they are less compatible with nitrile elastomers and diffuse slowly into the elastomer matrix. However, it is necessary not to underestimate their effect since they are usually present in high concentrations, up to 50 %.

D.4.2.2 Crude oil paraffin content

Lower-molecular-mass paraffin (C3 to C30) extract plasticizers from NBR elastomers and cause shrinkage and an increase in the modulus and the hardness. The amount of extraction depends on the type and concentration of plasticizer in the elastomer. Extraction of plasticizers can cause counter-acting effects of reducing the rotor/stator interference fit and increasing the elastomer stiffness, which can affect pump performance.

D.4.2.3 Water cut

Water usually possesses a limited swelling potential since it is more polar than normal nitrile elastomers. Water swelling tends to increase with the ACN content of nitrile elastomers. Water can act as a diluent for the most aggressive aromatic species present in the oil fraction, limiting the swelling potential of the water/oil mixture. However, over prolonged periods of time, the oil fraction effect can dominate, such that the water can delay the time required to observe the total swell caused by the oil phase.

The effect of water on the elastomer bond properties should be considered since several bonding systems are susceptible to water attack, especially at elevated temperatures.

The presence of ions (salt) in the water tends to decrease its swelling potential. As an example, brine tends to produce lower swelling values than distilled water for the same nitrile rubber. The total concentration of salt should be considered when estimating water-induced swelling of an elastomer.

D.4.2.4 H_2S and CO_2 content

H_2S causes hardening of nitrile elastomers due to a chemical reaction with the polymer component of the compound. This gas causes progressive cross-linking of elastomer chains resulting in hardening, shrinkage and, ultimately, material cracking. In general, HNBR or FKM elastomers tend to be more resistant to high H_2S concentrations.

CO_2 diffuses into the elastomer matrix causing swelling and softening due to physical interactions. CH_4 and other hydrocarbon gases can also cause similar changes to the elastomer. Specific elastomer formulations can be selected to provide better resistance to specific gas environments.

Gases in a producing well are capable of causing an additional effect on the elastomer. When a pump is operated in an environment with high free gas, the elastomer absorbs gas up to a saturation value. If a decompression process occurs and the gas is liberated too rapidly, then the elastomer suffers internal blistering, tearing or cracking due to the abrupt gas expansion. This phenomenon is commonly known as explosive decompression and occurs frequently in environments with a high concentration of CO_2. Elastomer permeability, degree of cross-linking as well as its mechanical properties define material resistance to explosive decompression. The use of a slow decompression rate and a minimum elastomer thickness helps in preventing this phenomenon.

As a rule of thumb, for nitrile elastomers, the higher the elastomer ACN content, the lower its permeability and, consequently, the higher its susceptibility to explosive decompression damage.

D.4.2.5 Service temperature

Elastomers, being organic compounds, exhibit limited temperature resistance. Typical service limits for PCP elastomers depend on each supplier/manufacturer's formulation. In general, FKM exhibits the highest temperature resistance, followed by HNBR (especially peroxide cross-linked compounds) and NBR. Increasing the service temperature resistance of elastomers can lead to changes in the elastomer properties such as hardness and tensile strength, which can affect overall pump performance.

In elevated-temperature applications (particularly in the presence of water), the bond system can be the limiting component of the pump performance.

D.4.3 Sand content

PCP applications with sand-laden oil require elastomers with an elastic recovery capability that allows the passage of sand particles across the seal line without causing elastomer tearing. This is typically accomplished with soft, resilient elastomers having a high ultimate elongation and good abrasion resistance. Resistance to sand embedment in the stator elastomer is also important to prevent rotor wear.

Elastomer wear is also influenced by sand content and particle size. Geometric parameters of the rotor-stator fit and pump speed are also important in providing optimized performance in sand-laden applications. Typically, short pitch, tighter fit and lower speeds improve wear performance.

D.4.4 Gas-volume fraction

PCP stators can handle wellbore fluids with a high free-gas content; however, in general, pump performance and run life decreases with increasing free-gas content. PCP operation requires a minimum amount of liquid to provide lubrication and cooling to prevent excessive friction and overheating of the elastomer. Pump size and rotor stator fit can be used to minimize the impact of free gas on pump performance and run life.

Annex E
(informative)

Installation guidelines

E.1 General

This informative annex provides a general outline of the techniques and procedures commonly used to install surface-driven, tubing-conveyed PCP systems. Installation procedures for other systems, such as insertable, wireline-retrievable and metal-stator PCPs, can require different procedures as specified by the supplier/manufacturer. Also, suppliers/manufacturers may supply special installation procedures for auxiliary equipment, such as surface and downhole instrumentation, diluent injection lines, etc. The installation procedures shall conform to the requirements of the operator's manual for the specific PCP system. The user/purchaser can also find value in the data contained in ISO 15136-2 for the surface-drive-system requirements.

Severe local well curvatures or doglegs above the pump landing depth can restrict the diameter and length of the PCP system that can be installed. Forcing the PCP through dogleg sections can permanently bend the stator, resulting in fatigue and wear that can significantly reduce the pump run life. Depending on the profile of the local curvatures, longer, more slender pumps can be more appropriate.

Care shall also be taken in selecting a pump landing depth where local well curvature is low to ensure that the stator is not bent or not supported only at discrete points along its length. Landing the pump in a section of well with large curvature can result in vibration and fatigue issues.

Minimizing the amount of rotor sticking out of the stator minimizes downhole vibration. It is necessary to take care to ensure that sufficient drive-string space-out is provided to ensure that the rotor/drive string connection does not contact the top of the stator elastomer during operation. The first rod connected to the top of the rotor shall be at least 3 m long to minimize pressure drop and wear in the first joint of tubing above the stator (orbit tube). If rod centralizers are used, place the first one above this first rod.

Where possible, the intake of the pump shall be landed below the level of the perforations. This enhances gas separation in the well annulus and minimizes the risk of solid debris accumulating in the well and plugging the perforations. Tail joints may be installed on the bottom of the pump to prevent running the torque anchor through perforations.

The annular space between the pump assembly (including auxiliary equipment) and the inside diameter of the casing or liner where the pump is landed shall allow for fluid flow without excessive pressure drop and shall allow for the free flow of solid material to the pump intake.

E.2 Pre-installation

It is recommended that the following steps be considered before installing a PCP pump system.

a) Remove solids such as sand or coal fines from the bottom of the wellbore before running a PCP system to allow landing the pump at the target depth and its start-up before a continuing inflow of solids into the wellbore interferes with pump installation or start-up.

b) Verify that working fluids left in the well from previous work do not affect the stator elastomer and rotor coating. If the fluids have the potential to significantly damage the pump, they should be either removed or diluted prior to installing the pump.

c) Verify that the PCP and related hardware on site complies with the documentation supplied by the supplier/manufacturer. Inspect all components to ensure that all packaging and protective devices are removed and that the equipment is not damaged.

d) Verify that all auxiliary equipment interfaces correctly with the PCP system and wellbore and that any special installation procedures for the auxiliary equipment are followed.

e) Ensure that all well servicing operations, personnel and hardware comply with the well operator's documented health, safety and environmental standards and procedures and local regulations and policies.

f) Ensure that well servicing equipment on location is sufficient to perform the required make-up of stator components, production tubing, rotor and drive string.

g) Ensure that all lifting and handling equipment on location is sufficient to handle the lengths and weights of the pump assemblies without causing damage.

E.3 Stator installation

It is recommended that the following steps be considered when installing a PCP pump stator.

a) Ensure that the stator assembly complies with the documentation supplied by the supplier/manufacturer.

b) Ensure that all stator-assembly connections are tightened to between optimum and maximum torque in accordance with the product operator's manual. Record all make-up torques.

c) Ensure that the tubing diameter immediately above the stator provides sufficient room for the rotor and connection rotation, taking into consideration the eccentric movement of the rotor.

d) Attach the stator assembly to the end of the production tubing string with the required auxiliary equipment such as tag bar, torque anchor, tail joints, gas separator and downhole gauge, as applicable.

e) Run the stator assembly and production tubing into the well and tighten all tubing connections to between optimal and maximum torque.

f) Record all serial numbers, supplier/manufacturer's model information, elastomer code, component lengths and ODs. Keep a tally of the production tubing as it is run in the well.

g) Run the stator assembly down to the specified landing depth and set the tubing anchor or no-turn tool, as applicable. Record all equipment landing depths.

E.4 Rotor installation — Landing procedures

It is recommended that the following steps be considered when installing a PCP pump rotor.

a) Clean all pin and box thread ends on the drive string.

b) Check used drive string components for excessive wear or other defects. Remove and replace damaged equipment according to the well operator's and the supplier/manufacturer's specifications.

c) Record rotor product identification (serial number, etc.). Care shall be taken while handling the rotor on surface to avoid damaging the pin threads or the finished surface. The rotor shall be supported in a manner as to prevent bending that can cause damage. Connect the rotor to the drive string and run it into the well.

d) Make-up all drive-string connections following recommended procedures. Record a tally of the drive string run in the hole. For information on special drive-string make-up procedures for PCP applications, see Annex J.

e) Prior to entering the stator with the rotor, record the hanging weight of the drive string and rotor.

f) Slowly lower the rotor into the stator to prevent damage to the stator elastomer. The drive string usually rotates to the right (clockwise) as the rotor enters the stator.

g) Lower the drive string until the rotor rests on the tag bar, which is a zero reading on the weight indicator. In horizontal wells, the zero reading can occur prior to the rotor reaching the tag bar due to drag in the production tubing. If the rotor cannot be inserted into the stator, consult with the supplier/manufacturer for alternative procedures.

h) Verify that the drive-string tally corresponds to the tubing-string tally.

i) Mark the drive string location where zero string weight is achieved.

j) Slowly pick up the drive string until the point of full string weight is achieved and mark the drive string location.

k) Repeat steps g) through j) until three consistent sets of marks are achieved.

l) Pick up the space-out distance from the tag bar as specified in the product operator's manual, which includes compensation for drive-string stretch, thermal expansion and other factors. The rotor shall now be in the operating position in the stator.

m) Measure the height of the surface drive from the bottom wellhead connection to the top clamp.

n) Determine the combination of pony rods and polished rod that it is necessary to add to the top of the drive string such that the polished rod extends between 0,1 m and 0,3 m above the clamping point. Do not make wrench marks on the polished rod.

o) Install the surface drive in accordance with the requirements of ISO 15136-2.

p) Install the polished rod clamp to support the polished rod within the surface drive.

Annex F
(informative)

Operational guidelines

F.1 General

This informative annex provides general information to the user/purchaser regarding common practices for the safe operation of PCP systems.

F.2 Start-up procedures

The recommended start-up procedure for a PCP system includes a pre-start check followed by a starting procedure.

NOTE For certain types of wells, special start-up procedures can be required to prevent excessive gas production through the PCP. Consultation with the supplier/manufacturer can be required.

F.3 Pre-start check

It is very important to confirm that the pump rotates in the proper direction when started. Since a PCP is a positive-displacement pump, it can pump in either direction, thereby pumping the tubing dry if operated in the reverse rotation. If the pump is allowed to “run dry”, the stator can be damaged due to lack of lubrication. The drive string also tends to unscrew if rotated in the reverse direction.

The following steps shall be followed prior to starting a PCP system.

a) Start the prime mover briefly to check for proper rotation direction of the surface drive.

b) Ensure that the following conditions are met.

   — The polished rod clamp is adequately tightened.

   — The maximum polished-rod stick-up above the surface drive does not exceed the supplier/manufacturer's recommendation (usually less than 0,3 m).

   — All guards are installed over rotating parts on the surface drive.

   — The bearings and stuffing box are lubricated and seal properly.

   — The packing gland is not over-tightened.

   — All valves in the flow line from the wellhead to the tanks or gathering line are open.

   — The brake system is functional; see detailed procedures in ISO 15136-2.

   — The surface drive is installed according to the supplier/manufacturer's specifications with appropriate oil levels and belt tension as applicable; see detailed procedure in ISO 15136-2.

   — Shut-down parameters are set correctly on the pump-control system, with the pressure shut-down based on the gathering-facility status, e.g. if a facility shuts in, the shut-down signal is sent directly to the well to avoid pumping against the shut-in system.

c) Shoot fluid level or record downhole sensor readings for baseline bottomhole pressure data prior to start-up.

F.4 Starting procedure

The following steps are recommended when starting a PCP system.

a) Perform health, safety and environmental procedures, such as ensuring that all parties are notified that the unit is about to start-up and notifying all personnel on location of the hazards, if any.

b) Turn motor switch to off position.

c) Turn on the main breaker on the electrical supply panel (if applicable) and attach an ammeter to measure the initial start-up and pump-up amperage.

d) Set the speed controller (if applicable) to minimum rotating speed.

e) Switch on the motor. Record the starting current of the motor (if applicable).

f) Observe the system for approximately 1 min to identify any unusual noises or vibrations.

g) Turn off the motor to verify that the brake is functioning properly. If no problems are encountered during shut down, restart the motor.

WARNING — Repeated restarts can cause overheating of the brake system, which can lead to a hazardous situation.

h) Close the flow-line valve to check proper setting and function of the high-pressure shut-down switch. If no problems are encountered, open the flow line valve and restart the motor.

i) Check wellhead, surface drive and flow line for leaks.

j) Check that the torque and rotating speed are within the supplier/manufacturer's specified limits.

k) Follow operator's rotating speed ramp-up procedure to protect completion (if applicable), e.g. minimize sand influx.

l) Adjust the rotating speed of the pump so that the pumping rate matches the well productivity. Normally, it is necessary to adjust the pumping speed frequently at the beginning of the pump operation to achieve the desired dynamic fluid level or pump-submergence level.

m) Use a short well test (e.g. to rig tank or test separator) to verify that pump efficiency is within supplier/manufacturer's specifications.

n) Monitor the well closely for 24 h to ensure that the fluid level and the production rate stabilize.

o) Measure daily fluid levels and record the pressures from downhole gauges and well tests until well stabilizes to confirm reliability of input and design data, and to determine whether the PCP is operating within specifications.

p) Avoid frequent shut-down and restart cycles, if possible.

