BS EN ISO 15551-1:2015

BSI Standards Publication

Petroleum and natural gas industries — Drilling and production equipment

Part 1: Electric submersible pump systems for artificial lift

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National foreword

This British Standard is the UK implementation of EN ISO 15551-1:2015.

The UK participation in its preparation was entrusted to Technical Committee PSE/17/-/4, Drilling and production equipment for petroleum and natural gas industries.

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

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Published by BSI Standards Limited 2015

ISBN 978 0 580 70785 8

ICS 75.180.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 May 2015.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN ISO 15551-1

May 2015

ICS 75.180.10

English Version

Petroleum and natural gas industries - Drilling and production equipment - Part 1: Electric submersible pump systems for artificial lift (ISO 15551-1:2015)

Industries du pétrole et du gaz naturel - Équipement de forage et de production - Partie 1: Systèmes électriques de pompes submersibles pour l'ascension artificielle (ISO 15551-1:2015)

Erdöl- und Erdgasindustrie - Bohrloch-Ausrüstungen - Teil 1: Elektrische Tauchpumpen zur Förderung (ISO 15551-1:2015)

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Ref. No. EN ISO 15551-1:2015 E

Foreword

This document (EN ISO 15551-1:2015) has been prepared by Technical Committee ISO/TC 67 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” in collaboration with Technical Committee CEN/TC 12 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2015, and conflicting national standards shall be withdrawn at the latest by November 2015.

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Endorsement notice

The text of ISO 15551-1:2015 has been approved by CEN as EN ISO 15551-1:2015 without any modification.

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

Introduction

This part of ISO 15551 has been developed by users/purchasers and suppliers/manufacturers of electric submersible pumps and is intended for use in the petroleum and natural gas industry worldwide. This part of ISO 15551 provides requirements and information to both parties in the selection, manufacturing, testing, and use of electric submersible pumps as defined in the scope. Further, this part of ISO 15551 addresses supplier requirements, which set the minimum parameters for claiming conformity with this International Standard.

This part of ISO 15551 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 two grades of design validation, three grades of quality control, and up to three grades of functional testing, depending on the component. Design validation grade V2 is restricted to legacy products, and the highest grade is V1. Quality control grade 3 is the standard grade and grades 2 and 1 provide additional requirements. Of the three functional evaluation grades, the lowest grade is the standard grade and higher grades provide additional requirements. The user/purchaser can specify requirements supplemental to these grades.

Users of this International Standard are informed that requirements above those outlined in this International Standard can be needed for individual applications. This International Standard 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.

Petroleum and natural gas industries — Drilling and production equipment —

Part 1:
Electric submersible pump systems for artificial lift

1 Scope

This part of ISO 15551 provides requirements for the design, design verification and validation, manufacturing and data control, performance ratings, functional evaluations, handling, and storage of tubing-deployed electrical submersible pump (ESP) systems as defined herein. This part of ISO 15551 is applicable to those components meeting the definition of centrifugal pumps including gas handling devices, discharge heads, seal chamber sections, intake systems, mechanical gas separators, induction motors (herein motor), shaft couplings, motor lead extension, pothead, and power cables, as defined herein. Components supplied under the requirements of this part of ISO 15551 exclude previously used subcomponents. Additionally, this International Standard provides requirements for assembled ESP systems.

This part of ISO 15551 includes normative annexes addressing design validation performance rating requirements by component, requirements for determining ratings as an assembled system, functional evaluation: single component and cable reference information.

This part of ISO 15551 includes informative annexes addressing functional evaluation guidelines for assembled ESP systems, establishing recommended operating range (ROR) of the ESP system, example user/purchaser ESP functional specification form, considerations for the use of 3-phase low and medium voltage adjustable speed drives for ESP applications, analysis after ESP use, downhole monitoring of ESP assembly operation, and information on permanent magnet motors for ESP applications.

Equipment not covered by this part of ISO 15551 includes wireline and coiled tubing-deployed ESP systems, motor and pump shrouds, electric penetrators and feed-through systems, cable clamps and banding, centralizers, intake screens, passive gas separators, by-pass tools, check and bleeder valves, component adaptors, capillary lines, electric surface equipment, downhole permanent magnet motors, and non-conventionally configured ESP systems such as inverted systems. Repair and redress equipment requirements are not covered in this part of ISO 15551.

The terminologies used within this part of ISO 15551 are; “ESP assembly” for a system of products combined into an operational machine, “component” for individual products such as, pumps or seal chamber sections, and “subcomponent” for individual parts or subassemblies that are used in the construction of an individual component.

2 Normative references

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

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

ISO 29001, *Petroleum, petrochemical and natural gas industries — Sector-specific quality management systems — Requirements for product and service supply*

API RP 11S2, *Electric Submersible Pump Testing*

API RP 11S7, *Recommended Practice of Application and Testing of Electric Submersible Pump Seal Chamber Section*

API RP 11S8, *Practice on Electric Submersible Pump System Vibrations*

ASTM B3, *Standard Specification for Soft or Annealed Copper Wire*

ASTM B8, *Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft*

ASTM B33, *Standard Specification for Tin Coated Soft or Annealed Copper Wire for Electrical Purposes*

ASTM B189, *Standard Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes*

ASTM B193, *Standard Test Method for Resistivity of Electrical Conductor Materials*

ASTM B258, *Standard Specification for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors*

ASTM B496, *Standard Specification for Compact-Round Concentric-Lay-Stranded Copper Conductors*

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

ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials*

NEMA WC 53, *Standard Test Methods for Extruded Dielectric Power, Control, Instrumentation and Portable Cables for Test*

3 Terms and definitions

For the purposes of this document, the following definitions shall apply. For quality system related terms used in this document and not defined below, see ISO 29001.

3.1
adapter
device used to connect components that are not directly compatible

3.2
adjustable speed drive
device which controls an electric motor's speed by manipulating the power frequency being supplied to the motor

Note 1 to entry: The term "adjustable speed drive" is interchangeable with other common industry names for this device such as "variable frequency drive" or "variable speed drive".

3.3
ampacity
maximum current that can pass through a power cable without exceeding its temperature limit for a specific operating environment

3.4
ampacity coefficient
temperature rise of the power cable divided by the square of the amperage for a specific operating environment

3.5
armor
outer covering to the power cable that can provide protection from mechanical damage and provides mechanical constraint against swelling or expansion of underlying materials on exposure to well fluids

3.6
assembled ESP system
assembly of downhole equipment which includes some or all components as identified in this part of ISO 15551

3.7
auxiliary equipment
equipment or components that are outside the scope of this part of ISO 15551 and are typically selected and/or installed by the user/purchaser

EXAMPLE Cable protectors, motor shrouds, by-pass tools, and electrical penetrators.

3.8
axial stage type
type of stage with inlet and exit flow path essentially parallel to the shaft axis

3.9
bag
bladder
bellows
flexible subcomponent of a seal chamber section that functions as a positive barrier that isolates the wellbore production fluid from the motor fluid

3.10
bag chamber
bladder chamber
bellows chamber
chamber which houses the bag/bladder/bellows

3.11
barrier
subcomponent of an ESP power cable that can be applied over the insulated conductors and provides fluid protection, hoop strength, or both

3.12
best efficiency point
BEP
pump performance values at the flow rate where the pump efficiency is highest

3.13
bleeder valve
valve placed above a check valve for the purpose of reducing pressure or draining the fluid from within the production tubing

3.14
braid
supplementary layer of material used to provide mechanical performance characteristics to the power cable system such as hoop strength for gas decompression

3.15
bubble point
pressure at which gas begins to break out of under-saturated oil/fluid and form a free gas phase

3.16
by-pass tool
device that is installed into the wellbore along with the ESP assembly that divides the tubing system to permit the installation of additional tubing string parallel to the ESP

3.17
cable band
metal band which is used to secure ESP power cable to production tubing

3.18
cable clamp
device, usually of rigid material, for strengthening or supporting power cable to production tubing

3.19
capillary line
independent tubing string commonly used for hydraulic control of safety valves and sliding sleeves or for chemical injection

Note 1 to entry: This device is also commonly referred to as a chemical injection line or control line.

3.20
casing
pipe extending from the surface and intended to line the walls of a drilled well

3.21
casing size
nominal casing outside diameter (od), mass (weight), inside diameter (id), and/or drift diameter as specified in ISO 11960

3.22
centralizers
device used to keep the ESP assembly or other downhole equipment in the centre of the tubing, casing, or wellbore

3.23
centrifugal pump
component of an ESP system that uses rotating impeller(s) to impart kinetic energy (velocity) by centrifugal force to a fluid and stationary diffusers to convert the kinetic energy to potential energy (pressure)

3.24
chamber
subcomponent of the seal chamber section

3.25
check valve
device that allows one-directional flow of fluid when a differential pressure exists

3.26
coefficient of determination
statistic used to determine the strength of a fit between a mathematical model and a set of observed data values

Note 1 to entry: The coefficient of determination is typically calculated using the following equation:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - y_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \overline{y}_i\right)^2}$$

3.27
coiled tubing
pipe typically supplied and installed in one continuous length and wound onto a reel or spool

3.28
coiled tubing deployed ESP
ESP system which is deployed into the wellbore using coiled tubing rather than by other deployment means such as jointed tubing or wireline

3.29
common hardware
hardware that does not require traceability and is included as part of an ESP component

EXAMPLE Bolts, washers, screws, and snap rings.

3.30
compact stranded cable
electrical conductor configuration in which a multiple-strand conductor has been compacted to reduce its circumference while maintaining conductor area

3.31
compression pump construction
configuration where the impeller is fixed to the shaft to prevent axial movement

3.32
conductor
subcomponent of the power cable that functions to conduct electrical power

3.33
conductor shield
layer adjacent to the conductor to distribute voltage stress evenly over the surface of the conductor

3.34
configuration
component designation that identifies the end connection designs for attaching additional components in series

EXAMPLE Upper tandem, lower tandem, middle/centre tandem, and single tandem.

3.35
contraction capacity
volume that a chamber or set of parallel chambers can draw in due to temperature and pressure cycles without allowing wellbore fluid ingress through the chamber or causing damage

3.36
coupling
device which connects the shafts of ESP components

3.37
deployment method
conveyance method
method used to deploy the ESP downhole equipment to its setting location

3.38
design validation
process of proving a design by testing to demonstrate conformity of the product to design requirements

3.39
design verification
process of examining the premise of a given design by calculation, comparison, or investigation, to substantiate conformity with specified requirements

3.40
deviation survey
measurement of a borehole's trajectory over the wellbore length for the purposes of ESP design and application

3.41
diffuser
stationary stage segment of a centrifugal pump which converts the pumped fluid velocity (kinetic energy) to a pressure (potential energy)

3.42
discharge head
component on the output end of the pump for connecting to the production tubing

3.43
dogleg severity
total angular inclination and azimuth in the wellbore, casing or liner, calculated over a standard length such as degrees per 30 metres, or degrees per 100 feet

3.44
effective diameter
theoretical minimum diameter through which the assembled ESP system passes including installation of all required ESP ancillary equipment

3.45
efficiency
output work divided by input work

3.46
elastomer
polymer with the property of viscoelasticity (elasticity), generally having a low Young's modulus and a high yield strain

3.47
electric penetrator
electrical connector that functions to transition power cable and/or instrument wires through a sealing barrier

EXAMPLE Wellhead, wellbore packer, ESP pod, or canister.

3.48
electric surface control equipment
electrical equipment used to control the operation of the ESP assembly commonly referred to as an adjustable speed drive or switchboard

3.49
electromagnetic region
region of an induction motor relative to the cylindrical boundary defined by the outside diameter of the stator laminations, and the axial length which encompasses all the coiled wire of the stator

3.50
feed-through system
fixture which allows the passage of electricity from one side of a barrier to another while maintaining a seal of gas or liquid through the barrier

3.51
floating pump construction
configuration where the impeller is not fixed to the shaft to permit limited axial movement

3.52
flowing pressure
pressure in the wellbore at a specific vertical depth at a specific flow rate

3.53
functional evaluation
test(s) performed to confirm ESP component operation or assembled ESP system operation as per design

Note 1 to entry: Occasionally referred to as factory acceptance test in case of ESP component and as string test in case of assembled ESP system.

3.54
gas handler
component of an ESP system that conditions multiphase flow, without gas separation, to decrease the degradation of pump performance

3.55
gas-oil ratio
produced gas-oil ratio
volumetric ratio of gas to oil at standard conditions

3.56
gas separator
component of an ESP system that mechanically separates a portion of the free gas from the wellbore fluids prior to the fluids entering the pump or gas handler

3.57
head curve
amount of head generated by the pump as a function of flow rate for a specific speed

3.58
housing pressure rating
value of the maximum allowable difference of internal less external pressure

3.59
impeller
stage segment rotated by the shaft which adds kinetic energy (velocity) to the fluid being pumped

3.60
inclination
angle, measured in degrees, by which the wellbore or survey-instrumented axis varies from a true vertical line

3.61
induction motor
component of an ESP system where alternating current power input is transformed to mechanical torque by means of electromagnetic induction

Note 1 to entry: Also referred to as an asynchronous or squirrel cage motor.