F.5 Shut-down procedures

The following steps are recommended when shutting down a PCP system:

a) Be familiar with the well history: speed, production rate, torque, operational constraints, etc.

b) Perform health, safety and environmental procedures, such as ensuring that all parties on location are notified that the unit is about to shut down and notifying all personnel of the hazards, if any.

c) Gradually slow the unit down to the minimum rotating speed and allow the system to stabilize.

d) Shut down prime mover once the system has stabilized.

e) While shielding oneself, check for abnormal backspin. Observe whether the brake is functioning and rate of backspin speed.

f) If brake is not functioning, shield yourself and others on location until the system has come to a complete stop.

WARNING — Do not approach the surface drive until the backspin has stopped.

g) Lock out and tag the system.

WARNING — After the surface drive has been shut down and the backspin stops, there is still potential for additional backspin. This additional backspin is caused by the fluid level in the tubing equalizing with the fluid level in the casing by flowing back through the pump. Approach the unit with caution and use caution when disassembling the polished rod clamp and surface drive system.

F.6 System monitoring

F.6.1 General

System monitoring refers to the periodic or continuous measurement and evaluation of pumping-system operating conditions and production parameters. The reasons for pumping system monitoring include production optimization, failure detection and production accounting. Additional production performance parameters, such as pump efficiency, may be calculated based on the measured values of the production and operating parameters. Table F.1 contains a list of parameters that may be measured and/or calculated.

Table F.1 — Recommended measured and calculated parameters

Production (measured)	**Operation** (measured)	**Calculated parameters**
gross fluid rate	pump speed	net fluid rate
load fluid	hydraulic pressure	gas rate through pump
sand cut	motor current	sand volume
water cut	polished-rod torque	volumetric pump efficiency
total gas rate	tubing-head pressure	pump-intake pressure
annular gas rate	casing-head pressure	pump-discharge pressure
fluid level	pump-intake pressure	pump-differential pressure
fluid viscosity	pump-discharge pressure	polished-rod torque
		polished-rod axial load

F.6.2 Measured production parameters

F.6.2.1 Gross fluid rate

Gross fluid rates are determined by producing to a test separator for a period of several hours. Rates are usually determined based on changes in tank weight or fluid volume (for non-gassy fluids). In cases where the produced fluids contain gas, the fluid volumes measured at the surface are not directly representative of the fluid volume produced by the downhole pump due to expansion and dissolution of the gas.

F.6.2.2 Load fluid

Load fluid is added to the well either by injecting directly into the well annulus or through a separate injection string. Load fluid could be treatment chemicals, water, oil or diluent intended for purposes such as production stimulation, viscosity reduction or sand management. The rate of load fluid injection should be monitored to estimate the well inflow based on the total produced fluid measurements at surface.

F.6.2.3 Sand and water cut

Sand and water cuts are usually determined based on centrifuge tests of produced fluid samples. Typically the fluid samples are taken at the wellhead. While the results of the sample tests are quite reliable and accurate, the fluid sample might not be representative of the average fluids being produced due to irregular or slug flow of water or sand.

F.6.2.4 Fluid level

Fluid level is used in conjunction with the wellbore geometry and the estimated density of the annular fluid column to estimate the intake pressure of the downhole pump. The interpretation of the fluid level output can be subjective and it is often very difficult to accurately determine the actual fluid-to-gas interface in the annulus due to the presence of foamy oil.

F.6.2.5 Total gas rate

Total gas-production rates are typically measured in conjunction with fluid rate tests. The total producing gas rate includes both the annular gas flow and the gas produced through the pump. Accurate measurements of gas volumes are important since they have a strong influence on the average densities of the fluid columns in both the tubing and the casing annulus. Gas produced up the tubing also affects fluid properties, such as compressibility and viscosity.

F.6.2.6 Annular gas rate

The annular gas rate is the portion of the produced gas that does not flow through the pump. Subtracting the annular gas rate from the total gas rate yields the gas flow rate through the pump. Correcting the gas flow rate through the pump for downhole conditions can provide a more accurate estimate of the actual pump efficiency; see Annex G for more information.

F.6.2.7 Fluid viscosity

Viscosity measurements are typically performed on produced fluid specimens collected at surface. This may include water/oil emulsions. Fluid viscosity can be used to estimate pressure losses in the production tubing to provide a better estimate of pump performance, such as discharge pressure, differential pressure and torque.

F.6.3 Measured operation parameters

F.6.3.1 Pump speed

Pump speed is used in calculating pump efficiency and is commonly monitored directly from the variable-speed drive. Pump speed can change due to the effects of changing ambient temperature on the hydraulic systems, wear of surface-drive equipment or changes in pump loading.

F.6.3.2 Hydraulic pressure or electric motor current

These values provide an indirect measure of polished-rod torque. The daily monitoring frequency does not permit detection of short-term variations in torque but it is sufficient for evaluating the general operating condition of the well. Polished rod torque may also be measured directly from a variable-speed drive.

F.6.3.3 Tubing-head pressure

Tubing-head pressure is required to calculate pump-discharge pressure.

F.6.3.4 Casing-head pressure

Casing-head pressure is required to calculate pump-intake pressure.

F.6.4 Calculated production parameters

Various production-accounting parameters, such as net fluid, net oil, net water and volume of sand production, are generally calculated. They are calculated from the gross fluid rates, load fluid rates, sand and water cuts.

F.6.5 Calculated operation parameters

F.6.5.1 Volumetric pump efficiency

The volumetric pump efficiency of a PCP is calculated based on pump downhole capacity per rpm, pump speed and gross fluid rate. The pump efficiency is affected by the properties of the produced fluid, the operating practices and the condition of the pump. The tracking of pump efficiency over time can aid in detecting pump failures, pump wear, inflow restrictions and tubing leaks; see Annex G for more information.

F.6.5.2 Pump discharge pressure

Pump discharge pressure may be estimated using the tubing-head pressure and knowledge of fluid properties, wellbore geometry, and flow losses in the production tubing. The calculation requires many assumptions and the result shall only be viewed as an approximation. The pump discharge pressure may also be measured directly using a downhole pressure gage. Pump discharge pressure is a good measure of pump loading and may be a determining factor in pump speed selection.

F.6.5.3 Pump intake pressure

The pump-intake pressure may be estimated based on the annular fluid level and gas flow rate taking the wellbore geometry into consideration, or it may be measured directly using a downhole pressure gauge. Close monitoring of the pump-intake pressure can be vital in successfully controlling pump speed to prevent pump failures while maximizing the production rate, especially in wells with low bottomhole flowing pressures.

To make full use of the pumping capabilities of the PCP system, the intake pressure should be minimized to maximize fluid inflow to the well. Low intake pressures can affect pump performance, resulting in reduced efficiencies and flow rates.

F.6.6 Polished-rod torque

Polished-rod torque is an important parameter for assessing rod loading, surface-equipment loading, pumping problems and pump performance. Polished-rod torque is typically calculated based on the measured motor current and pump speed.

F.6.7 Polished rod axial load

Polished-rod axial load is typically calculated based on the drive-string hanging weight, the pump differential pressure and the pump geometry. The polished-rod axial load is rarely measured directly.

F.7 System diagnostics

Most PCP systems operate without any sort of automated control system. In most cases, measurements are taken of key parameters as shown in Table F.1. There can be periods between assessments where either the pump is run too fast and the well becomes pumped-off (which increases the potential for pump damage), or the pump runs too slowly and the system does not produce fluid at the maximum rate possible. Therefore, from both equipment-protection and production-optimization perspectives, there is considerable incentive to optimize the production process by automating the measurement of a few key production and operation parameters and implementing a system that uses the data to control the pumping system operation.

F.8 System troubleshooting

Occasionally, problems arise with the operation of PCP systems after they have been successfully producing for a period of time. However, most of the operational problems encountered with the PCP system can be avoided, or at least minimized, if the symptom is recognized in time. Table F.2 is intended to aid in the diagnosis and correction of problems encountered with operating PCP installations.

Table F.2 — Troubleshooting guide

(Click here to access an electronic version of this table)

Possible causes	Observed problems												Suggested solutions
	No production	Production drops off	Intermittent production	Pump does not start	Motor stalls at pump-up	Motor overheats	Excessive power	Excessive noise and vibration	Wear on pump components	Excessive packing-gland wear	Packing-gland leakage	Pump locks up	
Percentage abrasion above maximum recommended									X	X			Select correct rotor fit, decrease pump speed.
Sucker rods parted	X							X					Fish parted rod and replace.
Tubing parted	X	X						X					Tighten new tubing adequately.
Inadequate fluid (reservoir or completion related)	X	X	X					X					Reduce pump speed/put well on timer.
Hole in tubing or collar	X	X	X										Replace tubing or collar.
Motor supply or wiring				X		X		X					Check electrical supply and wiring.
Pump intake blocked	X	X	X	X									Pull up rotor, circulate well.
Fluid viscosity above design point		X	X	X	X	X	X	X					Decrease pump speed.
Fluid temperature above/below design point		X						X				X	Select correct rotor fit.
Fluid viscosity below design point		X											Increase pump speed.
Discharge pressure above design point		X			X	X	X	X	X			X	Check flow line for blockage/closed valve.
Packing gland too tight				X	X	X	X			X		X	Adjust packing gland.
Packing gland not tight enough											X		Adjust packing gland.
Excessive free gas at pump intake		X	X					X					Install gas anchor, reduce speed or lower pump.
Pump speed above design point			X			X	X	X	X	X			Decrease pump speed.
Pump speed too slow	X	X											Increase pump speed.
Drive belts slipping		X	X	X				X					Check belt tension.
Incorrect rotor setting	X					X	X	X	X				Check and adjust rotor spacing.
Drive mounting insecure								X					Check/tighten all mounting hardware.
Drive head bearing wear/failure				X	X	X	X	X				X	Replace or overhaul surface drive.
Worn pump (rotor/stator)		X											Replace worn components.
Low voltage				X	X	X							Check voltage/wiring sizes.
Abrasives in the packing-gland area					X					X	X		Check packing type and condition.
Failure of drive arrangement	X			X		X		X				X	Check failed drive components.
Incompatible treating chemicals		X	X						X	X	X	X	Re-check chemical compatibility.
Pump discharge blocked/valve closed	X	X	X		X	X	X	X	X			X	Relieve pressure. Clear blockages.
Stator worn/damaged	X	X	X	X	X							X	Replace worn parts.
Packing glands destroy packing			X							X	X		Check polished rod for wear.
Motor too small				X	X	X							Check and re-calculate motor size.
Incorrect rotor spacing				X	X		X	X				X	Re-space rotor.
Stator elastomer swollen				X	X		X		X			X	Re-evaluate elastomer selection.
Pump sanded in	X			X	X							X	Perform flush by or pull pump.

F.9 System maintenance

F.9.1 General

Surface-driven PCP systems are quite simple and robust, and they typically perform well with minimum maintenance required. There are, however, a few simple tasks that can improve the operational reliability of a PCP system if they are performed regularly.

F.9.2 Surface drive unit

The user/purchaser shall consult the equipment operator's manual provided by the supplier/manufacturer for specific routine maintenance and monitoring activities.

The following daily maintenance activities shall be followed for the surface drive unit.

a) Check wellhead, surface-drive and hydraulic system for leaks.

b) Check that all safety guards are properly installed and functional.

c) Check oil levels in surface drive, gear box, brake and hydraulic system.

d) Check stuffing box for proper lubrication and seal. Lubricate and tighten stuffing box as required.

e) Inspect drive belts for damage, vibration and proper tension.

f) Monitor hydraulic pressure or electric motor current to evaluate system loading.

Scheduled maintenance activities shall include the following, as applicable.

- Change oil and oil filter in the surface drive, gear box, brake and hydraulic systems.
- Replace belts and sheaves.

F.9.3 Downhole pump

No maintenance can be performed on the PCP while it is installed in a well. When the efficiency of the PCP is no longer satisfactory, it shall be replaced. However, through inspection and testing, it may be decided that one of the pump elements, the stator or the rotor, or both, can be re-used; see Annex I.

It is advisable to verify test bench performance of every stator/rotor pair to verify its functional requirements are met prior to installing the pump in a well (see Annex C).

Annex G
(informative)

Supplemental information for PCP performance characteristics

G.1 General

This informative annex provides supplementary information on the critical PCP performance ratings and their relevance to PCP selection and application.

G.2 Volume capability

PCPs are positive displacement pumps and as such their fluid delivery rates are a function of their displacement and rotational speed. Displacements, in terms of the volume pumped per revolution, can be determined for PCPs from calculations based on geometric dimensions or from interpretation of performance testing results. However, the convention for PCPs, when used in downhole oilfield applications, is to reference the volume capability in terms of a capacity per rpm with units such as cubic metres per day per 100 r/min or barrels per day per 500 r/min. This enables users/purchasers to conveniently multiply the capacity per rpm by the intended rotational speed to determine the maximum flow rate in common units.

Suppliers/manufacturers are required to publish a nominal capacity per rpm, q_{TC}, expressed in units of cubic metres per day per 100 r/min, for each basic pump geometry. Normally, this is calculated theoretically using Equation (G.1) for a single lobe pump:

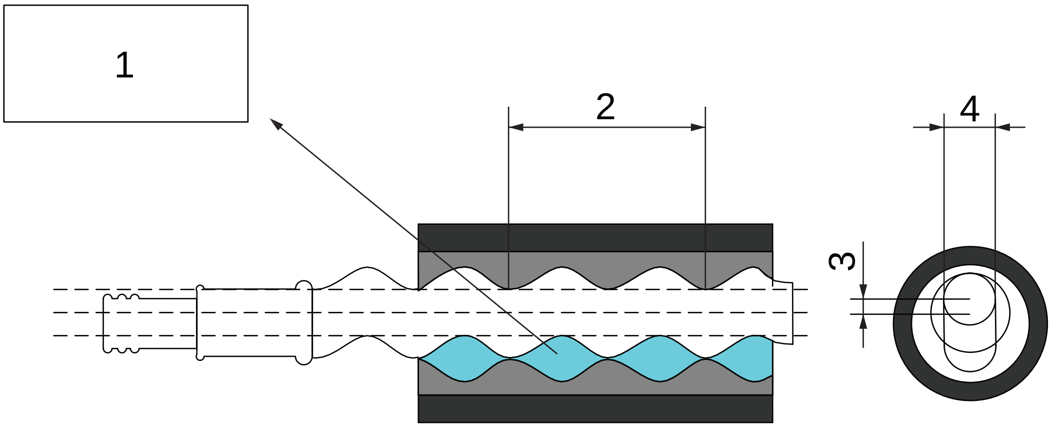
$$q_{\mathrm{TC}} = \frac{9 \times e \times D \times P}{15\ 625} \qquad \text{(G.1)}$$

where

e is the eccentricity, expressed in millimetres;

D is the minor diameter, expressed in millimetres;

P is the stator pitch, expressed in millimetres; see Figure G.1.