3.62
intake
subcomponent of a pump which provides a flow path to the first impeller, constructed either integral to the pump or bolted-on to the pump

3.63
intake screen
attachment to the pump intake used to filter solid particles from the produced fluid to protect the internal components of the pump

3.64
insulation
isolates the electrical potential between conductors and other conducting materials and minimizes leakage current from the conductors

3.65
inversion point
water cut percentage at which the emulsion viscosity is at its maximum

3.66
inverted system
ESP system configured with the pump on the bottom and motor on the top

3.67
jacket
subcomponent of an ESP power cable that covers the insulated conductors and provides mechanical protection from the downhole environment

3.68
labyrinth chamber
chamber which utilizes a vertical U-tube, maze-like, or tortuous flow path to delay wellbore fluid ingress through the chamber

3.69
lamination
thin electrical grade metallic subcomponents that form the magnetic core of the stator and the rotor(s)

3.70
liner
pipe extending from the surface or another point lower in the wellbore to a depth within or below the existing casing

3.71
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 1 to entry: 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.

3.72
mechanical seal
subcomponent used to prevent flow between a rotating shaft and a stationary body

3.73
megger
instrument that generates a high voltage in order to test the resistance of insulation, etc.

3.74
mixed flow stage type
type of stage with inlet flow path essentially parallel to shaft axis and exit between perpendicular and parallel to the shaft axis

3.75
model
equipment with unique components and operating characteristics which differentiate it from other equipment of the same type

3.76
modular pump construction
configuration that utilizes both compression and floating pump constructions within the same single component

3.77
motor fluid
fluid internal to the motor and seal chamber section that provides lubrication to the bearing systems, heat transfer to the unit skin, and dielectric insulation for the motor

3.78
motor lead extension
MLE
cable connected to the pothead for splicing to the power cable

3.79
motor operating temperature
temperature at or near the coils of the stator when it is energized

3.80
motor shroud
tube which covers the motor length of the ESP to promote fluid flow past the motor

3.81
non-conformance
non-fulfilment of a specified requirement such as a disagreement between equipment, part, practice, or procedure with an established standard

3.82
operator
user of the equipment

3.83
operator's manual
publication issued by the supplier/manufacturer which contains detailed data and instructions related to the design, installation, operation, and maintenance of the equipment

3.84
operating environment
set of downhole conditions to which the component is exposed during its full life cycle

3.85
parallel chambers
configuration of at least two seal chambers that function together to increase contraction capacity

3.86
passive gas separator
device intended to reduce the amount of free gas entering into the pump intake through a selective fluid intake point or directing fluid flow path

3.87
permanent identification
marking that remains legible over the intended service life of the component and/or subcomponent

3.88
permanent magnet motor
type of motor that uses permanent magnet rotor(s) instead of induction rotor(s) as a way to create torque

3.89
pothead
power connector on the end of the MLE or power cable which mates to the motor

3.90
power cable
component of the ESP system that connects the surface electrical equipment or electrical penetrator connector to the MLE or motor

3.91
pump construction
configuration of which the pump stages are assembled with respect to axial movement relative to the shaft such as compression, floater, or modular

3.92
pump differential pressure
difference between discharge and intake pressures

3.93
pump housing
tube containing pump subcomponents pertaining to the impellers and diffusers and functioning as a pressure barrier

3.94
pump shroud
tube which covers the pump length of the ESP intended to limit free gas migration into the pump intake

Note 1 to entry: This item is sometimes referred to as an inverted shroud.

3.95
qualified part
part manufactured under an authorized quality assurance program produced to meet or exceed the performance of the original part

3.96
qualified person
individual with 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

3.97
radial stage type
type of stage with inlet flow path essentially parallel to shaft and exit essentially perpendicular to the shaft axis

3.98
redress
activities performed to a component restricted to the replacement of qualified parts that restores the equipment to its original performance

3.99
reference fluid
water corrected to specific gravity of 1,0, at standard conditions

3.100
reference temperature
20 degrees centigrade

3.101
repair
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 restores the equipment to its original performance

3.102
rotor
subcomponent of a motor, mechanically attached to the shaft, whose magnetic field is induced by the magnetic field of the stator, resulting in torque applied to the shaft

3.103
safety factor
defined measure of a reduced value from a known capacity

3.104
sand cut
amount of sand or solid material in the wellbore fluid, typically expressed as a volumetric or mass percentage

3.105
seal chamber section
component of an ESP system that provides one or more of the following functions: protects the interior of the motor from well fluids and other contaminants, carries the pump thrust, maintains pressure equalization with wellbore fluid pressure, and transmits the motor torque to the component above it

3.106
semi-permanent identification
marking that remains legible until the component and/or subcomponent is installed, such as, a metal stamped nameplate or tag

3.107
series
component designation that identifies the outer diameter of its housing

3.108
series chambers
configuration of at least two seal chambers that function redundantly to increase protection to the subcomponents below them

3.109
shaft end play
axial movement the component shaft has generally measured from a reference point

3.110
shaft extension
measurement of the component shaft end in relation to a reference point

3.111
shaft side play
radial movement of a component shaft resulting from clearances between rotating and stationary radial support components

3.112
shipping hardware
auxiliary equipment that is shipped as part of an ESP component to help protect the component during the shipping and handling process

3.113
slip
difference between the AC motor synchronous speed and the actual operating speed divided by the synchronous speed expressed in percentage

3.114
slugging
well production characterized by cyclic flow of fluid mixtures of different densities, such as gas and liquid or two differing liquid viscosities

3.115
solution gas-oil ratio
amount of gas dissolved in the oil and increases with pressure until the bubble point pressure is reached, after which it is an constant

3.116
spline type
machined configuration of the end of component shafts to allow connection by couplings to adjoining components, such as modified SAE, involute, and others

3.117
stage
matched set of one impeller and one diffuser

3.118
stage name
nomenclature given to each pump stage type that typically defines its flowrate (bep), its size (diameter), and any special fluid handling characteristics

3.119
standard conditions
1 atmosphere (14,7 psia) and 15 °C (60 °F)

3.120
stator
subcomponent of the motor which contains laminations and coiled wire and housed in a tube, also known as wound stator

3.121
stock tank flow rate
wellbore fluid rate reported at standard conditions

3.122
subcomponent
portion of a component made up of one or more pieces

3.123
synchronous speed
supply power frequency divided by the number of poles of the AC motor

Note 1 to entry: When expressed in revolutions per minute, the formula to calculate synchronous speed is power frequency times 120 divided by the number of poles.

3.124
tandem
designation that indicates where in the modular system an ESP component, such as a motor, would be used

Note 1 to entry: There are four different tandem designations for ESP components: upper tandem, middle tandem, lower tandem, and single.

3.125
test open flow
maximum pump flow rate attainable on test

3.126
thrust bearing
device to support axial load of a rotating part

3.127
thrust load bearing capacity
axial load capacity of a thrust bearing as defined by the bearing design, lubrication fluid, and operating environment

3.128
thrust washer
subcomponent mounted on an impeller which carries the axial thrust

3.129
torsional yield ratio
ratio of the material yield point in torsion to the material yield point in tension

3.130
tubing deployed ESP
ESP system which is deployed into the wellbore using jointed tubing rather than by other deployment means such as wireline or coiled tubing

3.131
unique identifier
unique combination of alphanumeric characters to identify a specific component

3.132
water cut
ratio of produced water to produced liquids, expressed as a percentage

3.133
wireline deployed ESP
ESP system which is deployed into the wellbore using wireline rather than by other deployment means such as jointed tubing or coiled tubing

4 Symbols and abbreviated terms

AC	alternating current
ASD	adjustable speed drive
AWG	American wire gauge
BEP	best efficiency point
c	ampacity coefficient
C_{load}	derating factor
cP	centipoise
DC	direct current
dV/dt	change in voltage divided by change in time
E	efficiency
ESD	emergency shut down
ESP	electric submersible pump
F_a	adjusted thrust
F_n	thrust at test revolutions per minute
G	unit for g-force
GOR	gas oil ratio
GVF	gas volume fraction
H	head
H_a	adjusted head
H_n	head at test revolutions per minute
HP	horsepower
I	amperage
IEC	International Electrotechnical Commission

id	inside diameter
K	extrapolated temperature for zero resistance
kVA	kilovolt-amperes
kW	kilowatt
L_t	thrust test load
L_0	nominal thrust load rating of bearing at 3 500 r/min and 5 cP lubricating fluid viscosity
MD	measured depth
MLE	motor lead extension cable
mu_t	actual lubricating fluid test viscosity (absolute) in cP
NEMA	Nationalal Electrical Manufacturers Association
NDE	non-destructive examination
od	outside diameter
P_a	adjusted power
P_n	power at test revolutions per minute
pH	potential of hydrogen
p_i	pump intake pressure
p_o	pump discharge pressure
ρ_f	fluid density
P_f	fluid power
PID	programmable input digital controller
PMM	permanent magnet motor
P_s	shaft power
PSD	pump setting depth
PVT	pressure, volume, temperature
PWM	pulse width modulated
$P_{sc,\ kW}$	shaft coupling power rating expressed in kilowatt
$P_{sc,\ HP}$	shaft coupling power rating expressed in horsepower
P_{shaft}	shaft power rating
Q	flow rate
Q_a	adjusted flow rate
Q_n	flow rate at test revolutions per minute

Q_{GGE} gas flow rate out of gas exit

Q_{Gi} intake gas flow rate

Q_{Li} intake liquid flow rate

R^2 coefficient of determination

R_f resistance of winding at the time of motor de-energization

R_b resistance of winding before test at a known temperature

RMS root mean square

ROR recommended operating range

SCR silicon controlled rectifier

T temperature

T_f temperature of the test fluid at the time of motor de-energization

T_b temperature at the time R_b is taken

τ torque

THD total harmonic distortion

TVD true vertical depth

TVSS transient voltage surge suppressors

UL Underwriter's Laboratories

VI percentage of free gas

VDC volts direct current

VSD variable speed drive

VFD variable frequency drive

v_r rotational speed in revolutions per minute

$v_{r,ref}$ reference revolutions per minute

$v_{r,n}$ test revolutions per minute

WAG water alternating gas

ω_t actual shaft rotational speed during test in revolutions per minute

Y_i predicted value of the dependent variable as determined by the mathematical model

y_i observed value of the dependent variable

$\bar{y}$ mean of the observed data y_i

5 Functional specification

5.1 General

The user/purchaser shall prepare a functional specification when ordering components which conform to this part of ISO 15551 and specify the requirements and operating conditions as appropriate. This information is used by the supplier/manufacturer to recommend the components for the application. User/purchaser shall specify the units of measurement for the data provided

ESPs are designed for specific applications. When used in other applications re-evaluation is required. The process used for that re-evaluation shall be no less stringent or documented and approved than that required for the initial application.

5.2 Component type

The user/purchaser shall request an ESP system on the basis of the following conditions:

— production requirements;

— fluid characteristics.

5.3 Functional requirements

5.3.1 General

User/purchaser shall specify the known and anticipated application parameters and requirements to the best of their knowledge. Operational issues such as frequency of shut-downs, power interruptions, production fluid changes, electrical current changes, and other issues that might have an effect on the systems operation and durability shall also be specified.

5.3.2 Application parameters

5.3.2.1 General

While installed, the ESP system shall perform in accordance with its functional requirements which are typically determined based on application parameters.

5.3.2.2 Well information

5.3.2.2.1 Requirements

The following well information, whether planned or existing, shall be specified:

a) operating environment such as heavy and conventional oil production, coal bed methane applications, and source water production;

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

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

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

e) reservoir recovery mechanism or process such as aquifer drive, solution gas drive, water flood, thermal, coal dewatering;

f) enhanced oil recovery such as CO_2 flood, water-alternating-gas, or polymer flood;

g) existing or planned power supply details such as generator/utility, volts, frequency, kVA/Amp supply limitations;

h) existing or planned surface equipment details such as switchboard, 6-step ASD, PWM ASD, filtered PWM ASD, space restrictions.

5.3.2.2.2 Supplemental Information

The following well information shall be specified, if available:

a) well profile such as “S shaped”, “U shaped”, sinusoidal, multilateral;

b) geothermal gradient/profile;

c) pertinent production history using ESPs and other methods such as other artificial lift methods or natural flow.