Key

1	cavity	3	rotor eccentricity
2	stator pitch	4	rotor/stator minor diameter

Figure G.1 — Definition of stator pitch

While the stator pitch is a constant value for a given design, the dimensions associated with the cross-section, including eccentricity and diameter, vary for several reasons. The fit of the rotor within the stator is normally an interference fit; therefore, the cross-sectional dimensions between the components are different when the pump is assembled. In addition, the dimensions vary due to manufacturing tolerances but also, more importantly, by design depending on the application; see G.4. Finally, the dimensions of the elastomeric material in the stator can change due to thermal and fluid exposure. As a result, for the purposes of calculating the theoretical capacity, it is common practice to determine the values based on the average stator dimensions at ambient temperature. In addition, this theoretical value is often adjusted slightly in determining the nominal capacity per rpm so that it is a convenient number for commercial purposes.

The theoretical or nominal capacity per rpm represents the best case in terms of volume capability, as the rotor interference fit, elevated temperatures or fluid swell almost always serve to reduce the cavity size and associated volume capability. To provide a more accurate representation of volume capability, the supplier/manufacturer is required to publish a validated capacity per rpm for each pump geometry. This value is determined from a hydraulic validation test (see Annex C) that is done with a rotor sized to achieve a volumetric efficiency of 70 % to 90 % at rated lift and 300 r/min, but at ambient temperature with water to minimize stator elastomer dimension changes. This test replicates an ideal operating scenario and the validated capacity per rpm is typically 2 % to 5 % below the calculated theoretical value.

The volume capability of a PCP downhole can vary from that measured on surface and is normally not static, changing over time even with consistent fluid characteristics, well and operating conditions. This is due to changes that occur as a result of the elastomer material in the stator changing dimensions due to thermal and fluid swell. While dimensional changes due to thermal effects tend to occur rapidly over a matter of hours, changes associated with fluid swell occur gradually over days, weeks or even months. These changes are highly sensitive to the pump geometry, with configurations having thicker elastomer sections showing larger changes. Reductions in the volumetric capability from the validated capacity can approach 20 %. Dimensional changes due to temperature can be approximated for each elastomer and geometry combination but predicting the changes due to fluid swell is difficult due to the transient nature of the phenomena.

The elastic nature of the elastomer permits significant reductions in stator dimensions, while still allowing the rotation of the rotor. However, the associated increased rotor/stator fit can lead to high friction torque, internal heat build-up in the stator and eventually reduced longevity. Accordingly, it is common practice to adjust the rotor fit to the anticipated downhole stator dimensions to maximize performance, as is described in G.4.

G.3 Pump volumetric efficiency

To assess the ability of a PCP to deliver a required fluid rate, it is necessary to consider the pump capacity per rpm in conjunction with a rotational speed and also a volumetric efficiency. PCPs are subject to volumetric inefficiencies due to fluid slippage, which is the result of the complex interaction between the pump geometry, stator material, fluid characteristics and operating conditions.

Fluid slippage and the associated decline in volumetric efficiency increases with differential pressure, decreases with fluid viscosity and decreases with pump rotational speed. Design performance curves provided by the supplier/manufacturer for each model display fluid rates as a function of differential pressure and pump speed; see 6.5.3. When these curves are considered in conjunction with the pump's capacity per rpm, volumetric efficiencies are implied. The values implied from the design performance curves are reference values under ideal conditions and actual volumetric efficiencies can vary significantly over the wide range of potential downhole and operating conditions.

Performance curves are commonly determined for a pump and its specific rotor/stator combination based on functional testing with water over a range of pressure and speed combinations; see Annex C. The volume capability and associated volumetric efficiencies in these curves reflect the specific rotor sizing as well as the test conditions. However, in most cases, these test conditions do not reflect the intended downhole conditions, since it is not practical to test with actual well fluids or wait for equalization due to thermal or fluid swell. Rather, they serve primarily to confirm a performance target associated with a rotor-stator fit strategy. With experience, the bench test performance can be translated to expected performance under downhole conditions. Equipment suppliers/manufacturers provide guidelines and tools to assist users/purchasers in this process.

While fluid slippage is the fundamental contributor to reduced volumetric efficiency in a PCP, the nature of conventional efficiency calculations introduces a further consideration that can be significant. Specifically, volumetric efficiency is normally calculated solely on the surface liquid rates and does not consider the impact of solids and gasses as well as changes in fluid volumes between surface and downhole due to differences in temperature and pressure of the produced fluid. As a result, it is necessary to determine the downhole multiphase fluid rate at pump intake conditions from the fluid and operating parameters provided by the user/purchaser. It is necessary that this fluid rate be used by the supplier/manufacturer in selecting and configuring equipment to achieve the required surface liquid rate.

Volumetric efficiency, determined by the user/purchaser on the basis of surface liquid rates, represents a combination of the pump volumetric efficiency and the inefficiency implied by the differences between the multi-phase fluid rate at the pump intake and the surface liquid rate. Accordingly, to determine the actual pump performance, it is necessary to adjust for the changes in fluid volume due to the difference in pressure and temperature from downhole to surface. While pumps have the ability to produce multi-phase fluids up to relatively high contents of gas and solids, these components occupy pump cavity volume and reduce the volume available for liquids.

G.4 Rotor-stator fit selection

Suppliers/manufacturers attempt to optimize pump configurations for the specified downhole conditions through adjustments of the interference fit between the rotor and stator. Since this fit impacts not only the efficiency/performance but also the service life, it is necessary that it be done carefully. If the fit is too loose, then the pressure seal is inadequate to minimize fluid slippage, causing poor performance in terms of volumetric and overall efficiency and increased internal heating, which can result in reduced pump life. If the fit is too tight, then the displacement of the elastomer by the rotor is high, creating elevated material stresses, frictional loads, internal heating and wear, all of which reduce pump run life.

The supplier/manufacturer shall work with the user/purchaser to assess the application requirements and determine the appropriate rotor-stator fit to ensure the pump provides the required performance and service life. Suppliers/manufacturers have a variety of normally proprietary processes through which they determine rotor sizing for their PCP product.

The fit may be specified directly through measurements of the internal stator dimensions and accompanying rotor size. Alternatively, it may be specified indirectly using pump functional testing to characterize performance. In both cases, the initial fit or test performance is not usually representative of downhole performance due to thermal and fluid swell of the stator elastomer downhole. These and other conditions, such as fluid viscosity, pump speed, sand content and pressure loading, should be taken into consideration to optimize the rotor/stator fit for the intended application.

G.5 Pump pressure capability

The pressure capability of a PCP is dictated by a complex interaction between the pump geometry, stator elastomer material, fluid characteristics and operating conditions. Suppliers/manufacturers are required to publish a pressure rating for each pump configuration and, in most cases, also provide a nominal head rating. These ratings are related primarily to the number of individual cavities in a pump configuration, but can also be influenced by the fundamental pump geometry and elastomer.

Suppliers/manufacturers differ in terms of how they assign pressure ratings. To aid the user/purchaser in comparing the non-standardized ratings, the suppliers/manufacturers are required to provide, for each pump configuration, the pressure per cavity and the number of engaged cavities. Multiplying these two parameters yields the pressure rating for the pump. Suppliers/manufacturers may demonstrate the appropriateness of their assigned pressure rating and associated pressure per cavity through durability testing; see Annex C.

PCP flow rate versus pressure relationships are commonly quantified in bench testing but this is only a relative measure of the pump fit over a short period under standard test conditions. The pump pressure capability should be considered in the context of what can be delivered reliably by the pump over its expected service life under actual downhole conditions. To assess the ability of a pump to meet the functional specifications for the differential pressure, the pressure rating shall be considered in conjunction with the fluid characteristics (viscosity), operating conditions (pump speed) and, most importantly, the short-term (temperature) and long-term (fluid swell) impact of the downhole conditions on the stator material. While pump bench tests can quantify the pressure capability over a range of speeds and temperatures, it is usually impractical to accurately replicate the downhole conditions. As such, these tests usually serve only to characterize the pump performance. Experience is used to translate the pump performance measured in bench tests to expected performance under downhole conditions. Suppliers/manufacturers shall provide guidelines to assist users/purchasers in this process.

G.6 Pump torque and power

The torque required to rotate a PCP is comprised of a hydraulic component as well as a friction component. Depending on the configuration, there can also be incremental torque associated with rotating the drive string and surface equipment.

The PCP's hydraulic torque component is simply a function of the pump displacement (capacity) and the operating differential pressure. Although it can seem counter-intuitive, the pump speed and volumetric efficiency do not influence the hydraulic torque component. Accordingly, although a small-capacity pump turning quickly and a large pump turning slowly can potentially have the same fluid rate, the larger pump has a torque higher than the small pump in proportion to the ratio of their displacements.

A pump's frictional torque component is comprised of three main elements, which, in turn, are influenced by multiple pump design and operational factors, making it difficult to predict. The primary frictional elements include the sliding/rolling interaction between the rotor and stator, the hysteretic losses associated with the deformation of the elastomer and the fluid losses through the pump. The sliding/rolling interaction is highly dependent on the pump geometry, the rotor stator fit and the lubricating properties of the fluid. The hysteretic losses depend primarily on the pump geometry, the rotor stator fit and the elastomer properties. The fluid losses through the pump depend on the pump's cavity geometry, the flow rate and the fluid viscosity. Under normal operation, the friction torque in a PCP is typically only 10 % to 25 % of the pump's total torque. However, that can increase significantly in certain cases, such as for a tight rotor stator fit due to swell or in high viscosity fluids.

The power required to operate a PCP is a direct function of the applied torque and rotational speed. As such, while a small-capacity pump turning quickly can require a lower torque than a larger pump turning slowly, if they are producing similar fluid rates, at the same differential pressure, the powers are normally similar.

Suppliers/manufacturers provide design performance curves for each pump configuration that display, amongst other things, the pump torque and power as a function of differential pressure and pump speed. The values implied from the design performance curves are reference values under ideal conditions and actual torque and power values can vary significantly over a wide range of potential downhole and operating conditions. Pump torque and power values are also commonly shown on functional performance curves determined for a pump and its specific rotor/stator combination in accordance with Annex C. Since the functional test conditions normally do not reflect the intended downhole conditions, the associated torque and power values should also be used cautiously. Equipment suppliers/manufacturers provide guidelines and tools to assist users/purchasers in associating design and performance test torque and power values to downhole conditions.

G.7 Overall pump efficiency

PCP systems are often cited as having the highest overall system efficiency of the common artificial lift systems. While the overall system efficiency values can range from as low as 20 % to over 80 %, they are typically in the range of 55 % to 70 %. The overall system efficiency is the product of the individual efficiencies associated with the surface equipment, the drive string and the downhole pump.

For a PCP the overall efficiency, E_{all}, expressed as a percentage, is the ratio of the useful hydraulic power to the power input. The hydraulic power is a function of the flow rate at the discharge of the pump and the differential pressure across the pump. The power input is a function of the torque on the pump rotor and the pump rotational speed. Normally this is calculated according to Equation (G.2):

$$E_{\text{all}} = \frac{11\,050 \times Q \times \Delta p}{\tau \times \omega} \tag{G.2}$$

where

Q is the flow rate at a given differential pressure, expressed in cubic metres per day;

Δp is the differential pressure, expressed in megapascals;

τ is the shaft torque, expressed in newton-metres;

ω is the shaft speed, expressed in revolutions per minute.

Due to the positive displacement nature of the PCP, any volumetric inefficiencies directly impact the overall efficiency as they do not contribute to the hydraulic power but require power input. This can be demonstrated by an examination of pump-performance curves, which show that the measured torque and power do not change significantly even with large reductions in the volumetric efficiency. As a result, the maximum overall system efficiency is always less than the volumetric efficiency. In addition to volumetric inefficiencies, pump friction also contributes to a reduction in the overall efficiency. In accordance with G.6, the primary frictional elements in a PCP include the sliding/rolling interaction between the rotor and stator, the hysteretic losses associated with the deformation of the elastomer and the fluid losses through the pump. Under normal operation with most pump geometries, the total pump-friction typically contributes to an overall efficiency reduction of 10 % to 25 %.

G.8 Application changes

PCP systems are typically selected to operate in specific application environments. Changes in the application, such as changing fluid characteristics or composition and changes in surface facilities, can render the PCP system inappropriate for the new application. Also, in many instances, some or all of the PCP system is removed from one well and installed in another well. It is necessary for the user/purchaser to ensure that the equipment is appropriate for the new application, as most changes in application affect the efficiency and run life of the PCP system.

Annex H
(informative)

Example user/purchaser PCP functional specification form

The form given in Figure H.1 may be used by the user/purchaser to help specify the functional requirements of the PCP system as required by Clause 5. This form might not be fully inclusive of all requirements.