5.3.2.3 Completion information

5.3.2.3.1 Requirements

The following well information, whether planned or existing, shall be specified:

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

b) existing or planned total well depth such as plug back depth in terms of MD and TVD;

c) depth(s) of producing interval(s), top and bottom, in terms of MD and TVD;

d) casing/liner size including outside diameter and weight, connection type and grade of production casing;

e) minimum drift diameter through wellhead to bottom of the ESP assembly;

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

g) completion type such as perforated casing or open hole;

h) sand control measures such as none, slotted liner, gravel pack, or sand screen;

i) ESP system configuration such as single, dual back-up/boost, y-tool;

5.3.2.3.2 Supplemental information

The following completion information shall be specified, if available:

a) well deviation survey; if not provided, provide the following as a minimum:

   — inclination and estimated dogleg severity at pump setting depth;

   — maximum dogleg severity between wellhead and pump setting depth for each casing or liner segment that the ESP has to pass through during installation;

b) production tubing inner coating type and thickness;

c) completion thermal characteristics such as heat transfer coefficients for completion, insulated tubing/annulus, or flowing temperature profile;

d) completion diagram.

5.3.2.4 Operating and production information

5.3.2.4.1 Requirements

The following operating and production information shall be provided over the life of the system, such as early, mid, and late life.

a) expected well production flow performance, which shall include, as a minimum, expected flow rate such as stock tank flow rate or pump discharge rate and flowing pressure or fluid level at expected flow rate for a specified depth;

b) water cut;

c) tubing head flowing pressure;

d) casing head pressure;

e) static temperature at a reference depth;

f) total producing gas-oil-ratio;

g) special operational conditions such as unloading heavy completion fluids, sand face control limitations, delayed start-up, unusual anticipated duty cycles (stops and starts);

h) minimum expected bottomhole temperature;

i) maximum expected bottomhole temperature.

5.3.2.4.2 Supplemental information

The following operating and production information shall be provided over the life of the system, such as early, mid, and late life, if available.

a) sand cut;

b) wellhead flowing fluid temperature;

c) flowing temperature at a reference depth;

d) slugging tendency such as gas, water, solids, steam;

e) desired operating frequency range and desired operating frequency at target rate.

5.3.3 Environmental compatibility

User/purchaser shall specify the environmental compatibility requirements and preferred fluid property correlations. The following parameters shall be supplied:

a) Oil

    1) density at standard temperature and pressure or API gravity;

    2) viscosity at standard conditions;

    3) bubble point pressure at reservoir temperature;

    4) solution gas-oil-ratio.

b) Water

    1) pH;

    2) density;

3) chloride concentration/salinity.

c) Gas

1) composition such as:

i) CO_2 concentration (mole percentage);

ii) H_2S concentration (mole percentage);

2) specific gravity.

d) Solids

1) history of solids related problems such as erosion, plugging, wear;

2) morphology such as size, structure, angularity, composition;

3) scale deposition tendency;

4) asphaltene deposition tendency;

5) paraffin deposition tendency.

e) Other

1) emulsion properties such as:

i) inversion point data (percentage water cut);

ii) emulsion viscosity at downhole operating conditions over predicted pump life;

iii) emulsion forming tendency;

2) foamy oil behaviour such as that affecting annular fluid level;

3) other fluid types and concentrations such as diluent, corrosion/scale inhibitor, completion fluid, dispersants, and injection points in the wellbore.

5.3.4 Compatibility with related well equipment and services

5.3.4.1 General

The user/purchaser shall specify related well equipment and service considerations that can impact the compatibility of the proposed component for the well such as material requirements, dimensional limitations, transportation, and installation restrictions, to ensure that the component conforms to the intended application.

5.3.4.2 Accessory equipment and well operation

The following topics shall be considered for the application.

a) dimension of chemical injection tubing/string line and injection point such as above pump, below pump, annulus, tubing string;

b) surface instrumentation dimension and location such as above or below pump as applicable;

c) surface equipment dimensions, location relative to the pump and attachment to the pump such as by-pass systems, clamps, shrouds, pod, tail pipes, backflow valves, swages;

d) well intervention limitations such as; maximum allowable pump length, maximum coiled tubing diameter;

e) packer type, location in the wellbore relative to ESP assembly;

f) casing gas venting scheme such as vented to atmosphere, vented to production flow line, no venting.

5.4 User/purchaser selections

5.4.1 General

Table 1 is the compiled list of required selection criteria for ESP components which shall be selected by the user/purchaser. The grades can vary by component as selected by the user/purchaser. General guidance on the selections available is provided in 5.4.2, 5.4.3, and 5.4.4.

5.4.2 Design validation

This part of ISO 15551 provides two design validation grades, one of which shall be selected by the user/purchaser.

— V1 Highest grade

— V2 Basic grade

5.4.3 Component functional evaluation

The user/purchaser shall specify a component functional evaluation grade for each component as indicated in Table 1. This part of ISO 15551 provides requirements for three functional evaluation grades noting that some components can have fewer. For assembled systems, guidelines for completing a functional evaluation are provided in Annex E.

— F1 Highest level of functional evaluation

— F2 Intermediate level of functional evaluation

— F3 Basic level of functional evaluation

5.4.4 Quality grades

The user/purchaser shall specify one of the following quality grades. This part of ISO 15551 provides three quality grades as detailed in Clause 7.

— Q1 Highest level of quality;

— Q2 Intermediate level of quality;

— Q3 Basic level of quality.

Table 1 summarizes the list of components and the grades that are applicable for each under this part of ISO 15551. This table provides guidance to the user/purchaser in identifying the desired grades for each component.

Table 1 — User/purchaser grade selections

Component	Selected grades							
	Design validation (Annex A)		Functional evaluation (Annex C)			Quality control (7.4)		
	V1	V2	F1	F2	F3	Q1	Q2	Q3
Bolt on discharge			a	a	a			
Pump and gas handlers								
Bolt on intake				a	a			
Mechanical gas separators					a			
Seal chamber sections								
Motor								
Cable, MLE, and pothead								
Assembled ESP system	Annex B[b]		Annex E[c]					

[a] Unavailable sections.

[b] Indicates that component has no grade selections.

[c] Indicates an informative Annex.

5.4.5 Shipping, handling, and storage

The user/purchaser shall specify environmental conditions and projected storage duration as well as any special shipping and handling requirements for the components.

5.4.6 Additional documentation or requirements

The user/purchaser can specify additional documentation, testing, and acceptance criteria as necessary to meet their requirements.

6 Technical specification

6.1 General

The supplier/manufacturer shall provide to the user/purchaser a technical specification that conforms to the requirements defined in the functional specification, or identifies in detail where variance(s) are offered. The supplier/manufacturer shall also provide to the user/purchaser the documentation required by 7.2.

Where a covered component or system includes a non-covered component, the inclusion of the non-covered component shall not cause the defined requirements or performance ratings of the component or systems as established under this International Standard to be invalidated. The evidence supporting this shall be documented by the supplier/manufacturer. Components or systems not covered in this part of ISO 15551 can be addressed in other national or international standards.

This International Standard 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, the supplier/manufacturer shall clearly and completely identify any variations from the requirements of this International Standard.

6.2 Design criteria

6.2.1 General

The supplier/manufacturer shall conform to the functional specifications when designing the component conforming to the technical specifications. Manufacturing requirements are detailed in Clause 7.

6.2.2 Design documentation

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

a) design criteria: refers to the essential variables considered when designing the component conforming to the requirements of the technical specifications and functional requirements;

b) engineering drawings and bill of materials;

c) applicable specifications and standards;

d) validation testing procedures, acceptance criteria, and approved results (see Annex A);

e) design verification and acceptance criteria;

f) published performance curves, where applicable;

g) design changes and design change justifications.

6.2.3 Materials

6.2.3.1 General

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.

Material substitutions in validated equipment designs are allowed without validation testing, provided that the supplier/manufacturer's material selection criteria are documented and approved by a qualified person and meet all other requirements of this part of ISO 15551.

6.2.3.2 Metallic materials

6.2.3.2.1 General

The supplier/manufacturer's specifications shall define the following for all metallic materials:

a) chemical composition according to an applicable standard such as AISI (American Iron and Steel Institute), ASTM, NACE, or to a supplier/manufacturers' internal specification;

b) chemical composition limits;

c) mechanical property limits, to include as a minimum:

   1) tensile strength;

   2) yield strength;

   3) elongation;

4) hardness;

d) electrical properties where applicable:

1) resistivity or conductivity;

e) magnetic properties where applicable:

1) magnetic permeability;

2) core loss.

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

6.2.3.2.2 Welds, brazing, and soldering

Welds, brazing, and soldering shall be in accordance with the supplier/manufacturer's specifications as defined or referenced in 7.6.3. Weld identification and examination shall be in accordance with the specified quality grade. The supplier/manufacturer shall maintain documentation for qualified personnel performing these operations.

6.2.3.3 Coatings or surface treatments

Coatings or surface treatments shall be in response to the operating environment specified in the functional requirements. The supplier/manufacturer's specifications shall specify, where applicable, the characteristics and acceptance criteria of the coatings or surface treatments including but not limited to the following:

a) basic coating type, trade name, or surface treatment composition;

b) corrosion and/or chemical resistance;

c) hardness;

d) minimum and maximum coating thickness;

e) roughness;

f) application process;

g) bond strength.

6.2.3.4 Non-metallic materials

6.2.3.4.1 Polymers

The supplier/manufacturer's specifications shall define the following for all polymer materials, where applicable:

a) type of polymer;

b) mechanical property limits:

1) tensile strength, new and aged;

2) elongation at rupture new and aged;

3) durometer (hardness) or modulus;

4) thermal conductivity;

5) thermal expansion coefficient;

6) minimum and maximum recommended service temperature;

c) electrical properties:

1) volume resistivity;

2) dielectric constant;

3) dielectric strength;

4) dissipation factor at 60 Hz;

d) fluid compatibility.

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

6.2.3.4.2 Ceramics

The supplier/manufacturer's specifications shall define the following for all ceramic materials:

a) ceramic type, name, and grade;

b) chemical composition;

c) mechanical:

1) grain size (if applicable);

2) density;

3) hardness;

4) transverse rupture strength;

5) compressive strength;

6) fracture toughness;

d) thermal properties:

1) thermal expansion coefficient;

2) thermal conductivity;

e) electrical properties (if applicable):

1) volume resistivity;

2) dielectric constant;

3) dielectric strength;

4) dissipation factor at 60 Hz;

f) minimum and maximum recommended service temperature.

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

6.2.3.4.3 Motor fluid

The supplier/manufacturer's specifications shall define the following for the motor fluid:

a) fluid classification or type;

b) viscosity/temperature curve;

c) density;

d) flash point;

e) coefficient of thermal expansion;

f) pour point;

g) dielectric strength;

h) minimum and maximum service temperature.

Material test reports or certificates of compliance provided by the motor fluid supplier or the supplier/manufacturer shall be used to verify compliance of the motor fluid to the specifications.

6.2.4 Dimensional information

6.2.4.1 Dimensional information for assembled system

Dimensional information for the assembled system and auxiliary components shall be provided. An analysis can be necessary to calculate the stresses for deviated or high dogleg severity wellbores. The supplier/manufacturer shall specify the following:

a) effective diameter;

b) system schematic;

c) total mass (weight) with and without cable;

d) total length;

e) bending stress analysis.

6.2.4.2 Dimensional information for system components except cable

For each component, the supplier/manufacturer shall specify the following:

a) maximum component OD;

b) component schematic including external dimensional information;

c) component mass (weight) and length as installed and shipped.

6.2.4.3 Dimensional information for cable

For the cable, the supplier/manufacturer shall specify the following:

a) weight per unit length;

b) profile and outer dimensions;

c) shipping weight and dimensions including reel;

d) size of each conductor in terms of total diameter equivalent.

6.2.5 Component and assembled system design verification

Design verification shall be performed by the supplier/manufacturer to verify that the component design meets the technical specifications. Design verification includes documented activities, such as review of design calculations, component 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. All design verification documentation shall be included in the component design file and be approved by a qualified person other than the design's originator.

6.2.6 Component design validation

Design validation testing shall be performed to verify that the component design meets the technical specifications. The design validation grade specifies the process of proving a design by testing to demonstrate conformity of the product to design requirements for each validation grade per Annex A. Annex A provides a detailed description of the two validation grades (V1 and V2) in this part of ISO 15551.

6.2.7 Component functional evaluation requirements

Functional evaluations shall be performed in accordance with Annex C and approved by a qualified person to verify that each component 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 component.

6.2.8 Assembled system functional evaluation

When selected by the user/purchaser, functional evaluation is performed in accordance with Annex E and approved by a qualified person to verify that the assembled system meets the supplier/manufacturer's documented requirements. The results of these evaluations shall be recorded and become a portion of the quality documentation for that system.

6.2.9 Design changes

All design changes shall be documented and reviewed against the design verification and design validation to determine if the change is a substantive change. A design that undergoes a substantive change becomes a new design requiring design verification as specified in 6.2.5 and design validation as specified in 6.2.6.