Date	
Company name:	
Contact	
Phone	
E-mail	

Completion data		**Units circle one**
Pump seating depth [PSD] (measured depth [MD])		m - ft
Pump seating depth [PSD] (true vertical depth [TVD])		m - ft
Inclination at PSD		°/ 100 ft - ° / 30 m
Maximum deviation or dogleg severity for PCP		°/ 100 ft - ° / 30 m
Total well depth (TVD)		m - ft
Datum or reference depth		m - ft
Depth of producing interval (MD and / or TVD)		m - ft
Casing OD		mm - in
Min casing drift diameter between wellhead and PSD		mm - in
Casing weight and grade		Kg/m – lbm/ft
Casing connection type		
Tubing OD		mm - in
Tubing weight		Kg/m – lbm/ft
Tubing grade		
Tubing thread type		
Tubing inner coating type and thickness (if applicable)		
Packer? MD:		m - ft
Torque anchor depth MD:		m - ft
Torque anchor type		
Pump intake type: Slotted ☐ Selective ☐ Static gas separator ☐ Tail Joint ☐ Other ☐		

Fluid data					
API oil gravity		degrees			
Total fluid viscosity		cP		C - F	
Viscosity table		cP		C - F	
		cP		C - F	
		cP		C - F	
H_2S		% - ppm	Water S.G.		
CO_2		% - ppm	Water Salinity		ppm
Water pH					
Bubble point pressure at reservoir temperature		kPa - psi			
Aromatics (benzene, toluene, xylene)		%			

Well information		
Well name		
Field		
Well location	Onshore ☐ Offshore ☐	
Operating environment: Coalbed methane☐ Heavy oil ☐ Conventional oil ☐ Other ☐		
Reservoir type: Carbonate ☐ Consolidated sandstone ☐ Unconsolidated sandstone ☐ Coal ☐ Shale ☐		
Reservoir recovery process: Aquifer drive ☐ Solution gas drive ☐ Water flood ☐ Coal dewatering ☐ EOR ☐		
Well type: Vertical ☐ Directional ☐ Slant ☐ Horizontal ☐		
Completion type: Perforating casing ☐ Open hole ☐ Slotted liner ☐ Gravel pack ☐ Sand screen ☐		
Target production		m^3pd - bfpd
Target PCP service life		
Deployment method	Rod ☐ Tubing☐ Wireline ☐	

Production data		**Units circle one**
Current production		m^3pd - bfpd
Water cut		%
Solids		% by volume
Minimum/maximum operational pump speeds (if known)		rpm
Producing gas oil ratio		sM^3/sm^3– scf/stb
Wellhead pressure		kPa - psi
Casing pressure		kPa - psi
Pump intake temperature (static)		C – F
Wellhead temperature		C – F
Fluid level from surface: static		m - ft
Reservoir temperature at datum depth		C – F
Reservoir static pressure		kPa - psi
Producing pressure at pump intake or producing fluid level		kPa – psi m - ft
Productivity index		m^3/kPa – bbl/psi
Casing / tubing gas rate ratio or downhole free gas separation efficiency		sm^3/sm^3 – scf/stb
Slugging tendency of fluid / gas / solids into pump? Yes ☐ No ☐		
History of scale related problems? Yes ☐ No ☐ History of paraffin deposition? Yes ☐ No ☐ History of asphaltene deposition? Yes ☐ No ☐ Foamy oil behaviour? Yes ☐ No ☐		
History of solids related problems such as plugging and erosion of downhole components? Yes ☐ No ☐		
Emulsions? Yes ☐ No ☐ If yes, please provide inversion point and emulsion viscosity data		
Treating chemicals being injected in the well? Yes ☐ No ☐ If yes, please describe:		
Can you provide: Deviation survey Yes ☐ No ☐ Compositional fluid analysis Yes ☐ No ☐		

Page 1 of 2

If surface driven:				
Drive string type:	Standard ☐ Continuous ☐ Hollow ☐			
Drive string body OD		mm - in		
Coupling OD		mm - in		
Drive string material grade				
Connection Type:				
☐ Rotating centralizer	Type and #			
☐ Rod guide	Type and #			
☐ Electric prime mover		rpm		Hp
☐ Gas prime mover		Brand		Size
Surface drive	Direct ☐ Hydraulic ☐			
Belt & sheave ratio		Gear box ratio		
Operating frequency		Line voltage		
Hydraulic pump & motor				

If subsurface driven:		
Subsurface drive	Electric ☐	Hydraulic ☐
Gearbox ratio		
Motor speed at 60 Hz		rpm
Motor HP at 60 Hz		
Electric motor type:	2-pole ☐ 4-pole ☐	
Subsurface drive OD		mm - in
Subsurface drive assembly length:		m - ft
Subsurface drive assembly connection type:		
Operational and / or well intervention limitations?		
Subsurface Instrumentation details, if applicable (dimensions, type, placement relative to pump intake)		
Subsurface chemical injection: OD of injection tubing string and placement relative to pump intake.		

Design validation grade requirement (check one)		
☐ **V3:** **Legacy design validation**	☐ **V2:** **Basic design validation**	☐ **V1:** **Highest level design validation**

Product functional testing grade requirement (check one)							
☐ **F1: Functional hydraulic Test**				☐ **F2: Functional evaluation without bench testing**			
F1 Expected / F2 required operational ranges for functional testing:				Pump speeds			rpm
Volumetric efficiency		%	Test fluid type:		Test fluid temperatures		C - F
Fluid rates		m3pd - bfpd		Test intake / discharge pressures			kPa – psi

Quality control grade requirement (check one)		
☐ **Q3:** **Basic level**	☐ **Q2:** **Intermediate level**	☐ **Q1:** **Highest level**

Other requirements (check those applicable)

☐ Elastomer compatibility testing
☐ Bond testing
☐ Tear strength testing
☐ Abrasion resistance testing
☐ Compressive modulus testing
☐ Explosive decompression testing
☐ H_2S resistance testing
☐ Dynamic properties testing
☐ Additional documentation, such as operator manuals, certificate of compliance and / or product data sheet?
Please specify:

Page 2 of 2

Figure H.1 — Example user/purchaser PCP functional specification form
(Click here to access an electronic version of this form)

Annex I
(informative)

Analysis after use

I.1 General

This informative annex covers

- designations for PCP inspection grade;
- inspection processes included in each inspection grade;
- reporting requirements, including nomenclature, for each inspection.

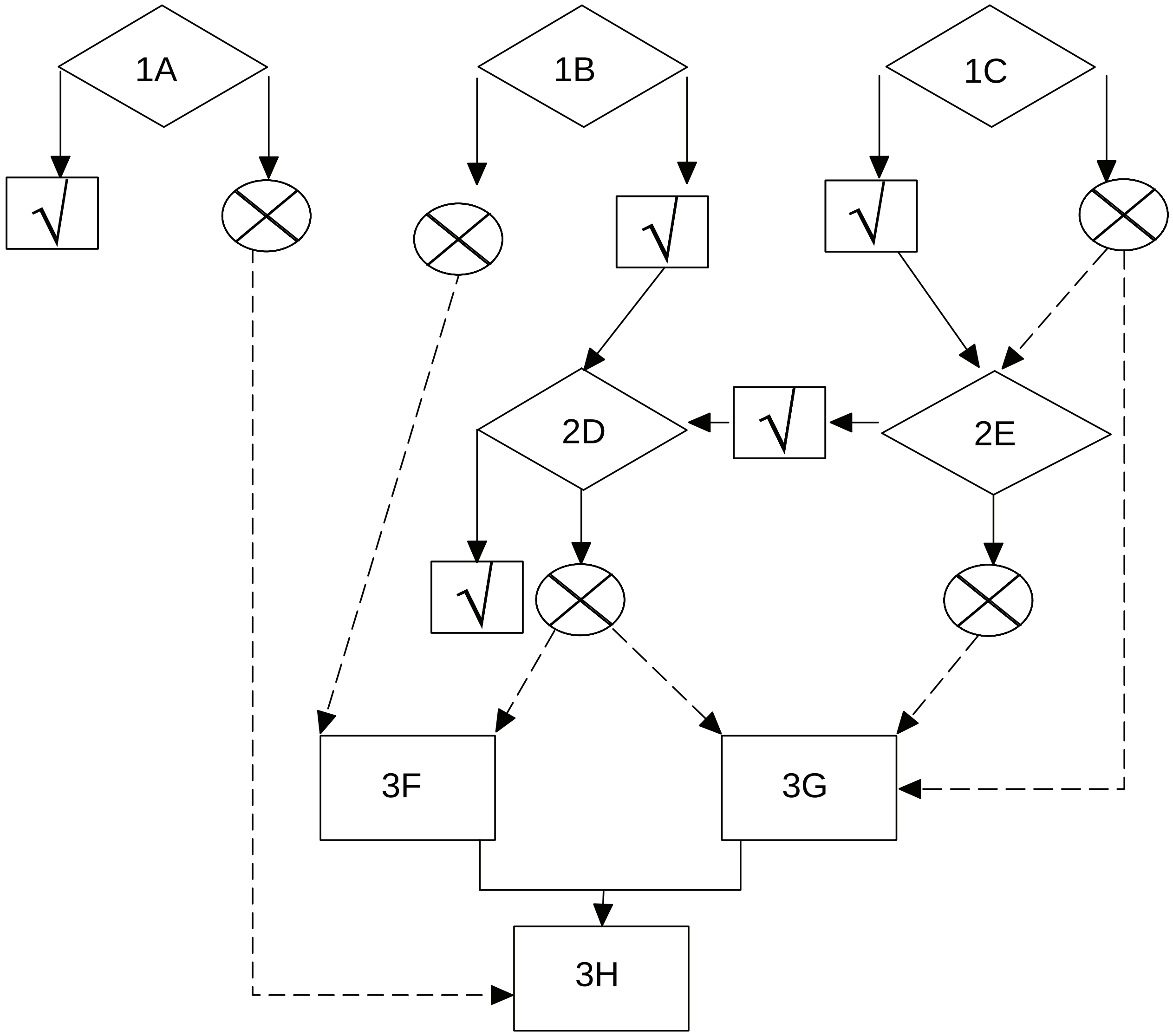
I.2 Inspection grades

I.2.1 General

Pump inspections shall be classified according to the reason for the inspection so that both the user/purchaser and supplier/manufacturer are clear as to the purpose of the inspection and the specific deliverables that result from each inspection grade. Three inspection grades are specified:

- grade 1: post-pull verification; see I.2.2;
- grade 2: used pump evaluation; see I.2.3;
- grade 3: failure investigation; see I.2.4.

The circumstances are described in I.2.2 to I.2.4 where each of these inspections is used and the information that shall be provided by the supplier/manufacturer from each inspection grade. Figure I.1 shows components of each inspection grade.



Key

Key designation	Inspection		Description
	Grade	Application	
1A	1	post-pull verification	auxiliary equipment inspection
1B	1	post-pull verification	rotor inspection
1C	1	post-pull verification	exterior stator inspection
2D	2	used pump evaluation	pump bench test
2E	2	used pump evaluation	interior stator inspection
3F	2	failure investigation	detailed rotor inspection
3G	3	failure investigation	detailed stator inspection
3H	3	failure investigation	failure-cause analysis
√	reusable		
⊗	not reusable		

Figure I.1 — Description and application of the pump inspection grades

I.2.2 Grade 1 inspection — Post-pull verification

I.2.2.1 Purpose and initiation

The purpose of the grade 1 inspection is to determine if there is any significant damage to a pump that is pulled from a well. If no damage is apparent in this inspection, the pump may be rerun.

This inspection is typically initiated by the user/purchaser.

I.2.2.2 Inspection location

This inspection is typically conducted at the wellsite or in the supplier/manufacturer's field service centre. The personnel responsible for the inspection shall be familiar with any special requirements imposed by either the application or the preferences of the user/purchaser.

I.2.2.3 Inspection of components

The grade 1 inspection shall include the following segments:

- rotor visual inspection in accordance with 7.9.9.2;
- stator exterior inspection in accordance with I.3.4;
- auxiliary equipment inspection in accordance with I.3.6.

I.2.2.4 Reporting

The report includes the information gathered during inspections and the pump identification (see 7.3) and well description. Also included are any indications of whether any of the damage identified would prevent the pump from being reused. If the primary failed item may be identified, it shall be documented using descriptors consistent with typical PCP failure nomenclature.

I.2.3 Grade 2 inspection — Used pump evaluations

I.2.3.1 Purpose and initiation

The purpose of a grade 2 inspection is to determine whether a used pump can adequately perform its function within the operating requirements specified by the user/purchaser. Components of the grade 2 inspection may also be used to assist in determining the scope of a grade 3 inspection. Grade 2 inspections are typically initiated by the user/purchaser to determine whether the pump may be reused.

I.2.3.2 Inspection location

This inspection is typically conducted in the supplier/manufacturer's local service centre and shall be performed by a qualified person.

I.2.3.3 Inspection of components

Grade 2 inspections include the following components:

- all components of the grade 1 inspection (post-pull verification);
- interior stator inspection in accordance with I.3.5;
- pump bench test in accordance with I.3.7.

The grade 1 inspections or the interior stator inspection may indicate that the pump damage is severe enough that a pump bench test would provide no additional information or that the stator condition prevents a pump bench test. In addition, the minor diameter of some stators can be too small to allow an interior inspection of the stator using a boroscope. It is the supplier/manufacturer's responsibility to indicate on the inspection reports why these tests cannot be conducted.

I.2.3.4 Reporting

The inspection report shall include all of the information gathered in inspections and the pump identification (see 7.3) and well description. The report shall state whether the pump is considered as “reusable” in the intended application, based on the results of the inspection. If the primary failed item can be identified, it shall be documented using descriptors consistent with typical PCP failure nomenclature.

I.2.4 Grade 3 inspection — Failure investigation

I.2.4.1 Purpose and initiation

The purpose of the grade 3 inspection is to collect additional information to assist in a comprehensive failure investigation. These inspections are typically initiated by the supplier/manufacturer in response to a warranty claim for equipment that the user/purchaser feels failed prematurely. However, users/purchasers may also initiate these investigations to learn more about the circumstances of the failures in their applications.

I.2.4.2 Inspection location

This inspection is typically conducted in the supplier/manufacturer's manufacturing facility or service centre. This inspection requires specialized measurement equipment and personnel with specialized technical expertise that are not typically available in the local service centres.