Changes to a component identified as a substantive change require design validation. Design change(s) shall be validated and verified through the same methods utilized for the original component or subcomponent. Where testing is performed on subcomponent(s), the test(s) shall simulate the design criteria conditions of the component at its rated limits. The supplier/manufacturer shall document the detailed test results and analysis that demonstrate that the component or subcomponent(s) test adequately simulates the required range of design criteria conditions.

6.3 Technical specification — All components

6.3.1 Technical characteristics

The following criteria shall be met.

a) The components shall be compatible with related well equipment and services as defined in Clause 5.

b) While installed and operated, the components shall perform in accordance with the functional specification.

6.3.2 Performance rating

6.3.2.1 Shaft power rating

The supplier/manufacturer shall specify the shaft power rating, where applicable, at the reference speed and temperature, typically reported as horsepower. The shaft power rating shall be determined through validation testing as outlined in 6.2.6 and detailed in Annex A.

6.3.2.2 Shaft coupling rating

The supplier/manufacturer shall specify the shaft coupling rating, where applicable, at the reference speed and temperature, typically reported as horsepower. The shaft coupling power rating shall be determined through validation testing as outlined in 6.2.6 and detailed in Annex A.

6.4 Technical specification — Bolt-on discharge

6.4.1 General

The supplier/manufacturer shall prepare the technical specification for the bolt-on discharge that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.4.2 Technical characteristics for the discharge

The discharge shall serve as a connection between the top of the ESP pump section and the well production tubing.

6.4.3 Performance ratings

6.4.3.1 Maximum flow capacity

The supplier/manufacturer shall provide the maximum recommended flow capacity rating of the bolt-on discharge in accordance with Annex A.

6.4.3.2 Pressure rating

The supplier/manufacturer shall provide the pressure rating in accordance with Annex A.

6.4.4 Scaling of design validation

Scaling of design for this component is not allowed.

6.5 Technical specification — Pump and gas handler

6.5.1 General

The supplier/manufacturer shall prepare the technical specification for the pump and gas handler that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.5.2 Technical characteristics for the pump and gas handler

The pump shall move fluid against a differential pressure.

The gas handler shall move fluid against a differential pressure and condition the fluid to change the properties or characteristics of the fluid.

Requirements for bolt-on intake and bolt-on discharge do apply when integral to the pump or gas handler.

6.5.3 Performance ratings

6.5.3.1 Design performance curves — Water only

The supplier/manufacturer shall provide the design performance curves – water only in accordance with Annex A.

6.5.3.2 Maximum gas volume fraction (GVF) rating

The supplier/manufacturer shall provide the maximum gas volume fraction rating in accordance with Annex A.

6.5.3.3 Pump stage thrust

The supplier/manufacturer shall provide the pump stage thrust in accordance with Annex A.

6.5.3.4 Housing pressure rating

The supplier/manufacturer shall provide the housing pressure rating in accordance with Annex A.

6.5.4 Scaling of design validation

Scaling of design for this component is not allowed. Changes to the number of stages in a given pump housing is not considered scaling.

6.6 Technical specification — Bolt-on intake

6.6.1 General

The supplier/manufacturer shall prepare the technical specification for the bolt-on intake that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.6.2 Technical characteristics for the intake

The following criteria shall be met.

a) The intake shall provide a flow path from the well bore to the inlet of the pump, gas handler, or gas separator.

b) The intake shall contain a shaft to transmit torque and thrust.

6.6.3 Performance ratings

The supplier/manufacturer shall provide the maximum flow capacity in accordance with Annex A.

6.6.4 Scaling of design validation

Scaling of design for this component is not allowed.

6.7 Technical specification — Mechanical gas separators

6.7.1 General

The supplier/manufacturer shall prepare the technical specification for the mechanical gas separator that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.7.2 Technical characteristics

The following criteria shall be met.

a) The gas separator shall separate free gas from the fluid entering the ESP pump or gas handler section and vent to bypass the pump or gas handler.

b) The gas separator shall contain a shaft to transmit torque and thrust.

c) Requirements for bolt-on intake also apply when it is integral to the gas separator.

6.7.3 Performance ratings

The supplier/manufacturer shall provide the gas separator performance curve in accordance with Annex A.

6.7.4 Scaling of design validation

Scaling of design for this component is not allowed.

6.8 Technical specification — Seal chamber sections

6.8.1 General

The supplier/manufacturer shall prepare the technical specification for the seal chamber section that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.8.2 Technical characteristics

The following criteria shall be met.

a) The seal chamber sections shall prevent contamination of the ESP motor with well fluid.

b) The seal chamber sections shall provide a means for pressure compensation between the interior and exterior pressure of the seal chamber sections.

c) When the seal chamber section contains the shaft, the shaft shall provide a means for transferring the required torque and, where applicable, thrust.

d) The seal chamber sections shall handle axial thrust generated by the pump and motor, as required by design.

6.8.3 Performance ratings

6.8.3.1 Volume contraction capacity

The supplier/manufacturer shall provide the volume contraction capacity in accordance with Annex A.

6.8.3.2 Operating deviation limits

The supplier/manufacturer shall provide the operation deviation limits in accordance with Annex A.

6.8.3.3 Thrust bearing load capacity

The supplier/manufacturer shall provide the thrust bearing load capacity in accordance with Annex A.

6.8.3.4 Minimum operating speed for thrust bearing

The supplier/manufacturer shall provide the minimum operating speed for the thrust bearing in accordance with Annex A.

6.8.3.5 Number and severity of pressure cycles

The supplier/manufacturer shall provide the number and severity of pressure cycles in accordance with Annex A.

6.8.4 Scaling of design validation

Scaling of design for this component is not allowed.

6.8.5 Horsepower requirement

The supplier/manufacturer shall provide the horsepower requirement in accordance with Annex A.

6.9 Technical specification — Motors

6.9.1 General

The supplier/manufacturer shall prepare the technical specification for the motor that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.9.2 Technical characteristics

The motor shall convert input electrical power to the required torque needed to rotate all coupled ESP components at the required design frequency.

6.9.3 Performance ratings

6.9.3.1 Motor voltage for minimum current

The supplier/manufacturer shall provide the motor voltage for minimum current in accordance with Annex A.

6.9.3.2 Motor performance parameters

The supplier/manufacturer shall provide the following motor performance parameters: motor amperage, speed, torque, input kilowatts, efficiency, power factor, and winding temperature rise at 100 % rated output power. These parameters shall be in accordance with Annex A.

6.9.3.3 Motor operating internal temperature limits

The supplier/manufacturer shall provide the minimum and maximum internal motor operating temperature limits in accordance with Annex A.

6.9.3.4 Locked rotor current, torque, and power factor

The supplier/manufacturer shall provide the locked rotor current, torque and power factor values in accordance with Annex A.

6.9.4 Scaling of design validation

Scaling of the design of this component is allowed per A.3.7.4.

6.10 Technical specifications — Power and motor lead extension cable

6.10.1 General

The supplier/manufacturer shall prepare the technical specification for the power cable and motor lead extension (MLE) cable, hereafter referred to as "cable" that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.10.2 Technical characteristics

The following criteria shall be met.

a) The cable shall conduct electricity from the surface to the downhole motor.

b) The cable shall insulate the voltage supplied to the downhole motor.

6.10.3 Performance ratings

6.10.3.1 Cable voltage rating

The supplier/manufacturer shall provide the cable voltage rating in accordance with Annex A.

6.10.3.2 Cable temperature rating

The supplier/manufacturer shall provide the cable temperature rating in accordance with Annex A.

6.10.3.3 Cable ampacity coefficients

The supplier/manufacturer shall provide the cable ampacity coefficients in accordance with Annex A.

6.10.3.4 Cable conductor size

The supplier/manufacturer shall provide the cable conductor size in accordance with Annex A.

6.10.3.5 Cable acceptable minimum bending radius rating

The supplier/manufacturer shall provide the cable acceptable minimum bending radius rating in accordance with Annex A.

6.10.4 Scaling of design validation

Scaling of the design of this component is not allowed.

6.11 Technical specifications — Pothead

6.11.1 General

The supplier/manufacturer shall prepare the technical specification for the pothead that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.11.2 Technical characteristics

The following criteria shall be met.

a) The pothead shall conduct electricity from the cable to the downhole motor.

b) The pothead shall insulate the voltage supplied to the downhole motor.

c) The pothead shall seal the connection to prevent motor contamination by well fluid.

6.11.3 Performance ratings

6.11.3.1 Pothead voltage rating

The supplier/manufacturer shall provide the pothead voltage rating in accordance with Annex A.

6.11.3.2 Pothead temperature rating

The supplier/manufacturer shall provide the pothead temperature rating in accordance with Annex A.

6.11.3.3 Pothead ampacity coefficients

The supplier/manufacturer shall provide the pothead ampacity coefficients in accordance with Annex A.

6.11.3.4 Pothead differential pressure performance

The supplier/manufacturer shall provide the pothead differential pressure performance rating in accordance with Annex A.

6.11.3.5 Pothead thermal cycling performance

The supplier/manufacturer shall provide the pothead thermal cycling performance rating in accordance with Annex A.

6.11.4 Scaling of design validation

Scaling of the design of this component is not allowed.

6.12 Assembled ESP system

6.12.1 General

The supplier/manufacturer shall prepare the technical specification for the assembled ESP system that responds to the functional requirements. The supplier/manufacturer shall also provide to the user/purchaser component data defined in 7.2.

6.12.2 Technical characteristics

The ESP assembled system shall be designed to convert input electrical power into hydraulic power to move fluid to a point.

6.12.3 System capabilities

6.12.3.1 Axial strength and bending tensile load

The supplier/manufacturer shall provide the axial strength and bending tensile load capability in accordance with Annex B.

6.12.3.2 Surface temperature rating

The supplier/manufacturer shall provide the surface temperature rating in accordance with Annex B.

6.12.3.3 Amperage rating

The supplier/manufacturer shall provide the maximum amperage rating in accordance with Annex B.

6.12.3.4 Dogleg severity limits

The supplier/manufacturer shall provide the dogleg severity limits in accordance with Annex B.

6.12.3.5 Deviation limits

The supplier/manufacturer shall provide the maximum deviation limits which the ESP assembly can be run through and operating at in accordance with Annex B.

6.12.3.6 Installed operating temperature

The supplier/manufacturer shall provide the installed operating temperature range in accordance with Annex B.

6.12.3.7 Maximum pressurization and depressurization rates

The supplier/manufacturer shall provide the maximum pressurization and depressurization rates in accordance with Annex B.

6.12.3.8 Surface power requirements

The supplier/manufacturer shall provide the input surface power required to the power cable at the wellhead in accordance with Annex B.

6.12.3.9 Assembled ESP system motor fluid percentage utilization of each seal chamber contraction capacity

The supplier/manufacturer shall provide the assembled ESP system motor fluid percentage utilization of each seal chamber contraction capacity in accordance with Annex B.

6.12.3.10 Minimum operating speed

The supplier/manufacturer shall provide the minimum operating speed in accordance with Annex B.

6.12.3.11 Maximum operating speed

The supplier/manufacturer shall provide the maximum operating speed in accordance with Annex B.

7 Supplier/manufacturer requirements

7.1 General

This clause contains the detailed requirements to verify that each component manufactured meets the requirements of the functional and technical specifications. Design validation performance rating requirements by component are addressed in Annex A.

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 15551. These documents and data shall be maintained to demonstrate conformance to specified requirements. All documents and data shall be legible and can be in any type of media, such as hard copy or electronic.

All documents and data shall be available and auditable by the user/purchaser within 14 d after request. The supplier/manufacturer can limit availability and auditing of sensitive or proprietary documents and data to visual, controlled access review only.

Design documents (6.2.1), data, and component data sheet(s) shall be maintained for 10 years after date of last manufacture of that component.

Delivery and manufacturing related documentation shall be maintained for 5 years after date of delivery and manufacture.

7.2.2 Delivery documentation

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

a) identification by component including ancillary equipment;

b) name and address of supplier/manufacturer and assembly location identification where component was assembled;

c) serial number;

d) parts number(s);

e) nameplate values;

f) dimensions and weights of each component;

g) functional evaluation documentation according to the specified functional grade (including testing facility location);

h) quality documentation according to specified quality grade;

i) validation grade;

j) design summary sheets for the application, where applicable;

k) component internal fluids used such as motor fluid type, pump preservation fluid.

7.2.3 Operator's manual

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

a) name and address of supplier/manufacturer;

b) supplier/manufacturer component identification;

c) representative illustration(s) identifying major ESP 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 and removal guidelines;

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

7.2.4 Certificate of compliance

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

a) quality grade;

b) functional grade;

c) validation grade.

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

7.2.5 Component data sheet

7.2.5.1 General

When required by the quality grade or the user/purchaser, a component data sheet shall be supplied and shall contain the following information in 7.2.5.2 for all components and the additional applicable information contained in 7.2.5.3 through 7.2.5.10.

7.2.5.2 All components

The supplier/manufacturer shall provide the following information for all components:

a) quality grade;

b) validation grade;

c) product identification by component including ancillary equipment;

d) dimensions and weights, installed;

e) shaft power rating, where applicable

f) where applicable, radial bearing configuration description, such as bearing material type and spacing;

g) spline diameter and type, where applicable;

h) materials for housings, shafts, and fasteners, where applicable;

i) external coating types used, where applicable;

j) maximum operating temperature rating, where applicable;

k) flange compatibility as defined by the supplier/manufacturer;

l) rotational direction (bi-directional or clockwise/counter-clockwise as viewed from the top);

m) shipping, handling, and storage requirements for appropriate storage environmental conditions and duration.

7.2.5.3 Bolt on discharge

The supplier/manufacturer shall provide the following information for each type of bolt on discharge to be supplied:

a) connection specifications such as thread type, size, and weight;

b) flow capacity rating;

c) pressure rating.

7.2.5.4 Pump and gas handler

The supplier/manufacturer shall provide the following information for each type of pump and gas handler components supplied:

a) design performance curves (water only);

b) maximum GVF rating;

c) pump stage thrust;

d) housing pressure rating;

e) pump construction;

f) number of stages;

g) stage type (axial, mixed flow, radial), name, and material;

h) pump stage coating type, where applicable.

7.2.5.5 Bolt on intake

The supplier/manufacturer shall provide the following information for each type of bolt on intake to be supplied:

a) flow capacity rating;

b) inlet screen material, opening size, and total inlet area, where applicable.

7.2.5.6 Mechanical gas separator

The supplier/manufacturer shall provide the following information for each type of mechanical gas separator supplied:

a) performance curve;

b) inlet screen material, opening size, and total inlet area, where applicable.

7.2.5.7 Seal chamber section

The supplier/manufacturer shall provide the following information for each type of seal chamber component supplied:

a) volume contraction capacity;

b) operating deviation limits;

c) thrust bearing type, load capacity, rotational direction, and location (such as top or bottom);

d) horsepower requirements;

e) minimum operating speed for thrust bearing;

f) number and severity of pressure cycles;

g) total number and type of seal chamber sections;

h) bag/bladder/bellows material, where applicable;

i) chamber sequence order from top to bottom and connection type between seal chambers (parallel or series);

j) total number of mechanical shaft seals;

k) total motor fluid volume;

l) check valve operating pressure.

7.2.5.8 Motor

The supplier/manufacturer shall provide the following information for each type of motor supplied:

a) motor performance parameters, per 6.9.3.2 and Annex A;

b) motor voltage for minimum current;

c) motor operating internal temperature limits;

d) locked rotor current, torque, and power factor;

e) nameplate horsepower, motor voltage, and resulting amperage;

f) thrust bearing type, load capacity, rotational direction, and location (such as top or bottom);

g) motor insulation voltage rating;

h) motor fluid volume;

i) connection type to the MLE, such as tape-in or plug-in.

7.2.5.9 Power and motor lead extension (MLE) cable

The supplier/manufacturer shall provide the following information for each type of cable and MLE supplied:

a) voltage rating;

b) temperature rating;

c) ampacity coefficients;

d) conductor size;

e) acceptable minimum bending radius rating;

f) conductor type (such as solid, stranded, or compact stranded), and conductor coating, where applicable. If the conductor uses stranded cable, the supplier/manufacturer shall specify the number of strands;

g) conductor shield material and thickness, where applicable;

h) geometry (flat or round);

i) insulation material(s) and thickness;

j) barrier layer material and thickness, where applicable;

k) braid, where applicable;

l) jacket(s) material, where applicable;

m) armor material and construction details (such as thickness, width of wrap, class of galvanization);

n) maximum acceptable DC leakage value expressed in ampere/volt/length;

o) minimum ambient temperature for handling.

7.2.5.10 Pothead

The supplier/manufacturer shall provide the following information for each type of pothead supplied:

a) voltage rating;

b) temperature rating;

c) ampacity coefficients;

d) differential pressure performance rating;

e) thermal cycling performance rating;

f) minimum ambient temperature for handling;

g) connection type to the motor, such as tape-in or plug-in and motor series;

h) housing material;

i) sealing element material(s).

7.3 Component identification

7.3.1 Permanent identification

Each component, with the exception of the discharge head, shall be permanently marked with the component's unique identifier.

The bolt-on discharge head shall be permanently identified with the material type and thread type.

7.3.2 Semi-permanent identification

Each component shall be semi-permanently identified according to the supplier/manufacturer specifications, with the following information:

a) Pump and gas handler: stage name, number of stages, shaft material, pump construction, part number, unique identifier, series, configuration, housing material, shaft size, bearing material.

b) Bolt-on intake: series, part number, shaft size, shaft material, bearing material, housing material.

c) Mechanical gas separator: configuration, unique identifier, model, series, part number, shaft size, shaft material, bearing material, name (such as rotary), housing material.

d) Seal chamber section: configuration, motor fluid, model, part number, unique identifier, shaft material, housing material, series, bag/bladder/bellows type and material, o-ring material, thrust bearing type (such as standard, high load), chamber type and sequence.

e) Motor: series, horsepower, configuration, motor fluid, part number, unique identifier, shaft material, housing material, thrust bearing type (such as standard, high load), radial bearing material, voltage, current, frequency.

f) Power and motor lead extension cable: part number, unique identifier, conductor size, length (for main power cable, length of cable to be indicated on cable reel; for motor lead extension cable, length to be indicated on removable tag or stamped on pothead housing).

7.4 Quality

7.4.1 General

The supplier/manufacturer shall have documented quality control procedures implemented by qualified personnel to ensure that each component supplied/manufactured conforms to the supplier/manufacturer's applicable specifications drawings, procedures, and standards. This requirement also applies to all sub-suppliers to the supplier/manufacturer. This requirement applies to any component or sub-component supplied as conforming to the requirements of this part of ISO 15551.

Each supplier of components used in the assembled ESP system shall have quality systems implemented that validate conformity of each component to the specified requirements. Verifiable evidence of conformity to the requirements shall be recorded and provided by the supplier/manufacturer with the component in conformance with the selected quality grade. Component validation records shall conform to the supplier/manufacturer's data controls.

7.4.2 Quality grade requirements

The requirements defined in Table 2 shall be implemented as specified in the referenced subclauses. Table 2 specifies the percentage of components to be inspected for each purchase order with a minimum of 1. Where the percentage of components inspected is less than 100 %, the supplier/manufacturer shall use a documented method for determining the sample size.

For Table 2, sub-component by defined sample size refers to the percentage of sub-components to be inspected per heat or batch lot with a minimum of 1. Where the percentage of sub-components inspected is less than 100 %, the supplier/manufacturer shall use a documented method for determining the sample size.

Testing methods specified in Table 2 are considered minimum requirements to meet the quality grade. Conformance to the requirements of a higher quality grade automatically qualifies the final component for lower grades. These procedures include acceptance criteria for all manufactured components furnished to this part of ISO 15551.

Table 2 — Quality grade requirements summary for ESP components/sub-components

Property	Q3	Q2	Q1
Material certificate (metals and non-metals) (see 7.5)	Per supplier/manufacturer	Subcomponents by defined sample size excluding: — common hardware — process materials (such as penetrants, solvents) — shipping materials/equipment	Per Q2 with 100 % for sub-components excluding: — common hardware — process materials (such as penetrants, solvents) — shipping materials/equipment

Table 2 *(continued)*

Property	Q3	Q2	Q1
Coatings and surface treatments (see 7.6.2)	Per supplier/manufacturer	Per supplier/manufacturer	Subcomponents by defined sample size (hardness shall be measured using coupons and/or dedicated subcomponent test samples)
Non-destructive weld examination for welds (see 7.9.2)	Visual inspection as to 7.9.2.2	Per Q3 with 100 % of components and sub-components with magnetic particle or liquid penetrant or radiographic or ultrasonic per supplier/manufacturer inspection type selection criteria.	Per Q3 with 100 % of components and sub-components with magnetic particle or liquid penetrant or radiographic or ultrasonic per supplier/manufacturer inspection type selection criteria.
Component and subcomponent dimensional inspection (see 7.9.3)	Per supplier/manufacturer	100 % of components and subcomponents by defined sample size	Per Q2 with 100 % of the components and sub-components not including: pump stage flow path, common hardware — tapes — motor laminations — process materials (such as penetrants, solvents) — encapsulation materials — shipping hardware and materials
Securing of stator laminations (see 7.9.4.1)	100 % of sub-components	100 % of sub-components	100 % of sub-components
Securing of rotor laminations (see 7.9.4.2)	Sub-components by defined sample size	Sub-components by defined sample size	100 % of sub-components
Electrical integrity (see 7.9.4.3)	100 % of sub-components	100 % of sub-components	100 % of sub-components
Gas block test for power and motor lead extension cable (see 7.9.4.4)	Per supplier/manufacturer	Per supplier/manufacturer	One sample of each production run
Documentation (see 7.2)	Per supplier/manufacturer	Per Q3 with component data sheet, certificate of compliance	Per Q2 with Functional drawings which are to include external profiles/dimensions and a cut away view showing the internal subcomponents, operator's manual
Traceability	Per supplier/manufacturer	Per supplier/manufacturer	100 % per 7.7
NOTE 1 For the purposes of this table, "Per Supplier/Manufacturer" requires that the supplier/manufacturer has documentation that supports the processes used which are approved by a qualified person. NOTE 2 For the purposes of this table, 100 % refers to all components/sub-components (not including common hardware) and not 100 % of the component/sub-component itself (such as surface area).			

7.5 Raw materials

When required by the quality grade or when specifically requested by the user/purchaser, raw material used in the manufacture of components and subcomponents shall have a material certification report to verify conformance to the chemistries and properties defined in the supplier/manufacturer's documented material specifications. All materials shall be provided by audited and approved material suppliers. Material certifications are not required for common hardware or shipping hardware.

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:

— certificate of conformance stating that the material and processes applied shall conform to the supplier/manufacturer's documented specifications and acceptance criteria; or

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

7.6.2 Coatings and surface treatments

Coatings and surface treatments shall be performed according to documented procedures or international or national reference standards that result in a component or subcomponent which meets the supplier/manufacturer's acceptance criteria.

When required by the quality grade, the surface hardness shall be measured using coupons and/or dedicated subcomponent test samples, based on the supplier/manufacturer's sampling program. When coupons are used, they shall be placed or selected to reflect known sources of potential process variation.

7.6.3 Welding

Welding and brazing procedures and personnel qualifications shall be in accordance with a national or international standard such as ASME BPVC Section IX or AWS D1.1/D1M. Material and practices not listed in these standards shall be applied using weld procedures qualified in accordance with a national or international standard such as the methods of ASME BPVC Section IX or AWS B2.1/B2M, or an international standard.

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. Supplier/manufacturer shall have documented acceptance criteria for all welds. Supplier/manufacturer shall have a documented procedure approved by a qualified person for selecting the non-destructive weld inspection process used.

7.6.4 Heat treating

Heat treating shall be performed according to documented procedures that results in a component which meets the supplier/manufacturer's acceptance criteria.

7.7 Traceability

For Q3 and Q2 quality grades, traceability shall be in accordance with supplier/manufacturer's documented procedures.

For Q1 quality grade, all sub-components, with the exception of common hardware, process materials (such as penetrants, solvents), and shipping hardware shall be traceable to their raw material heat(s) or batch lot(s) and shall have a unique identifier. The unique identification of subcomponents shall allow for traceability of the subcomponent to the point that it is installed into the finished component.

Traceability of equipment is considered sufficient if the equipment meets the requirements of this part of ISO 15551 when it leaves the supplier/manufacturer's inventory as a finished component.

7.8 Calibration systems

Inspection, measuring, and testing equipment used for acceptance shall be used only within its calibrated range and shall be identified, controlled, calibrated, and adjusted at specific intervals in accordance with the manufacturer's procedures, not to exceed one year. Manufacturer's procedures shall be based on an internationally recognized standard such as ISO/IEC 17025 or ANSI/NCSL Z540.3.

Technologies for inspection, measuring, and testing with verifiable accuracies equal to or better than those listed in this part of ISO 15551 can be applied with appropriate documentation and when approved by qualified personnel.

Calibration intervals shall be established based on repeatability and degree of usage. Intervals can be lengthened or shortened based on documented repeatability, amount of usage, and calibration history, however, calibration shall occur on an annual basis.

The ranges, calibrations, resolutions, reading capabilities, time based increments, and recording capabilities shall have a confirmed accuracy that allows each parameter used for acceptance to be measured to a level of accuracy that ensures the conformance to the defined acceptance criteria. Each measured parameter shall be recorded as directly as practical from the subcomponent, component, or assembly under test. All measuring and instrumentation systems shall be calibrated as a fully operational system and used only within their calibrated ranges that facilitate repeatable readings by a qualified person.