I.2.4.3 Inspection components

A grade 3 inspection shall include the following components:

- all components of grades 1 and 2 inspections;
- detailed rotor inspection in accordance with I.3.9;
- detailed stator inspection in accordance with I.3.8;
- failure-cause analysis in accordance with I.3.10.

I.2.4.4 Reporting

The failure investigation report shall include all of the information gathered in inspections. The failure investigation report shall be a written summary of the information (including pictures to illustrate the key damage features identified). In addition to reviewing the information gathered in the pump inspections, the report shall provide a comprehensive review of the factors that can have contributed to the failure. This includes an examination of the pump history and manufacturing quality-control records.

The report shall include a summary of the investigation, indicating the following items:

- primary failed item and descriptors;
- failure cause (and any contributing cause).

I.3 Inspection components

I.3.1 General

The information that shall be included in the inspection report, as applicable, is described in I.3.2 to I.3.10.

I.3.2 Installation and operational conditions

Information in I.3.2 identifies the pump, where it was installed, and describes the general operating conditions in the well prior to the pump being pulled. This information may be used to track the service life of the pump and the operating conditions to ensure that the pump model was appropriate for the application. The following information may be included:

a) well operator (company, division) and contact person;

b) field name and well name (i.e. unique well identifier);

c) pump supplier/manufacturer and model;

d) date received by supplier/manufacturer;

e) date inspected by supplier/manufacturer;

f) name of person who performed the inspection;

g) date installed and pulled;

h) reason for pull;

i) equipment accessibility (stator left downhole; stator not inspected; rotor seized in stator; rotor not inspected);

j) date production period started and ended;

k) pump speed and average total fluid rate;

l) pump intake temperature;

m) wellhead tubing and casing-head pressure;

n) producing fluid level and pump seating depth;

o) oil density (API gravity), aromatics content, water cut and gas-oil ratio of produced fluids;

p) CO_2 and H_2S content of gas;

q) sand cut.

I.3.3 Rotor visual inspection

This inspection provides information on the condition of the rotor and results in a decision as to whether the rotor is or is not reusable as-is. The following information may be recorded:

a) rotor serial number;

b) rotor coating type (e.g. chrome, boron, etc.);

c) pull descriptors for rotor components using descriptors in Table I.1, including severity and location of the observations;

d) rotor pull condition (i.e. reusable or not reusable);

e) criteria used to reject the rotor if it is designated as not reusable.

A rotor that is not reusable may be repaired (e.g. recoated, rethreaded, straightened) as described in Annex K to return it to full serviceability. The repair shall be indicated permanently on the rotor in accordance with 7.3.

Pictures of damaged rotors that correspond to some of the descriptors in Table I.1 are presented in I.4.

I.3.4 Exterior stator inspection

This inspection collects information to describe the condition of the stator. In some cases, only the rotor is pulled to surface, leaving the stator downhole where it cannot be inspected. In these cases, the inspection report shall indicate that the stator was left downhole, rather than simply leaving the stator inspection section blank.

The result of this inspection shall be a recommendation as to whether the stator is or is not reusable as-is. The following information may be recorded:

a) stator serial number;

b) elastomer type;

c) pull descriptors for stator components using descriptors in Table I.2 as applicable, including severity and location of the observations;

d) stator pull condition (e.g. appears to be reusable or not reusable);

e) criteria used to reject the stator if it is designated as not reusable.

If the stator appears to be reusable, the user/purchaser may elect to perform a grade 2 inspection to verify that the pump is reusable.

I.3.5 Interior stator inspection

This inspection collects information to describe the condition of the stator elastomer along the entire length of the stator. This inspection may be performed using a boroscope or similar tool to visually inspect the interior surface of the stator elastomer. The tool may be run from each end of the stator along its full length to allow inspection of the complete helical elastomer surface.

The descriptors listed in Table I.2 may be used to report the condition of the stator. These descriptors may be added to the information already collected in the exterior stator inspection. The result of this inspection shall be a recommendation whether the stator is in adequate condition for a pump bench test or is not reusable (discarded). The inspection report shall also indicate the criteria used to reject the stator if it is designated as not reusable.

The interior inspection may also include

a) measurement of the stator internal dimensions using a caliper tool or plug gauges;

b) collection of any foreign material found in the stator (i.e. sand, paraffin) and its analysis, as applicable.

I.3.6 Auxiliary-equipment inspection

PCP installations may include various auxiliary equipment, such as tag bars, no-turn tools, downhole check valves and gas separators. The result of this section of the inspection shall be a recommendation as to whether the auxiliary equipment is or is not reusable as-is. Auxiliary equipment may be “reusable” after some minor repair (e.g. thread redressing, fitting replacement, painting) to return the equipment to full serviceability.

The following information may be recorded during the inspection:

a) auxiliary equipment type, manufacturer and model;

b) pull descriptor, e.g. reason for pull;

c) pull condition, i.e. reusable or not reusable;

d) criteria used to reject the auxiliary equipment if it is designated as not reusable;

e) other observations to assist in the root-cause failure analysis of the PCP system.

I.3.7 Pump bench test

A pump bench test may be used to assess the performance of a stator-rotor combination that is considered as reusable. Procedures for pump bench testing are provided in Annex C.

I.3.8 Detailed stator inspection

It is generally necessary to cut a stator open to perform a detailed stator inspection and, therefore, this inspection component is reported as part of a failure-cause analysis. Typically, it is not necessary to subject the entire stator to the detailed inspection; sections measuring approximately 0,5 m long may be cut from the top, middle and bottom of the stator. This selection of specimens may be modified if other evidence, such as a boroscope inspection, indicates that significant problems exist in other sections of the stator. Each specimen is cut longitudinally (slabbed) to expose the elastomer. The following information may be collected:

a) description of the elastomer condition in each section using the descriptors provided in Table I.2;

b) photographs of any features with a detailed description of the location of the feature in the stator;

c) measurements of elastomer hardness (Shore A) on the cut surface, seal lines and major diameters with at least three measurements on each slabbed section; these measurements may be compared with the nominal material parameters for the specific elastomer type;

d) measurements of the major and minor thicknesses in at least three locations in each slabbed section to determine the degree of elastomer swell present and the degree of centralization of the stator cavity in the stator housing; these measurements shall be compared to the manufacturing tolerances.

Selected pictures of damaged stator elastomers that correspond to the descriptors are presented in I.5.

The detailed inspection may also include measurements of the specific gravity, hardness, bond strength, tensile strength and elongation of specimens removed from the stator elastomer. These properties may be compared to the nominal material parameters for the specific elastomer and bonding system.

I.3.9 Detailed rotor inspection

A detailed rotor inspection shall collect and report the following information as part of a failure-cause analysis:

a) photographs of any features with a detailed description of the location of the feature on the rotor;

b) measurements of the major and minor diameter of the rotor with at least three measurements of each parameter in each segment of the rotor (top, middle, bottom) plus in any segment showing damage to the rotor coating;

c) measurements of the hardness (Vickers and Knoop) of the coating;

d) measurement of the hardness (Rockwell C) of the base metal if it is exposed by wear or a rotor break;

e) if the rotor is broken, ametallographic analysis, which may include micrographs of the failure surface, micro-hardness measurements and an analysis of corrosion products and features.

Selected pictures of damaged rotors that correspond to the descriptors are presented in I.4

I.3.10 Failure-cause analysis

I.3.10.1 General

A failure-cause analysis is performed to identify the circumstances that led to the failure. The failure cause shall be specified using typical failure nomenclature. It might not be possible to determine the failure cause from the information in the PCP inspection reports. To determine the failure cause, the information collected during the pump inspection may be augmented by a comprehensive review of the pump operating history and the quality control documentation from the manufacturing process. The information that it is necessary to collect as part of the analysis in addition to the inspection reports is described in I.3.10.2 and I.3.10.3.

I.3.10.2 PCP history

The report should summarize the installation history for both the rotor and stator, including any installations prior to the installation in which the failure occurred. This may include the following:

a) a brief description of the well geometry and completion configuration;

b) any auxiliary equipment that was run with the pump;

c) the operating conditions during the period when the pump was in the well.

I.3.10.3 PCP quality control documentation

The manufacturing and quality control records for the rotor and stator may be reviewed to identify any irregularities, as appropriate. This may include identifying any circumstances where the material properties, dimensions and manufacturing procedures used for the pump in question vary from the allowable tolerances described in the standard manufacturing procedures.

Table I.1 — Rotor condition inspection results

(Click here to access an electronic version of Table I.1)

Rotor component	OK	N/A	Descriptor	Top			Middle			Bottom		
				Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
Body			Bent									
			Broken/fractured									
			Base metal worn									
Coating			Cracked/heat cracked									
			Pitted									
			Worn									
			Discoloured									
			Burn/overheated									
			Corroded									
			Scratched/grooved									
Coupling			Damaged									
Weld			Broken/fractured									
			Cracked/heat cracked									
Base metal			Worn									

Table I.2 — Stator condition inspection results

(Click here to access an electronic version of Table I.2)

Stator component	OK	N/A	Descriptor	Top			Middle			Bottom		
				Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
Housing			Bent									
			Broken/fractured									
			Corroded									
Elastomer			Burned									
			Brittle									
			Eroded/pressure washed									
			Scratched/grooved									
			Worn									
			Swollen									
			Blistered									
			Hardened									
			Debonded									
			Torn/chunked									
			Contaminated/foreign material									
Coupling			Damaged									
Tag bar			Worn									
			Broken/fractured									
			Bent									
			Missing									

I.4 Examples of damaged rotors

Figures I.2 to I.4 show examples of different types of rotor damage.

(Click here to access an electronic version of Figures I.2 to I.4.)

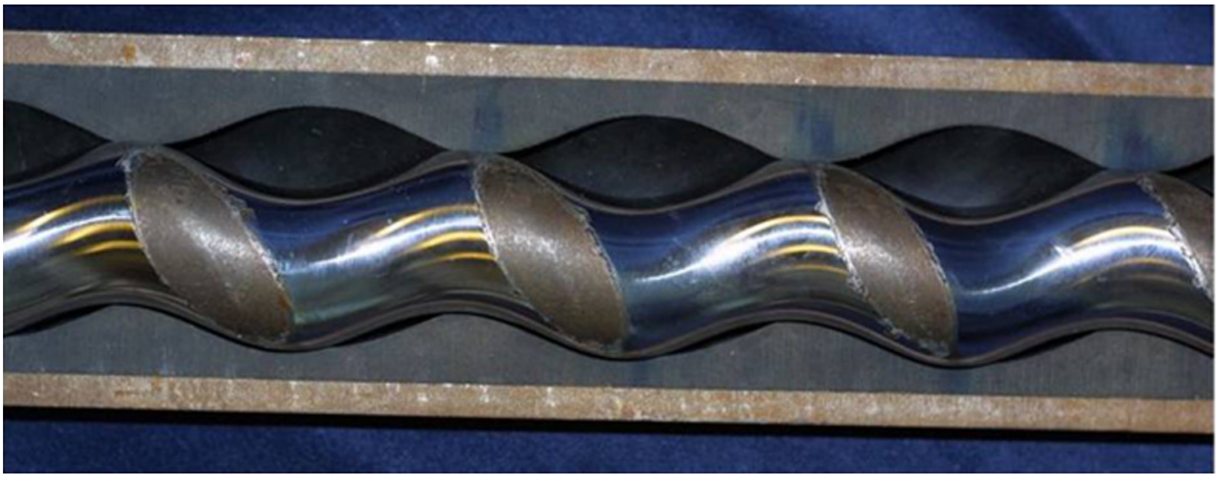


Figure I.2 —Worn rotor
(provided courtesy of CFER Technologies)

Figure I.3 — Cracked/heat cracked rotor
(provided courtesy of Kudu Industries)

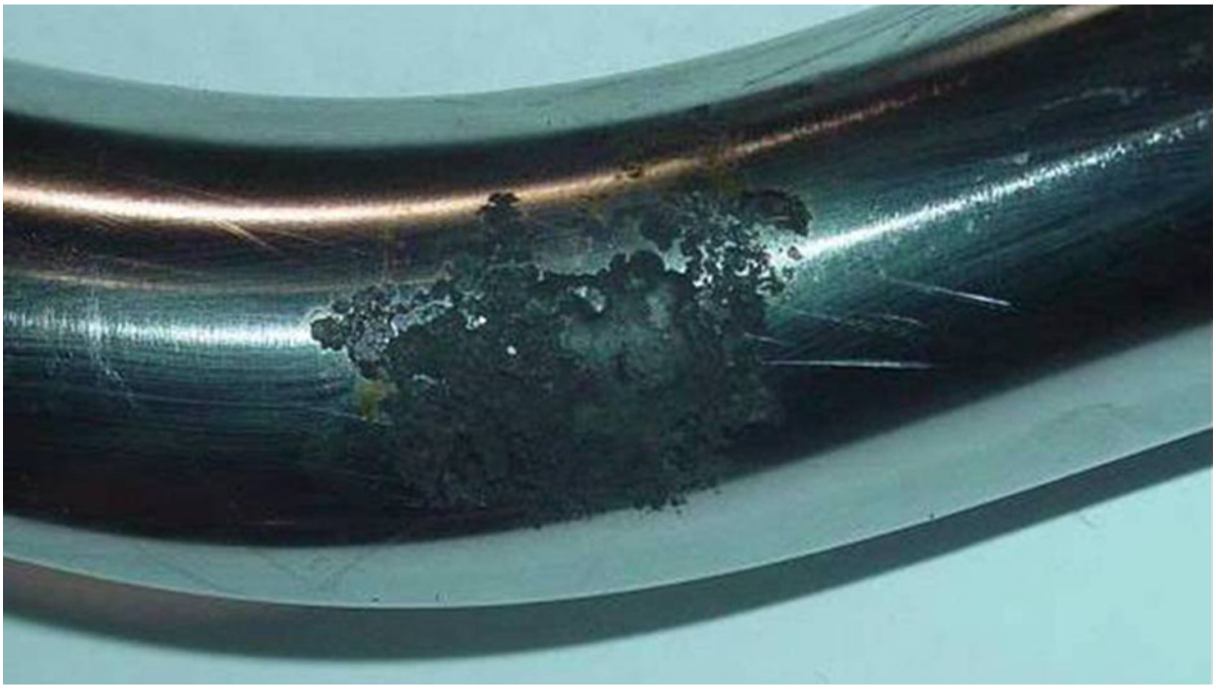


Figure I.4 — Pitted rotor
(provided courtesy of Kudu Industries)

I.5 Examples of damaged stators

Figures I.5 to I.12 show examples of different types of stator damage.