7.9 Examination and inspection

7.9.1 General

When specified by the supplier/manufacturer or user/purchaser, non-destructive examinations (NDE) and inspections shall be performed and accepted according to the supplier/manufacturer's documented specifications that shall include the requirements defined in this clause and acceptance criteria.

NDE instructions shall be detailed in the supplier/manufacturer's documented procedures and comply with this part of ISO 15551. All NDE instructions shall be approved by a qualified ISO 9712 Level III examiner and performed by a qualified person. Personnel performing and accepting NDE 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 to be performed. As an alternative, the quality manager shall be authorized to qualify quality inspector's reading/observation capabilities based on pre-specified criteria (such as eye examination chart readings from a specified distance).

The inspection results shall be documented.

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

7.9.2 Weld

7.9.2.1 General

Weld inspections shall be performed as specified by the quality grade and according to the requirements of this clause.

7.9.2.2 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:

a) cracks in base or filler metal;

b) inclusions;

c) surface defects.

Visual inspection requires implementation of inspections with documented procedures that included specific acceptance criteria and with approved and recorded results. Visual inspection requires that 100 % of the accessible/visible surfaces are inspected.

7.9.2.3 Radiographic inspection

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

7.9.2.4 Ultrasonic inspection

Ultrasonic inspections shall meet the requirements of a national or international standard such as ASME BPVC Clause V, (Non-destructive Examination), Article 5. Acceptance criteria shall be in accordance with a national or international standard such as ASME BPVC, Clause VIII, Division 1, Appendix 12.

7.9.2.5 Magnetic particle inspection

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

7.9.2.6 Liquid penetrant inspection

Liquid penetrant inspection shall be in accordance with a national or international standard such as ISO 12095 or ASTM E165.

7.9.3 Component and subcomponent dimensional inspection

7.9.3.1 General

Components and subcomponents shall be dimensionally inspected in accordance with the quality grade to ensure compliance with the supplier/manufacturer's design criteria and specifications.

7.9.3.2 Shaft straightness

The supplier/manufacturer shall have documented procedures performed by qualified personnel for shaft straightness to ensure compliance with the supplier/manufacturer's design criteria and specifications prior to final assembly. The documentation of the final straightness measurements shall be provided to the user/purchaser where applicable.

7.9.3.3 Stator bore straightness

The supplier/manufacturer shall have documented procedures performed by qualified personnel for stator bore straightness to ensure compliance with the supplier/manufacturer's design criteria and specifications prior to final assembly. The documentation of the final straightness measurements shall be provided to the user/purchaser where applicable.

7.9.4 Construction features

7.9.4.1 Securing of stator laminations

The supplier/manufacturer shall have documented procedures performed by qualified personnel to secure the stator laminations inside the stator housing from rotating under full voltage starting conditions. The supplier/manufacturer shall have a documented quality check procedure performed by a qualified person to verify the laminations have been secured.

7.9.4.2 Securing of the rotor laminations

The supplier/manufacturer shall have documented procedures performed by qualified personnel to secure the rotor laminations from shifting or loosening under starting or steady-state operating conditions. The supplier/manufacturer shall have a documented quality check procedure performed by a qualified person to verify the rotor laminations have been secured.

7.9.4.3 Electrical integrity

Throughout the manufacture of the stator, cable, and pothead, the supplier/manufacturer shall have documented procedures performed by qualified personnel to ensure the electrical integrity. The electrical integrity of the finished component shall be validated per Annex C.

7.9.4.4 Gas block test for power and motor lead extension cable

The supplier/manufacturer shall have documented procedures performed by qualified personnel to ensure a gas block test conforming to IEEE 1018 or IEEE 1019 is performed on the manufactured section of power and motor lead extension cable.

7.10 Manufacturing non-conformance

The supplier/manufacturer shall establish and maintain documented procedures to ensure that a component or subcomponent 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 a non-conforming component or sub-component.

Non-conforming components or sub-components dispositioned for re-work shall be re-inspected to the same requirements as the original component or sub-component. Non-conforming components or sub-components dispositioned for use as-is, are acceptable for Q2 and Q3 quality grades provided that the dispositioned component or sub-component is evaluated and approved by a qualified person. Responsibility for review and authority for disposition of non-conforming components and sub-components shall be defined by the supplier/manufacturer’s documented procedures.

7.11 Component functional testing

Functional testing shall be successfully performed by the supplier/manufacturer on each component manufactured in accordance with this part of ISO 15551. 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. Functional testing shall conform to requirements of Annex C.

8 Repair/redress

Repair/redress activities are not covered within this part of ISO 15551. Components supplied under the requirements of this part of ISO 15551 shall not include previously used subcomponents.

9 Shipping, handling, and storage

9.1 General

Components shall be handled, stored, and shipped according to the documented processes and specifications of the supplier/manufacturer to prevent deterioration. Components shall be packaged for transport according to supplier/manufacturer documented specifications to prevent damage from normal handling and contamination. All material provided for transport shall be clearly identified for removal prior to use. API RP 11S3 provides guidelines for appropriate practices of component handling.

9.2 Storage

Components shall be stored in compliance with the guidelines provided in the component data sheet to prevent damage or deterioration under environmental conditions specified in the functional requirements.

For components that have been stored for prolonged periods, or that have been stored under environmental conditions that are outside those specified in the user functional requirements, the user/purchaser shall consult with the supplier/manufacturer to determine the shelf life of the components.

Annex A
(normative)

Design validation performance rating requirements by component

A.1 General

This annex defines the validation grade requirements which include multiple individual validation procedures(s), process(s), and test(s) and provides supplier/manufacturer requirements for establishing the performance ratings as defined in Clause 6. The supplier/manufacturer shall document the validation test procedures and results in a design validation file conforming to the requirements of 7.2. 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 15551 have been met. All testing shall be performed to conform to the requirements of 7.2, 7.3, 7.4, 7.6, and 7.8 and to document procedures which include acceptance criteria with the results approved by a qualified person.

Ratings shall be established at performance identified during the validation testing process.

NOTE Results from design validation testing are not necessarily directly applicable for prediction of downhole performance during operation.

A.2 Design validation grades

A.2.1 General

This part of ISO 15551 provides two grades of design validation for the components, as defined below. Previous documentation or testing applicable to existing components shall be accepted at its relevant grade. Components qualified to higher grades of design validation shall be considered qualified for lower grades of design validation. The specific requirements of each design validation grade are in Table A.1.

— V1 Highest grade — applies to a component that satisfies the applicable functional, technical, and manufacturing requirements of this part of ISO 15551. The V1 design validation file shall include all of the design validation assumptions, calculations, evaluations, test results, and other supporting documentation used to validate the design.

— V2 Basic grade — applies to a component that satisfies the applicable functional, technical, and manufacturing requirements of this part of ISO 15551. Validation grade V2 is a designation provided to accommodate experience gained from existing ESP component installations through documentation of historical performance to ensure the component satisfies the requirements of this part of ISO 15551.

Table A.1 — Design validation grade requirements

ESP component	Requirement	V2	V1
All, where applicable	Shaft power rating	Per supplier manufacturer	As A.3.1.1
	Shaft coupling rating	Per supplier/manufacturer	As A.3.1.2
Bolt on discharge head	Maximum flow capacity rating	Per supplier/ manufacturer	As A.3.2
	Pressure rating	As A.3.2.2	As A.3.2.2

Table A.1 *(continued)*

ESP component	Requirement	V2	V1
Pump and gas handler	Design performance curves — water only	Per supplier/manufacturer	As A.3.3.2
	Maximum GVF rating	Per supplier/manufacturer	As A.3.3.3
	Pump stage thrust	Per supplier/manufacturer	As A.3.3.4
	Housing pressure rating	As A.3.3.5	As A.3.3.5
Bolt on intake	Maximum flow capacity rating	Per supplier/manufacturer	As A.3.4
Mechanical gas separator	Design performance curve	Per supplier/manufacturer	As A.3.4
Seal chamber section	Volume contraction capacity	Per supplier/manufacturer	As A.3.6.2
	Operation deviation limits	Per supplier/manufacturer	As A.3.6.3
	Thrust load bearing capacity	Per supplier/manufacturer	As A.3.6.4
	Minimum operating speed for thrust bearing	Per supplier/manufacturer	As A.3.6.5
	Number and severity of pressure cycles	Per supplier/manufacturer	As A.3.6.6
	Horsepower requirement	Per supplier/manufacturer	As A.3.6.7
Motor	Motor performance parameters	Per supplier/manufacturer	As A.3.7.1
	Motor voltage for minimum current	Per supplier/manufacturer	As A.3.7.2.3
	Motor operating internal temperature limits	Per supplier/manufacturer	As A.3.7.5
	Locked rotor current, torque and power factor	Per supplier/manufacturer	As A.3.7.6
Power cable and MLE	Voltage rating	Per supplier/manufacturer	As A.3.8.2.5
	Temperature rating	Per supplier/manufacturer	As A.3.8.2.5
	Ampacity coefficients	Per supplier/manufacturer	As A.3.8.2.4
	Conductor size	Per supplier/manufacturer	As A.3.8.2.2
	Acceptable minimum bending radius rating	Per supplier/manufacturer	As A.3.8.2.3
Pothead	Voltage rating	Per supplier/manufacturer	As A.3.9.2
	Temperature rating	Per supplier/manufacturer	As A.3.9.2
	Ampacity coefficients	Per supplier/manufacturer	As A.3.9.3
	Differential pressure performance	Per supplier/manufacturer	As A.3.9.4
	Thermal cycling performance	Per supplier/manufacturer	As A.3.9.5

For the purposes of Table A.1, the term “per supplier/manufacturer” requires either component design validation/verification documentation availability or documented and verified historical use of the component in an environment justifiably similar to that of the functional specification. Each document requires verification by a qualified person.

For this purpose, verifiable historical data shall include a minimum of 20 installations of at least one continuous year of acceptable performance each. After the publication of this part of ISO 15551, components provided as V2 shall additionally conform to 6.2.9.

A.3 Method for determining performance ratings

A.3.1 For all components

A.3.1.1 Shaft power rating

A.3.1.1.1 General

The supplier/manufacturer shall specify the shaft power rating at the reference speed and reference temperature and the maximum rated operating temperature, typically reported as horsepower.

A.3.1.1.2 Method

Verification of diameters and materials shall be through physical testing or scaling and shall include the following:

a) a minimum of 10 samples from the same heat lot for a diameter shall be used for physical testing;

b) performance of a standard ASTM pull test on 5 of the samples according to ASTM E8. Samples are machined only for connection requirements to the test equipment. All samples shall be machined per the supplier/manufacturer test specimen drawing;

c) performance of torsion testing on 5 of the samples. Samples are machined with all production features, such as splines, keyways, and locating grooves. All samples shall be machined per the supplier/manufacturer test specimen drawing;

d) chemical and mechanical specifications that fall within the material requirements of the supplier/manufacturer.

Scaling of physical testing is permitted based on the following conditions:

a) Select 3 diameters of each alloy for physical testing. For proper scaling, the minimum, maximum, and mean diameter materials with the same production features shall be selected.

b) Perform physical testing of the samples.

c) Perform theoretical analysis by Finite Element Analysis or equivalent analysis method against the test sample's actual dimensions and material properties.

d) Compare the results of the physical testing and theoretical analysis by calculating the ratio of the torsional yield between the theoretical and physical results. The yield point is determined by plotting an angle vs. torque graph to show the transition from linear to plastic deformation and taking the standard 0,2 % offset on this curve.

e) Scaling to other diameters is permitted if the theoretical versus physical torsional yield ratio varies <5 %. Scaling to other diameters is not permitted if the theoretical versus physical torsional yield ratio varies >5 %.

The theoretical or physical torque at the torsional yield point is converted to horsepower. The shaft power rating shall be calculated by applying a temperature correction factor, based on a yield strength degradation versus temperature curve, which is determined either from data provided by source supplier or by physical testing and approved by a qualified person. Supplier/manufacturer can elect to apply additional de-rating correction factors to this calculation which shall be defined in the design validation documentation.

A.3.1.1.3 Calculation

The shaft power rating shall be calculated using Formula (A.1) (metric units) or Formula (A.2) (US Customary units).

$$P_{shaft} = C_{load}\,(\tau \times v_r)/9\,549 \tag{A.1}$$

where

P_{shaft} is the shaft power rating expressed in kilowatt;

τ is the torque at yield point expressed in Newton-meters;

v_r is the rotational speed expressed in revolutions/minute;

C_{load} is the de-rating factor (such as temperature and design margin).

$$P_{shaft} = C_{load}\,(\tau \times v_r)/5\,252 \tag{A.2}$$

where

P_{shaft} is the shaft power rating expressed in Horsepower;

τ is the torque at yield point expressed in ft-lbs;

v_r is the rotational speed expressed in revolutions per minute;

C_{load} is the de-rating factor (such as temperature and design margin).

A.3.1.1.4 Documentation and reporting

The following data shall be recorded:

a) material certification data, diameter, and machined features;

b) unique identifiers and type descriptions of the test equipment and instrumentation.

The following data shall be recorded during the test:

a) for pull test sample, per ASTM E8:

   1) ultimate tensile strength;

   2) yield strength;

   3) % elongation;

   4) de-rating factors applied;

b) for torsional test samples:

   1) ultimate tensile strength;

   2) yield strength;

   3) angle of Twist (radians);

   4) de-rating factors applied.

A.3.1.2 Shaft coupling rating

A.3.1.2.1 General

The supplier/manufacturer shall specify the coupling rating at the reference temperature and the maximum rated operating temperature typically reported as horsepower.

A.3.1.2.2 Method

Verification of the spline diameters and materials shall be through physical testing. A minimum of 5 samples from the same lot for a diameter and spline type shall be used for physical testing. Chemical and mechanical specifications shall fall within the material requirements of the supplier/manufacturer.

Perform torsion testing on the 5 samples. All samples shall be manufactured per the supplier/manufacturer specification.

a) Prepare short sections of shafting, splined for the coupling to be tested. Shaft length shall be the minimum required for the test fixture/system.

b) Select the shaft material to match the intended rating of the coupling.

c) Insert the two shafts into the coupling and apply torque until either the shaft yields or the coupling fails.

   — If a shaft yields (per A.3.1.1.2), the coupling shall be rated at the same horsepower rating as the shaft that yielded.

   — If the coupling fails (such as by fracturing, splitting, deformation) the coupling shall be rated at 66 % of the horsepower at the torque failure point.

The shaft coupling rating shall be calculated by applying a temperature correction factor, based on a yield strength degradation versus temperature curve, which is determined either from data provided by source supplier or by physical testing and approved by a qualified person. Supplier/manufacturer can elect to apply additional de-rating correction factors to this calculation which shall be defined in the design validation documentation.

A.3.1.2.3 Calculation

The shaft coupling power rating shall be calculated using Formula (A.1) (metric units) or Formula (A.2) (US Customary units).

A.3.1.2.4 Documentation and reporting

The following data shall be recorded:

a) material certification data, part number, unique identifier (where applicable), spline diameter, and type;

b) unique identifiers and type descriptions of test equipment and instrumentation;

c) torque applied, angle of twist (radians), and de-rating factors applied.

A.3.2 Bolt on discharge

A.3.2.1 Maximum flow capacity rating

The supplier/manufacturer shall provide the maximum recommended flow capacity rating of the bolt on discharge. The supplier/manufacturer shall have a documented process that supports the reported maximum recommended flow capacity. Flow capacity shall be reported as a maximum rate and maximum velocity.

A.3.2.2 Pressure rating

Design validation shall be performed to a documented procedure and successfully completed to the supplier/manufacturer's established acceptance criteria for each size, type, and pressure rating. The pressure rating shall be the value of the maximum allowable difference of internal less external pressure.

A.3.3 Pump and gas handler

The supplier/manufacturer shall specify the pump performance curves (catalogue curves), the maximum free gas at the intake, and the housing pressure rating of the pump and gas handler components.

A.3.3.1 Standard test fluids

Reference fluids shall be used for testing. Gas used for testing shall be air or nitrogen. Specific gravity of the test fluids are measured/calculated at intake conditions.

A.3.3.2 Design performance curves — Water only

A.3.3.2.1 General

Design performance curves shall be prepared showing the head, shaft input power, and efficiency as a function of flow rate. The performance curves shall be created by testing at a target rotational speed of either 2 916 r/min (±3 %) or 3 500 r/min (±3 %).

A.3.3.2.2 Test points

Tests shall be performed on a minimum of three different pump sections, in three different housing lengths.

A test point includes direct measurements of discharge and intake pressure, flow rate, and data required to correct test fluid to standard conditions. The data to be recorded for correcting fluid to standard conditions shall include shaft torque, rotational speed, and intake fluid temperature.

For each pump section, starting at zero flow, a minimum of seven test points shall be taken, at approximately equal flow intervals, with the last point being recorded at a flow which results in test open flow. Then, starting at test open flow, a minimum of seven test points shall be taken, at approximately equal flow intervals, with the last point being recorded at zero flow rate. This test shall be performed a minimum of three times.

A.3.3.2.3 Calculations

The following calculations shall be made to generate the pump performance curve and documented per A.3.3.2.4. Shaft power will be calculated as per Formulae (A.1) and (A.2).

Head:

$$H = (p_o - p_i) \times 101\,970 / \rho_f \qquad \text{(metric units)} \qquad (A.3)$$

$$H = (p_o - p_i) \times 144 / \rho_f \qquad \text{(US Customary units)} \qquad (A.4)$$

Fluid power:

$$P_f = (H \times Q \times \rho_f) / 8\,810\,348 \qquad \text{(metric units)} \qquad (A.5)$$

$$P_f = (H \times Q \times \rho_f) / 8\,463\,627 \qquad \text{(US Customary units)} \qquad (A.6)$$

Efficiency:

$E (\%) = 100 \times P_f / P_s$ (metric units) (A.7)

$E (\%) = 100 \times P_f / P_s$ (US Customary units) (A.8)

Flow rate adjustment:

$Q_a = Q_n \times (v_{r,ref} / v_{r,n})$ (A.9)

Head adjustment:

$H_a = H_n \times (v_{r,ref} / v_{r,n})^2$ (A.10)

Thrust adjustment:

$F_a = F_n \times (v_{r,ref} / v_{r,n})^2$ (A.11)

Power adjustment:

$P_a = P_n \times (v_{r,ref} / v_{r,n})^3$ (A.12)

where

H is the head in height of water column expressed in m (ft);

P_f is the fluid power measured at pump discharge expressed in kW (HP);

p_i is the pressure measured at pump intake expressed in MPa (psi);

p_o is the pressure measured at pump discharge expressed in MPa (psi);

Q is the flow rate measured at pump discharge expressed in m^3/d (bbl/d);

ρ_f is the fluid density measured at pump discharge expressed in kg/m^3 (lb/ft^3).

A.3.3.2.4 Documentation and reporting

The following data shall be recorded for each pump housing length tested:

a) The stage name, series, pump construction type, number of stages, and unique identifier (such as serial number);

b) Unique identifiers, calibration data, and type descriptions of test equipment and instrumentation.

The following data shall be recorded during the test at each of the test points:

a) intake pressure;

b) discharge pressure;

c) intake temperature;

d) discharge temperature;

e) flow rates;

f) rotational speed;

g) shaft torque.

All raw test data should be retained in the original units of measure.

Tests performed at the target rotational speed of 2 916 r/min shall be reported in metric units and tests performed at the target rotational speed of 3 500 r/min shall be reported in US Customary units as shown below:

— head shall be reported in meters of water or in feet of water;

— flow rate shall be reported in cubic meters per day or in barrels per day;

— power shall be reported in kW or in horsepower;

— thrust shall be reported in Newtons or in pounds force.

Best fit curves for head and power vs. flow shall be determined using all the test points corrected to reference revolutions per minute.

A graph of head and power vs. flow, using the best fit curves and test points corrected to target rotational speed, shall be constructed as follows:

— The horizontal scale of the graph shall show flow rate at the bottom of the graph using a scale that allows the data on the graph to be easily viewed. The scale on this axis shall start at zero and shall allow representation of the whole curve.

— The vertical axis shall show head, power, and efficiency using scales that allow the data on the graph to be easily viewed. The scales on these axes shall start at zero and shall allow representation of the whole curves.

The supplier/manufacturer shall report pump curves at both 2 916 r/min and 3 500 r/min. These pump curves can be generated using affinity laws extrapolated from actual tests performed at a different rotational speed if required.

A.3.3.3 Maximum Gas Volume Fraction (GVF) rating — Air and water

A.3.3.3.1 General

Maximum GVF shall be determined based upon test data at BEP and reference fluid properties. Maximum GVF rating shall be determined for each stage type, using the maximum number of stages as determined in Table A.2, or for specific fixed length pump and gas handler designs.

Table A.2 — Maximum allowable differential pressure by pump housing outer diameter

Pump housing outer diameter cm (in)	**Maximum differential pressure at BEP & 100 % liquid** kPa (psi)
<9,78 <(3,85)	1 379 (200)
9,79 – 11,68 (3,86 – 4,60)	2 068 (300)
11,69 – 15,24 (4,61 – 6,00)	3 447 (500)
15,25 – 20,32 (6,01 – 8,00)	2 758 (400)
>20,33 > (8,01)	3 447 (500)

A.3.3.3.2 Test points

The test points for each stage type or specific pump and gas handler design consist of the following steps.

a) Tests shall be performed on a minimum of one pump/gas handler component.

b) Tests shall be performed at a target rotational speed of both 2 916 r/min (±3 %) and 3 500 r/min (±3 %).

c) Intake pressure shall be 1 400 kPa (±5 %). Intake temperature shall be at reference fluid conditions or, alternatively, corrected to reference fluid conditions.

d) Establish the BEP flow rate ±2 % by starting with the discharge choke closed and then opening it until the target rate is achieved and stabilized.

e) Gas is introduced until the free gas content at the intake (GVF) is 5 % (±1 %). Data are recorded after intake flow and pressure are stabilized (at values ±5 %) for a minimum of 5 min.

f) Additional gas is introduced to increase the intake GVF by an additional 5 % (±2 %). The data are recorded after flow is stabilized (at values ±5 %) for a minimum of 2 min. The process is continued by increasing GVF by increments of 5 % (±2 %) until pump differential pressure cannot be stabilized (at values ±5 %) for a minimum of 2 min or head becomes zero.

g) Perform steps a) through f) a minimum of 3 times to ensure repeatability of results. Repeatability of results is achieved if the repeated test results are evaluated and documented as acceptable by a qualified person.

h) The reported rating shall be the average of the test results from step g).

A.3.3.3.3 Calculations

The following calculations shall be made to generate the pump GVF rating and documented per A.3.3.3.3.

Percentage of free gas:

$$VI = (100)(Q_{Gi})/(Q_{Gi} + Q_{Li}) \quad (A.13)$$

Gas volume fraction:

$$GVF = (Q_{Gi})/(Q_{Gi} + Q_{Li}) \quad (A.14)$$

where

Q_{Gi} is the flow rate of gas at intake;

Q_{Li} is the flow rate of liquid at intake.

A.3.3.3.4 Documentation

The following pump and test fluid data shall be recorded. All raw test data shall be recorded in the original units of measure.

a) the stage name, series, pump construction type, number of stages, and unique identifier (such as serial number);

b) unique identifiers, calibration data, and type descriptions of test equipment and instrumentation

c) intake pressure;

d) discharge pressure;

e) intake liquid flow rate;

f) intake gas flow rate;

g) intake temperature;

h) discharge temperature;

i) shaft torque;

j) rotational speed.

Tests performed at the target rotational speed of 2 916 r/min shall be reported in metric units and tests performed at the target rotational speed of 3 500 r/min shall be reported in US Customary units as shown below:

— differential pressure shall be reported in MPa or in pounds per square inch;

— liquid flow rate shall be reported in cubic meters per day or in barrels per day;

— maximum GVF shall be reported as the GVF at the point at which pressure readings become unstable (fluctuate more than ±5%).

The pump design performance curves shall be generated based on the data collected in this testing as per A.3.3.2.

A.3.3.4 Pump stage thrust

A.3.3.4.1 General

Design performance curves shall be prepared showing the axial thrust for one pump stage as a function of flow rate, at both 2 916 r/min and 3 500 r/min, using reference fluid.

Test points shall be taken per A.3.3.2.4 with the addition that pump shaft axial down thrust and flow rate shall be included in the data measurements and the tested pump construction is of compression type.

Documentation of data shall comply with A.3.3.3.4, with the addition that the pump shaft cross sectional area shall be recorded.

A.3.3.4.2 Calculation method

The total axial thrust measured at each test point shall be corrected to standard conditions and target rotational speed. This total axial thrust value divided by the number of pump stages shall result in the thrust value per stage for the compression type pump construction.

The pump shaft axial thrust generated by the differential pressure on the shaft shall be calculated at each test point by multiplying the pump differential pressure at that test point, corrected to standard conditions and target rotational speed, by the shaft cross sectional area. For vertical pump tests, the portion of pump shaft axial thrust contributed by the mass of the shaft and impeller assembly shall be computed and subtracted from each test point. For horizontal tests this value shall be zero.

For floater type pump construction, the hydraulic portion of the pump thrust at each test point shall be calculated by subtracting the pump shaft axial thrust measured at the test point from the thrust values calculated for the compression type pump construction.