(Click here to access an electronic version of Figures I.5 to I.12.)

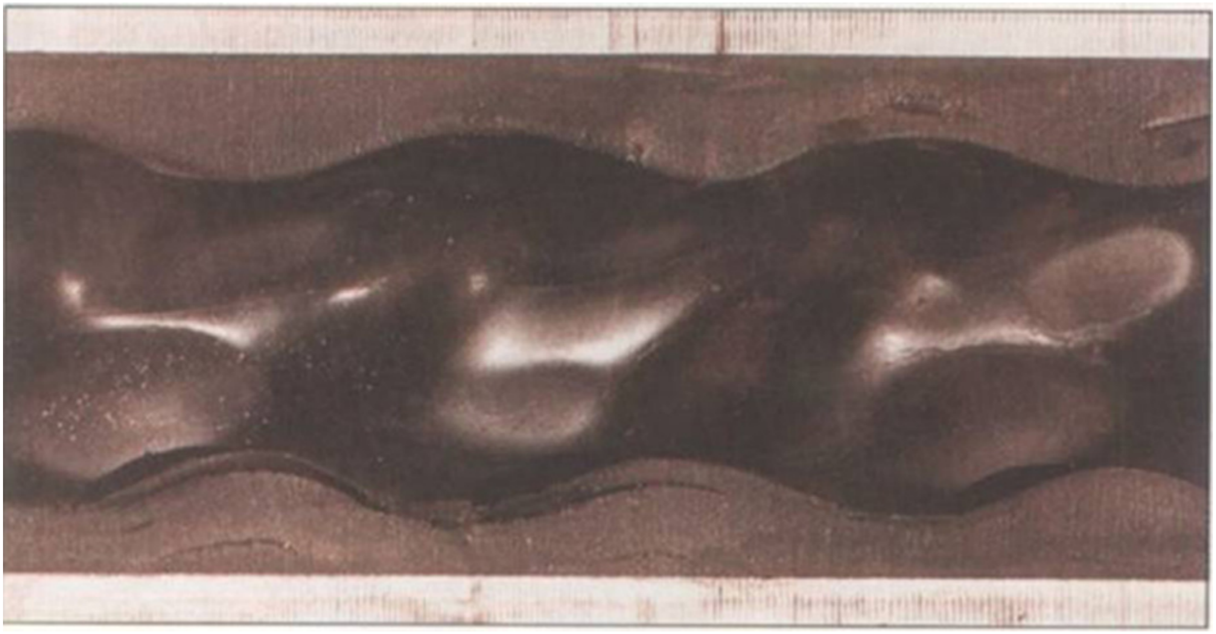


Figure I.5 — Blistered stator
(provided courtesy of Weatherford)

Figure I.6 — Burned/overheated stator
(provided courtesy of CFER Technologies)

Figure I.7 — Eroded/pressure washed stator
(provided courtesy of CFER Technologies)

Figure I.8 — Debonded stator
(provided courtesy of CFER Technologies)

Figure I.9 — Scratched/grooved stator
(provided courtesy of Weatherford)

Figure I.10 — Torn/chunked stator
(provided courtesy of CFER Technologies)

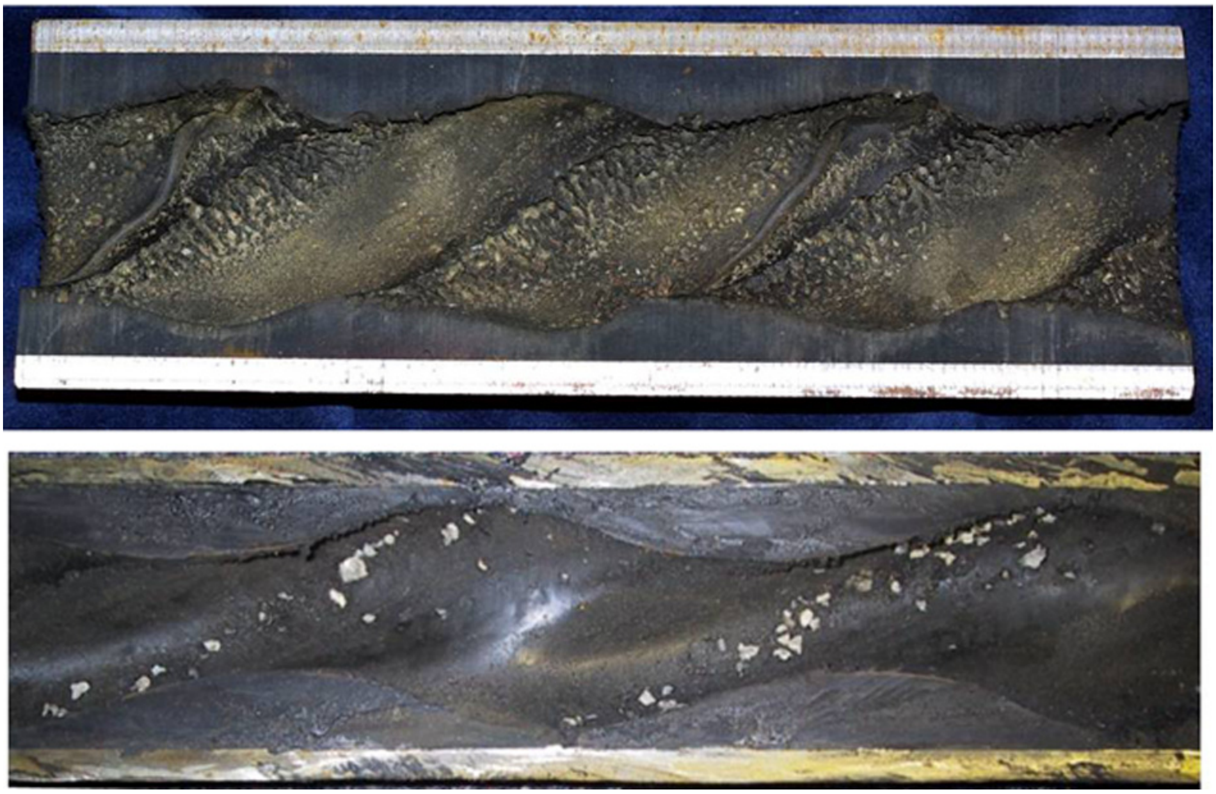


Figure I.11 — Stator contaminated/foreign material (two examples)
(provided courtesy of CFER Technologies)

Figure I.12 — Stator worn
(provided courtesy of Kudu Industries)

Annex J
(informative)

Selection and use of drive-string equipment in PCP applications

J.1 General

This informative annex describes the considerations related to the application of drive strings in rotary pumping applications that typically include a surface-driven PCP system. ISO 10428 covers the technical requirements of sucker rods used in reciprocating pump applications; the use of sucker rods for PCP rotary applications is addressed in this part of ISO 15136.

J.2 Background

PCP systems typically use a drive string to transmit power (torque) from the surface drive system to the downhole pump. Although drive strings are most commonly composed of sucker rods, other equipment such as hollow rods and continuous rods are also used.

The PCP application subjects the drive string to a combination of torsion and axial load that introduces the following unique issues related to drive string performance not seen in reciprocating-pumping applications.

a) The drive string loading includes the combined effect of torsion and axial loading.

b) Bending due to wellbore curvatures can impose millions of stress cycles on the drive string in a matter of days, making fatigue a potential failure mode.

c) Drive string make-up is critical. A make-up torque less than the applied operating torsional load can lead to an incremental make-up that can damage the drive string connections.

d) Drive string and tubing wear can be accelerated due to the connection rotating in the same location, where side loads are concentrated at the maximum OD of the drive string, and the possible presence of abrasive solids in the fluid.

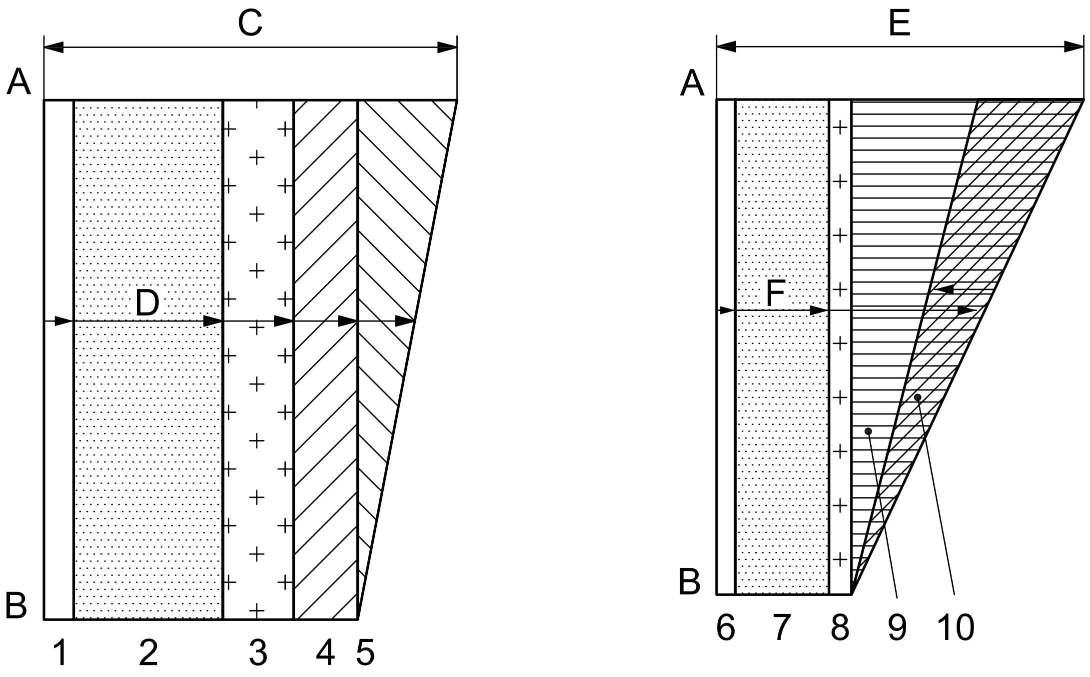
e) A backspin effect, or reverse rotation, occurs as a result of the fluid draining from the tubing when the surface drive stops. During reverse rotation, there can be a transient torque reversal, which can result in decoupling of the drive string.

These issues are discussed in J.3 to J.9.

J.3 Drive string loading

J.3.1 General

In a PCP system, the drive string should be designed to carry the imposed axial load and transmit torque to the downhole pump. The axial load and torque at any location along a drive string is made up of several different components as shown in Figure J.1. Several major load components are applied to the drive string at the pump (e.g. pump hydraulic torque and pump axial load), while others are developed in a distributed manner along the length of the drive string (e.g. resistive torque and drive-string weight). In almost all cases, the drive-string axial load and torque are largest at the polished-rod connection at surface.



a) **Torque components**

b) **Axial-load components**

Key

A	surface
B	pump
C	polished-rod torque
1	pump hydraulic torque (tubing-head pressure)
2	pump hydraulic (hydrostatic pressure)
3	pump hydraulic (flow losses)
4	pump-friction
5	resistive
D	rod-string torque
E	polished-rod axial load
F	rod-string axial load
6	pump axial (tubing-head pressure)
7	pump axial (hydrostatic pressure)
8	pump axial (flow losses)
9	rod weight
10	uplift forces

Figure J.1 — Components that contribute to drive string torque and axial load

The operating conditions in many PCP applications expose the drive string to severe load fluctuations. Variations in pump-discharge pressure caused by gas slugs, the evolution of gas from produced fluids in the production tubing, or increases in pump-friction due to sand, fluid slugs or elastomer swell can cause significant fluctuations in pump torque and axial load. In deviated wells, the drive string is subjected to cyclic bending stresses at the rotational speed of the pump. Given the typical operating speeds of PCPs, the number of loading cycles can reach several million in just a few days.

If the combined axial load and torque produce a combined stress that exceeds the load capacity for the size and grade of the drive string, failure can occur. Additionally, cumulative cyclical stresses can result in fatigue failures. Following proper design, installation and operating practices can prevent failures and extend the operating life of the drive string.

J.3.2 Pump-friction torque

Pump-friction torque is a function of the pump geometry including its profile, length, and interference fit between the rotor and the stator. Pump-friction torque is typically measured during a pump bench test. However, pump-friction torque can increase downhole if the stator elastomer swells due to thermal or chemical effects. When pumping high-viscosity fluids at high rates, a viscous torque can also add to the torsional resistance in the pump. Pump-friction torque is typically highest at start-up due to the effect of static friction between the rotor and stator.

J.3.3 Resistive drive string torque

As the drive string rotates, the body and connections contact the production tubing. Friction between the drive-string body and tubing creates resistive torque on the drive string that is a function of the contact load between the rods and tubing, the diameter of the components and the coefficient of friction between the components. The contact load, in turn, is directly proportional to the axial load on the drive string and the wellbore curvature. The coefficient of friction depends on the material properties of the components, and on the properties of the fluid and solid particles between the components.

In addition, as the drive string spins in the fluid in the production tubing, surface shear forces due to viscosity develop between the fluid and drive string that resist the rotation of the drive string.

J.3.4 Pump axial load

The pump axial load is a function of the pump load-bearing area (related to the cross-sectional profile of the stator) and is proportional to the differential pressure across the pump.

J.3.5 Drive string weight

The weight of the drive string and pump rotor, adjusted for buoyancy effects, add to the axial load.

J.3.6 Drive string uplift forces

Flow losses produce forces that act on the drive string in the direction of flow, causing a reduction in drive string axial load. These forces are applied to the couplings and drive-string body in the form of area uplift forces and surface uplift forces, respectively.

J.4 Drive-string ratings

The drive-string-rod body stress can be represented by the Von Mises stress (effective stress, σ_e), which considers the combination of axial load and torque. In PCP applications, this stress is primarily a function of torque, with the axial load having a lesser effect. This stress is assumed to occur at the worst-case location (outer surface) of the rod string and, due to the predominance of the torsional component, the stresses within the inner portion of the body are much lower. The effective stress, σ_e, expressed in megapascals, can be defined as given in Equation (J.1):

$$\sigma_e = \sqrt{\frac{16 F_r^2}{\pi^2 d_r^4} + \frac{7{,}68 \times 10^8 T_r^2}{\pi^2 d_r^6}} \qquad \text{(J.1)}$$

where

F_r is the drive string axial load, expressed in newtons;

T_r is the drive string torque, expressed in newton-meters;

d_r is the drive string diameter, expressed in millimetres.

In contrast to the cyclic drive-string stresses that occur in beam pumping, the drive-string stresses in PCP applications are relatively constant. As a result, equivalent drive-string stresses can approach the yield stress of the drive-string material without causing failures in PCP applications. Fatigue induced by bending can be an issue in directional and horizontal well applications.

In calculating fatigue life, it is recommended that both the high-frequency effects (i.e. bending) and low-frequency effects (e.g. gas slugging) be considered. It is well established that mechanical components subjected to alternating loads are susceptible to metal fatigue. In PCP drive-string applications, this can be the result of several factors, which include the accumulation of rotating cycles while under torsional loading and the variations between the maximum and minimum tensile loading. Fatigue failures can occur if the peak stress level in the material is well below the material's yield strength. Most steels exhibit an endurance limit, the maximum alternating stress that results in an “infinite” fatigue life. Designing drive strings for alternating stress levels below the endurance limit or incorporating service factors can be an effective design approach.

J.5 Drive-string service and design factors

Two factors are typically applied to the yield strength of a drive string to establish an allowable operating stress (load): a design factor and service factor. The design factor is generally applied by the supplier/manufacturer to the drive-string design to allow for variability in the material properties and manufacturing tolerances of the drive string. For instance, a drive-string supplier/manufacturer may recommend that a drive string be operated at no more than 90 % of the nominal yield strength of the drive string material. This service factor is typically applied by the user/purchaser to account for factors in the application that tend to reduce the load-carrying capacity of the drive string, resulting in a reduction (de-rating) of the drive string from the published ratings. These factors may include

- corrosive or abrasive environment that leads to rapid metal loss;
- sour environment that leads to material embrittlement;
- high well curvature applications that impose excessive bending;
- severe load fluctuations that cause incremental variability in the applied loads.

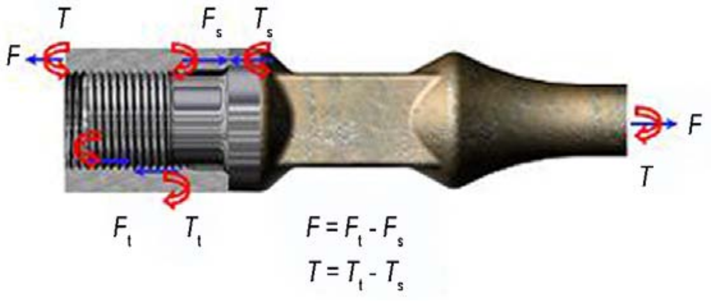
It is recommended that the user/purchaser discuss the drive-string load-rating methodology used by the supplier/manufacturer prior to selecting a drive string for a particular application.

J.6 Connection make-up

J.6.1 General

Connection make-up is critical in PCP applications since the applied torsional load during pumping can cause incremental make-up of the connections where the applied torque exceeds the torsional resistance in the connection. To obtain the required make-up without damage to the drive-string system while in operation, it is important to remove any coatings or contaminants from the surfaces of the coupling face and connection shoulder and to carefully follow the supplier/manufacturer's recommended installation procedures. This includes the application of the recommended amount of the appropriate thread lubricant, which is usually applied only to the pin threads.

The torsional resistance in the connection is a function of the pre-load on the threads and torque shoulder created during make-up as shown in Figure J.2. Incomplete make-up results in lower pre-loads in the connection, and therefore, a lower torsional resistance. A high tensile load in the drive string can also reduce the pre-load on the torque shoulder, thereby causing a reduction in the torsional resistance of the connection.



Key

F_t axial force on threads

T_t torsion on threads

F_s axial force on torque shoulder

T_s torsion on torque shoulder

Figure J.2 — Loading at connection

The torsional resistance of a made-up connection is determined by the static coefficient of friction on the threads and torque shoulder. The static coefficient of friction, and subsequent torque imparted to the connection, is affected by the roughness of the coupling face and drive-string torque shoulder and the presence or application of lubricants, corrosion protectors, contaminants, etc. If the torsional resistance is exceeded, the frictional characteristics are determined by the kinetic coefficient of friction, which can be significantly lower than the static coefficient. In addition, rapid movement between contacting surfaces (i.e. torque shoulder and coupling face) can lead to dynamic lubrication that further reduces the friction effect. This causes the torsional resistance in the connection to decrease dramatically, allowing the connection to make-up further. This can impose damaging loads within the connection.

Signs that incremental make-up has occurred in a connection can include any or all of the following:

- stripped threads;
- belled coupling or yielding of the coupling and rod faces;
- tensile deformation or failure of the pin undercut.

Incremental make-up can be particularly severe in a well since the drive string acts as a large torsion spring that stores energy in the form of elastic twists of the drive string. When the torsional resistance in a connection is exceeded, the stored energy maintains the applied torque, which causes the incremental make-up to occur very rapidly. This is referred to as dynamic make-up and can result in damage to the connection. Ensuring that the drive string connections are made-up to the supplier/manufacturer's specification can minimize the potential for incremental make-up.

J.6.2 Displacement based make-up

The traditional method for making-up drive-string connections is to use a circumferential displacement approach where the connection is turned a specified distance past hand tight. A displacement card is usually provided by the supplier/manufacturer to gauge the amount of make-up. Initially, the reciprocating displacement criteria and associated make-up cards were used for PCP installations, but research showed that this make-up criteria did not result in sufficient make-up torque. Consequently, drive-string suppliers/manufacturers have developed make-up displacement criteria and associated make-up cards especially for PCP applications. The distance, or displacement, is typically based on laboratory test results and is intended to impart a make-up torque that is equal to or in excess of the torque rating of the drive string. Actual make-up torques are impacted by manufacturing variations, thread lubrication or contaminants on the contacting surfaces.

J.6.3 Torque-based make-up

Drive-string suppliers/manufacturers may also recommend a “torque-based” approach to drive-string assembly. The premise of this approach is to ensure that the make-up torque exceeds the anticipated start-up and operating torques, so that incremental make-up does not occur during operation. Typically, the make-up torque is estimated based on the hydraulic pressure applied using a power tong system. This involves measurement of the hydraulic pressure, using a mechanical pressure gauge. There is a direct correlation between the hydraulic pressure and the applied torque, which is dependent on the make and model of the power tong.

Some tong suppliers/manufacturers have developed systems to directly measure applied torque to reduce uncertainty. It is recommended that low-speed, high-torque power-tong systems be used for assembling drive-string connections. The torque-based make-up approach is especially recommended in high-torque applications where the drive string is operated near its rated load capacity or PCP systems where the drive string experiences frequent failures.

The torque-based make-up approach is incorporated as an integral component of some new drive-string designs that make use of unconventional connections, such as tapered threads or connections with more than one torque shoulder. As previously noted, the torsional resistance of a made-up connection is determined by the static coefficient of friction on the threads and torque shoulder.

J.7 Drive-string and tubing wear

Drive-string and tubing wear in PCP systems differs from that of beam-pumping systems in that the drive-string coupling rotates in one position on the tubing, causing the wear to be localized. In addition, PCPs are often used in applications where formation solids are produced, which can substantially increase wear rates.

Wear rates can be reduced by either using couplings coated with soft, expendable material (e.g. urethane or elastomer) or by distributing the drive string contact load among several rod guides placed along the body of the drive string between connections. Caution should be exercised when using wear-mitigation devices, because they typically increase pressure losses in the production tubing, which results in higher rod tension and can increase the contact load between the drive string and tubing. Therefore, the net result of installing the wear-mitigation devices can, in some cases, be increased drive-string loading and an associated increase in wear.

Eliminating the connection upsets in the drive string distributes the contact load along the full length of the drive string. This can be achieved with continuous rod, coiled tubing and flush-joint products.

Manual or automated tubing rotators can be used to distribute the wear around the full circumference of the production tubing, thereby extending tubing run life.

Since tubing wear in PCP applications is concentrated in a single spot adjacent to the couplings, operators can extend tubing life by incrementally raising or lowering the drive string so that the coupling wears in a different location on the production tubing. It is necessary that care be taken to ensure that the space-out requirements for the drive string are maintained when raising and lowering the drive string to ensure that the rotor stays fully engaged in the stator and that the rotor does not contact the tag bar below the pump. In cases where severe wear is anticipated or observed, heavy-wall, internally coated or surface-hardened production tubing can be installed to prolong the operating life of the well.

J.8 Continuous drive string

Continuous drive strings are installed in a manner similar to that for coiled tubing. The drive string is stored in a coil on surface and inserted or pulled from the well using a mechanical injector system. Continuous drive strings can distribute side loading to minimize drive string and tubing wear, and reduce installation time to run the rotor into the well for tubing-conveyed pumps or can be used to run the entire pump in an insertable PCP system. Additionally, these systems can reduce flow pressure losses due to the elimination of the flow restriction caused by the connection upset.

J.9 Hollow drive string

Hollow drive strings are (usually) installed using a pipe-tong and torque-based make-up. They permit the injection of treatment chemicals, such as corrosion inhibitors, paraffin inhibitors and diluents, at the pump intake. Hollow drive strings may also be designed with externally flush connections to provide flow and wear advantages similar to those of continuous drive strings.

J.10 Storage and handling

The storage and handling of drive rods should be as described in ISO 10428 or ANSI/API RP 11BR, where applicable. Alternatively, the suppliers/manufacturers shall have documented procedures for storage and handling to respond to local and environmental conditions.

Annex K
(informative)

Repair and reconditioning

K.1 General

This informative annex provides guidelines for repairing and reconditioning used rotors, stators and tag bars. Rotors, stators and auxiliary equipment shall be repaired and reconditioned in accordance with the supplier/manufacturer's documented procedures, which should include consideration of the information given in K.2 to K.4.

K.2 Rotor

The rotor shall be cleaned prior to re-use. Accumulated contaminants can cause damage to the stator elastomer and threads. Any number of common detergents and degreasers may be used to clean steel, plated, or carbide-coated rotor surfaces. The cleaner shall be washed from the rotor with water. A thread protector shall be used if the rotor is to be stored before re-use.

NOTE 1 Rotors can be damaged through shipping, handling and abuse in operation.

The cleaned rotor shall be examined for damage or material loss. If significant material loss is observed, dimensional measurements shall be compared to the original measurements. Minor damage such as dents can reduce volumetric efficiency of the pump. If significant material loss or damage is noted, a functional test of the pump can be required to determine if the rotor condition is acceptable.

NOTE 2 Rotor threads can yield slightly during use. Consequently, the threads on used rotors might not pass a gauge test intended for assessing new threads.

Table K.1 lists common rotor damage and repair options.

Table K.1 — Rotor repair options

Observed damage	Cause	Common repair and reconditioning operation
Wear	Ordinary use, abrasive fluid	Strip and replate/recoat rotor wear surface.
Minor thread damage[a]	Ordinary use, contaminants	Remove burrs or damaged threads within the specification tolerance, generally API Spec 11B.
Severe thread damage[b]	Handling, abuse, contaminants, excessive load	Replace rotor head. This operation shall be conducted by the supplier/manufacturer.
Minor bend (no plating or coating damage)[a]	Handling, abuse	Straighten rotor by mechanical methods. This operation shall be conducted by the supplier/manufacturer.
Severe bend/warp (plate/coating damage)[b]	Handling, abuse	Strip plating/coating and inspect rotor substrate. Determine if rotor shall be scrapped or repaired. Straighten and plate/coat rotor wear surface.
Severely dented surface[b]	Handling, abuse	Strip and re-plate/recoat rotor wear surface.
Cracked or chipped plating/coating	Handling, abuse	Strip and re-plate/recoat rotor wear surface. Note that some cracks can be due to manufacturing processes, in which case the rotor is acceptable for re-use.
Broken or fractured rotor	Handling, abuse	Scrap rotor. Additional micro-fractures are normally present and undetectable to visual inspection. Subsequent rotor and stator damage can be initiated by these fractures.
Damaged or worn substrate	Use in abrasive fluid, handling, abuse	Scrap rotor.

[a] Part may be reconditioned to meet the appropriate specification.

[b] Part requires repair or can be beyond repair.

The following repair operations are discouraged:

- grinding or blending edges of damaged plating or coatings instead of repairing, which can lead to erosion of exposed substrate or stator elastomer damage during normal pump operation;
- welding, brazing, or other heat treatments by non-qualified personnel, which can compromise the structural integrity of the rotor and often results in failure during normal operation;
- removal of damaged threads exceeding the tolerance of the applicable thread specification, such as ISO 10428.

K.3 Stator elastomers

Repair of stator elastomers is not recommended. Used stators shall be cleaned with an inert fluid and inspected. If significant damage is noted by a qualified person, a functional test of the pump can be required to determine whether the stator condition is acceptable. The results of the functional test shall not be considered conclusive. The suitability of a stator for re-use is at the discretion of the user/purchaser. Table K.2 lists common stator damage and repair options.

Table K.2 — Stator repair options

Observed damage	Cause	Common repair and reconditioning operation
Minor thread damage[a]	Ordinary use, contaminants	Remove burrs or damaged threads within the specification tolerance, generally API Spec 5B.
Severe thread damage[b]	Handling, abuse, contaminants, excessive load	Scrap stator.
Split/bent tube	Abuse, material defect	Scrap stator.
Visible damage or swell of elastomer	Ordinary use, contaminants, abuse	Scrap stator.

[a] Part may be reconditioned to meet the appropriate specification.

[b] Part requires repair or can be beyond repair.

K.4 Tag bar

The tag bar shall be cleaned and inspected prior to re-use. Accumulated contaminants can cause thread damage during make-up. Any number of common detergents and degreasers may be used to clean the tag bar surfaces, but can remove any remaining paint. The cleaner shall be removed from the tag bar with an appropriate fluid. A thread protectant shall be used if the tag bar is being stored before re-use.

Table K.3 lists common tag-bar damage and repair options.

Table K.3 — Tag-bar repair options

Observed damage	Cause	Common repair and reconditioning operation
Minor thread damage[a]	Ordinary use, contaminants	Remove burrs or damaged threads within the applicable specification tolerance, such as API Spec 5B.
Bent/broken/worn tag pin	Abuse, incorrect rotor space-out	Discard tag pin, rebuild weld bevel, weld in new tag pin, or scrap tag-bar.
Severe thread damage[b]	Handling, abuse, contaminates, excessive load	Scrap tag-bar.
Split/bent tube	Abuse, material defect	Scrap tag-bar.

[a] Part may be reconditioned to meet the appropriate specification.

[b] Part requires repair or can be beyond repair.

Annex L
(informative)

Auxiliary equipment

L.1 General

This annex describes auxiliary equipment that is often included in PCP systems. This auxiliary equipment is not covered by this part of ISO 15136. See Figures L.1 and L.2 for example illustrations.

L.2 Torque ring

These are inserts that fit the J-section of API and other non-shouldered tubing connections to allow higher torque capacity during make-up and operation.

L.3 Drive string centralizers

When drive string and tubing wear is expected, the use of wear reducing mechanisms, such as centralizers, is recommended.

It is not recommended to fit the rotor-to-lower-string connection with a centralizer.

The use of centralizers introduces restrictions that it is necessary to consider in the calculation of the total head and power required by the system.

L.4 Tubing rotators

Manual or automated tubing rotators can be used to distribute the wear around the full circumference of the production tubing, thereby extending tubing run life.

L.5 Torque limiter

A torque limiter can be required to prevent damage to any of the system components. Typically, it limits the stress in the drive string below the minimum yield.

L.6 Pump-off control

This is a device that senses a pump-off condition and controls the prime mover to prevent damage to the PCP.

L.7 High-pressure shut-down switches

Flow-line pressure is monitored using a pressure gauge or pressure transducer, which protects the system against excessive flow-line pressure.

L.8 Downhole check valve

A downhole check valve provides a means of controlling back-flow through the PCP. It is installed below the rotor stop.

L.9 Variable-speed controllers

Variable-speed controllers allow the PCP speed to be easily adjusted in order to accommodate changing well conditions.

L.10 Tubing drain

This is a device that may be used to drain the tubing for workover purposes. It is used when the PCP intake is equipped with a downhole check valve or if there is a risk of blockage.

L.11 Drive string shear

This is a device installed near the rotor that is used to release the drive strings in the event that the rotor cannot be removed from the stator.

L.12 Gas separator

This is a device installed at the PCP intake that is used to divert free gas away from the PCP.

L.13 Drive string clamp

This is a device located on top of the drivehead that suspends the drive string and/or transmits torque to the drive string.

L.14 Lock-out clamp

This is a safety device that is attached to the drivehead for the purpose of preventing accidental rotation of the drivehead.

L.15 Solid-shaft surface drive

A solid-shaft surface drive transmits power to the drive string by a fixed attachment.

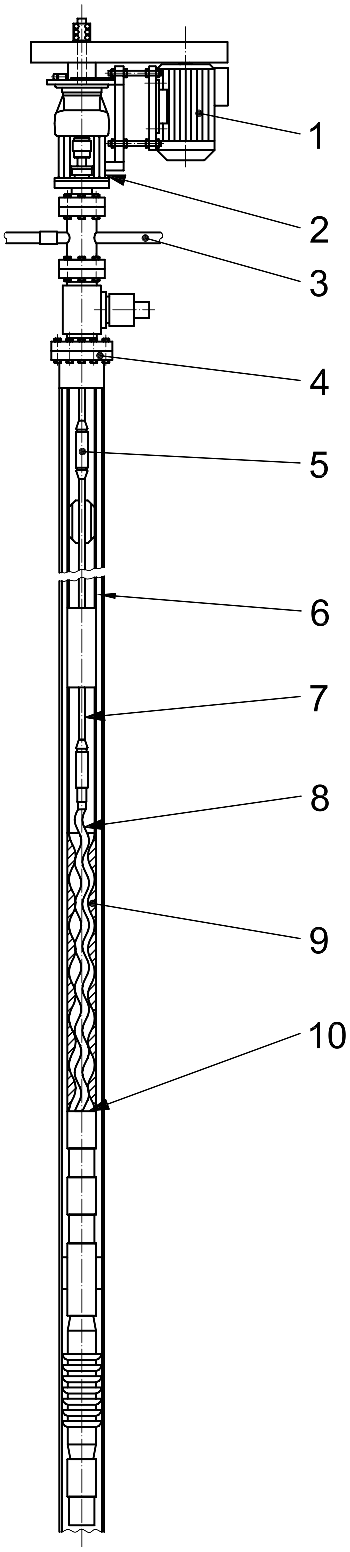
L.16 Hollow-shaft surface drive

A hollow-shaft surface drive uses a drive-string clamp rather than a fixed attachment. This provides a means to extend the drive string through the surface drive, which allows vertical movement of the drive string without dismantling the surface drive.

L.17 Surface-drive brake

This is a device that is a portion of the drivehead systems designed to dissipate stored energy, to limit, and/or stop rotation of the drive string during shut-down events. Brakes may be of the following type:

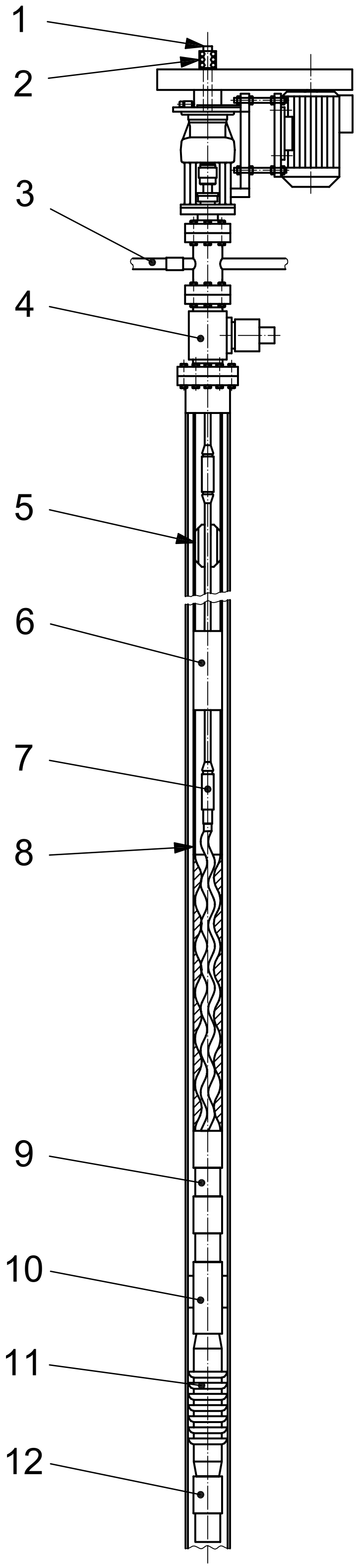
- friction brake;
- hydraulic brake;
- electrical motor brake;
- manual brake.



Key

1	prime mover	6	tubing
2	drive head	7	drive string
3	storage flow line	8	rotor
4	wellhead	9	stator
5	coupling	10	rotor stop

Figure L.1 — Standard equipment



Key

1	hollow shaft
2	clamp
3	casing relief line
4	tubing rotator
5	drive-string centralizer
6	tubing drain
7	drive-string shear
8	pup joint
9	downhole check valve
10	torque anchor
11	gas separator
12	intake assembly

Figure L.2 — Accessory equipment

Bibliography

[1] ANSI B46.1, *Surface Texture, Surface Roughness, Waviness and Lay*3)

[2] API TR 5C3, *Technical Report on Equations and Calculations for Casing, Tubing, and Line Pipe Used as Casing or Tubing; and Performance Properties Tables for Casing and Tubing*4)

[3] API Spec 5B, *Specification for Threading, Gauging and Thread Inspection of Casing, Tubing, and Line Pipe Threads*

[4] ANSI/API RP 11BR, *Recommended Practice for the Care and Handling of Sucker Rods*

[5] ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*5)

[6] ASTM A388/A388M, *Standard Practice for Ultrasonic Examination of Steel Forgings*

[7] ASTM A450/A450M, *Standard Specification for General Requirements for Carbon and Low Alloy Steel Tubes*

[8] ASTM A609/A609M, *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

[9] ASTM A789/A789M, *Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service*

[10] ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

[11] ASTM D1414, *Standard Test Methods for Rubber O-Rings*

[12] ASTM D1415, *Standard Test Method for Rubber Property —International Hardness*

[13] ASTM D1418, *Standard Practice for Rubber and Rubber Latices — Nomenclature*

[14] ASTM D2887, *Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography*

[15] ASTM D3239, *Standard Test Method for Aromatic Types Analysis of Gas-Oil Aromatic Fractions by High Ionizing Voltage Mass Spectrometry*

[16] ASTM D5790, *Standard Test Method For Measurement Of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry*

[17] ASTM D5963, *Standard Test Method for Rubber Property — Abrasion Resistance (Rotary Drum Abrader)*

[18] ASTM D5992, *Standard Guide for Dynamic Testing of Vulcanized Rubber and Rubber-Like Materials Using Vibratory Methods*

---

3) ANSI, 25 West 43rd Street, New York, NY 10036, USA.

4) American Petroleum Institute, 1220 L Street North West, Washington, DC 20005, USA.

5) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

[19] ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*

[20] ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

[21] ASTM E92, *Standard Test Method for Vickers Hardness of Metallic Materials*

[22] ASTM E94, *Standard Guide For Radiographic Examination*

[23] ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*

[24] ASTM E165, *Standard Test Method For Liquid Penetrant Examination*

[25] ASTM E273, *Standard Practice for Ultrasonic Examination of the Weld Zone of Welded Pipe and Tubing*

[26] ASTM E309, *Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation*

[27] ASTM E426, *Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys*

[28] ASTM E446, *Standard Reference Radiographs for Steel Castings Up to 2 in. [51 mm] in Thickness*

[29] ASTM E570, *Standard Practice for Flux Leakage Examination of Ferromagnetic Steel Tubular Products*

[30] ASTM E709, *Standard Guide for Magnetic Particle Examination*

[31] ASME BPVC, Section IX, *Welding and Brazing Qualifications*[6)]

[32] ANSI/AWS D1.1/D1.1M, *Structural Welding Code — Steel*[7)]

[33] ANSI/AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*

[34] BS 2M 54, *Specification for temperature control in the heat treatment of metals*[8)]

[35] ISO/IEC 17050 (all parts), *Conformity assessment — Supplier's declaration of conformity*

[36] ISO 31-0: *Quantities and units — Part 0: General principles*

[37] ISO 80000-4, *Quantities and units — Part 4: Mechanics*

[38] ISO 1302, *Geometrical Product Specifications (GPS) — Indication of surface texture in technical product documentation*

[39] ISO 1817, *Rubber, vulcanized — Determination of the effect of liquids*

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

[7)] American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, USA.

[8)] British Standards Institute, Customer Services, 389 Chiswick High Road, London W4 4AL, UK.

[40] ISO 4649, *Rubber, vulcanized or thermoplastic — Determination of abrasion resistance using a rotating cylindrical drum device*

[41] ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

[42] ISO 9606-1, *Approval testing of welders — Fusion welding — Part 1: Steels*

[43] ISO 10428, *Petroleum and natural gas industries — Sucker rods (pony rods, polished rods, couplings and sub-couplings) — Specification*

[44] ISO 12095, *Seamless and welded steel tubes for pressure purposes — Liquid penetrant testing*

[45] ISO 13665, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube body for the detection of surface imperfections*

[46] ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

[47] ISO 15611, *Specification and qualification of welding procedures for metallic materials — Qualification based on previous welding experience*

[48] ISO 15612, *Specification and qualification of welding procedures for metallic materials — Qualification by adoption of a standard welding procedure*

[49] ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test*

[50] ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

[51] ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

[52] ISO 18265, *Metallic materials — Conversion of hardness values*

[53] ISO/TS 29001, *Petroleum, petrochemical and natural gas industries — Sector-specific quality management systems — Requirements for product and service supply organizations*

[54] MIL-STD-792F, *Identification Marking Requirements for Special Purpose Components*9)

[55] NACE TM0192, *Standard Test Method — Evaluating Elastomeric Materials in Carbon Dioxide Decompression Environments*10)

[56] NORSOK M-710, *Qualification of non-metallic sealing materials and manufacturers*11)

[57] SAE AMS-H-6875, *Heat Treatment of Steel Raw Materials*12)

[58] SAE AS4059, *Aerospace Fluid Power — Cleanliness Classification for Hydraulic Fluids*

[59] ISO 2859 (all parts), *Sampling procedures for inspection by attributes*

---

9) Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094, USA.

10) NACE 1440 South Creek Drive, Houston, Texas 77084-4906 USA.

11) Standard Norge, Postboks 242, 1326 Lysaker, Norway.

12) SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, USA.

[60] ISO 9000, *Quality management systems — Fundamentals and vocabulary*

[61] ASNT SNT-TC-1A, *Recommended Practice No. SNT-TC-1A — Non-Destructive Testing*13)

---

13) American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, OH 43228-0518, USA.

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