The single stage hydraulic portion of the pump thrust at each test point shall be calculated by dividing the hydraulic portion of the pump thrust by the number of pump stages.

A.3.3.4.3 Documentation

A graph of flow rate vs. single stage hydraulic thrust, using data calculated above, shall be constructed so that the horizontal scale shall be identical to the graph of head and power vs. flow for the tested pump stage type and the vertical axis shall show stage thrust using a scale that allows the data on the graph to be easily viewable and provides representation of the entire thrust curve range.

A.3.3.5 Housing pressure rating

Design validation shall be performed to a documented procedure and successfully completed to the supplier/manufacturer's established acceptance criteria for each series, design, and material configuration. Test results shall determine the maximum allowable difference of internal less external pressure that can be exerted on the housing and this shall become the rating. The test results are to be approved by a qualified person other than the design engineer and the testing engineer. Scaling does not apply to housing pressure rating.

A.3.4 Bolt-on intake

The supplier/manufacturer shall provide the maximum recommended flow capacity rating and pressure drop of the intake and have a documented process that supports the rating.

A.3.5 Mechanical gas separator

A.3.5.1 General

The supplier/manufacturer shall prepare mechanical gas separator performance curves for design validation.

A.3.5.2 Standard test fluid conditions

Reference fluid shall be used for testing. Gas used for testing shall be air or nitrogen. Specific gravity of the test fluids are measured/calculated at intake conditions.

A.3.5.3 Test fixture

The testing fixture shall have the following features.

a) The intake shall be isolated to ensure all fluids pass through to the interior of the component and capable of maintaining a constant pressure of 100 psi ± 5 %.

b) The vents shall be isolated to ensure all vented fluids are contained for measurement and the differential pressure between the intake pressure and the gas vent shall be not greater than 5 psi.

c) The drive system shall be able to measure input power.

d) The test fixture shall have a pumping method incorporated in order to generate the required flow rate and pressure through the device. The pumping method shall be either of the following:

   — The test fixture shall have a pump which is to be connected to the discharge side of the gas separator which is capable of producing a maximum liquid flow rate greater than that of the mechanical gas separator and a differential pressure of 200 psi ± 10 %.

   — A booster pump to provide inlet flow at the specified pressure provided that the flow rate it generates is not greater than the maximum water only capacity of the component being tested (per A.3.5.4.2).

A.3.5.4 Design performance curves

A.3.5.4.1 General

Design performance curves shall be prepared showing mechanical gas separator efficiency and horsepower as a function of intake free gas percentage at a constant intake liquid flow rate. The performance curves shall be created by testing at target rotational speeds of both 2 916 r/min (±3 %) and 3 500 r/min (±3 %) at the test intake pressure.

A.3.5.4.2 Water only test points

Testing shall be conducted with the reference fluid to prepare a water only performance curve per A.3.3.2.2.

A.3.5.4.3 Gassy fluid test points

Test points shall be taken at the following conditions and in enough quantity to fully define the curve being created.

a) Intake pressure shall be at 100 psi (±5 %) throughout testing at all rates.

b) Intake liquid flow rates of 20 %, 40 %, 60 %, 80 %, and 100 % of maximum of the component.

c) Intake free gas percentage shall start at 5 % and increase in increments of 5 % until the component gas separation efficiency is less than 20 %. The testing shall be performed at each of the five prescribed liquid flow rates.

A.3.5.4.4 Calculations

The calculation for percentage of free gas shall be per Formula (A.13). The calculation for P_S (in kW or HP) shall be per Formula (A.1) or (A.2).

The calculation for mechanical gas separator efficiency shall be per Formula (A.15).

$$\text{Efficiency} = Q_{GGE} / Q_{Gi} \times 100 \quad \text{(A.15)}$$

where

Q_{Gi} is the gas flow rate at inlet;

Q_{GGE} is the gas out gas exit.

A.3.5.4.5 Documentation and reporting

The following data shall be recorded:

a) the series;

b) construction type;

c) unique identifier.

d) test pump details, such as series, stage name, number of stages, and construction.

The following data shall be recorded during the test, at each of the test points:

a) inlet pressure;

b) gas exit pressure;

c) liquid exit pressure;

d) inlet, liquid flow rate;

e) inlet, gas flow rate.

The following data shall be recorded or calculated during the test, at each of the test points:

a) component shaft torque;

b) component shaft rotational speed.

The following data shall be recorded or calculated based on mass balance equations during the test, at each of the test points:

a) liquid exit, liquid flow rate;

b) liquid exit, gas flow rate;

c) gas exit, gas flow rate;

d) gas exit, liquid flow rate.

The gas separator design performance curves shall be generated based on the data collected in this testing as per A.3.5.4.

A.3.6 Seal chamber section

A.3.6.1 General

To establish the performance ratings of the seal chamber section the supplier/manufacturer shall perform the defined actions.

A.3.6.2 Volume contraction capacity

A.3.6.2.1 General

This subclause specifies the method that determines seal chamber contraction capacity. Ratings provided shall be at both vertical orientation and at the component's maximum deviation limit as defined on the component data sheet.

A.3.6.2.2 Gravity chambers

A.3.6.2.2.1 General

For a chamber that relies on gravity to separate seal chamber fluid from well fluid, such as labyrinth-type chamber designs, calculations or computer-based solid modelling can be used to determine the contraction capacity of the chamber. The calculations or models used to determine the capacity are subject to the following conditions.

A.3.6.2.2.2 Sweep volume

The sweep volume capacity of a chamber is defined as the total volume in the chamber less any inactive volumes which can exist due to the physical design of the chamber.

A.3.6.2.2.3 Contraction capacity while deviated

When calculating the contraction capacity of the chamber when at the component's maximum deviation limit, there can be features that shall affect the contraction capacity based on the component's polar orientation. If the orientation of these features cannot be controlled, then the features shall be assumed to be in the orientation that results in the smallest contraction capacity for calculation purposes.

A.3.6.2.3 Positive seal chambers

Positive seal chambers, such as bags/bladders/bellows or pistons use a physical barrier to separate the well fluid from the internal seal chamber fluid. For these chambers and for the purposes of this part of ISO 15551, contraction capacity shall be determined using experimental methods subject to the following.

a) The test fixture shall simulate a seal chamber section to support the positive sealing element(s) and provide a path from the internal chamber volume through a check valve which is rated for the specific seal chamber section design.

b) The chamber(s) internal and external volumes shall be filled with an incompressible fluid that has a viscosity of less than 3 cP.

c) The chamber(s) internal volume shall be filled with additional fluid until such time that the internal pressure of the chamber causes the check valve to open. Once the check valve opens, the filling process is stopped. Apparatus to capture fluid that shall expel out in the following step from the internal chamber volume is required.

d) The chamber(s) external volume shall be pressurized with fluid to contract the positive barrier. The external pressure shall be increased to the supplier/manufacturers specification for the maximum differential pressure rating for the specific seal chamber design.

e) The expelled fluid volume from the internal chamber shall be measured and reported as the maximum contraction volume of the chamber. The temperature of the expelled fluid shall also be measured and recorded.

f) Single positive seal chambers shall be tested independently to determine its contraction capacity. Multiple positive seal chambers that are connected in parallel to increase the contraction capacity shall be tested together to determine the contraction capacity of the combined chambers.

A.3.6.3 Operating deviation limitations

The supplier/manufacturer shall have documented procedures and acceptance criteria to support that the seal chamber section can perform its designed function at the stated maximum deviation as indicated on the component data sheet.

A.3.6.4 Thrust bearing load capacity

A.3.6.4.1 General

The objective of this test is to verify the load rating in both the clockwise and counter-clockwise directions of a hydrodynamic axial thrust bearing when immersed in lubricating fluid. This test verification shall be performed for each combination of runner and bearing designs.

A.3.6.4.2 Test equipment and procedure

The supplier/manufacturer shall use the following test equipment and procedure.

a) As a minimum, the test equipment shall comprise of a thrust bearing, a thrust runner, a shaft, equipment required to fix the runner to the shaft, a drive motor, a housing to contain test oil and hold test pressure, equipment to regulate test pressure, test temperature, and to monitor the parameters as outlined above.

b) The test shall be conducted such that the motor fluid temperature within the test apparatus is at the rated maximum temperature of the seal chamber section as specified by the supplier/manufacturer or higher. The temperature shall be monitored by measuring the motor fluid temperature within the test apparatus and shall be maintained within a range of ±2,5 °C (±4,5 °F) throughout the test.

c) The test fluid shall be supplier/manufacturer specified motor fluid and shall have a viscosity no higher than 3 cP at the maximum test temperature.

d) The test setup shall provide test fluid that is essentially free of debris and contaminants such as air or water throughout the test.

e) The chamber pressure shall be between 96 kPa and 2,76 MPa (14 psia and 400 psia). The pressure shall be maintained within a 69 kPa (10 psi) range throughout a given test.

f) The test shall be conducted at revolution speed between 2 916 r/min and 3 500 r/min.

g) A minimum of three samples shall be tested. Each sample shall be tested in both clockwise and counter-clockwise rotational direction.

h) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test, with the exception of modifications to allow for temperature measurements of bearing pads.

i) Apply an axial load equal to the required test load and rotate the sample for a minimum of 30 min.

A.3.6.4.3 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to support the thrust bearing load ratings as indicated on the component data sheet.

The bearing passes these test acceptance criteria if there is no evidence of fluid film breakdown as determined by visual inspection of the bearing surfaces and approval by a qualified person other than the one performing the test.

Testing is to be completed successfully on all three consecutive samples. Should one of the set of three samples fail original testing, then testing is to be performed with a new group of three samples.

A.3.6.4.4 Determination of thrust bearing test load

The following formula shall be used to determine the thrust bearing load:

$$L_t = [(L_0 \times 1{,}25) \times (\omega_t / 3\,500)(mu_t/5)] \qquad \text{(A.16)}$$

where

L_t is the test load;

L_0 is the nominal load rating of bearing at 3 500 r/min and 5 cP lubricating fluid viscosity;

ω_t is the actual shaft rotational speed during test expressed in r/min;

mu_t is the actual lubricating fluid test viscosity (absolute) expressed in cP;

1,25 is the standard safety factor.

A.3.6.5 Minimum operating speed for thrust bearing

A.3.6.5.1 General

The objective of this test is to validate the ability of the axial thrust bearing to handle a nominal load at the minimum rated rotational speed in both clockwise and counter-clockwise rotational directions. This test verification shall be performed for each combination of runner and bearing designs.

A.3.6.5.2 Test equipment and procedure

The supplier/manufacturer shall use the following test equipment and procedure:

a) The test equipment shall be per A.3.6.4.2.

b) The test shall be conducted at any temperature. The temperature shall be monitored by measuring the motor fluid temperature within the test apparatus and shall be maintained within a range of ±2,5 °C throughout the test.

c) The test fluid shall be supplier/manufacturer specified motor fluid and shall have a viscosity no higher than 3 cP at the maximum test temperature.

d) The test setup shall provide test fluid that is essentially free of debris and contaminants such as air or water throughout the test.

e) The chamber pressure shall be between 96 kPa and 2,76 MPa (14 psia and 400 psia). The pressure shall be maintained within a 69 kPa (10 psi) range throughout a given test.

f) Thetestshallbeconductedatthespecifiedminimumfrequencyasdictatedbythesupplier/manufacturer. The speed shall be held to +0 %/-2 % tolerance throughout the duration of the test.

g) A minimum of three samples shall be tested. Each sample shall be tested in both clockwise and counter-clockwise rotational direction.

h) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test, with the exception of modifications to allow for temperature measurements of bearing pads.

i) Initial load applied to the thrust bearing before start-up shall be no less than 445 N (100 lbf). Once the test speed is reached, apply an axial load equal to 2 224 N (500 lbf) (±5 %). Maintain the load for a minimum of 30 min.

A.3.6.5.3 Test acceptance criteria

The supplier/manufacturer shall have requirements and documented procedures and acceptance criteria to verify the minimum operating speed as indicated on the component data sheet.

Testing is to be completed successfully on all three consecutive samples. Should one of the set of three samples fail original testing, then testing is to be performed with a new group of three samples.

A.3.6.6 Number and severity of pressure cycles

The supplier/manufacturer shall have requirements and documented procedures and acceptance criteria to validate the number and severity of positive seal chamber section pressure cycles as indicated on the component data sheet.

A.3.6.7 Horsepower requirement

The supplier/manufacturer shall have requirements and documented procedures and acceptance criteria to validate the horsepower requirement as indicated on the component data sheet.

A.3.7 Motor

A.3.7.1 Motor performance

The objective of the motor performance test is to validate the motor performance parameters. This is accomplished by recording the motor amperage, speed, torque, input kilowatts, efficiency, power factor, and average winding temperature rise at 100 % of rated output power under defined test conditions. This test applies a load device to the motor such as a dynamometer.

The test shall be performed in a controlled environment, where key input parameters ambient fluid temperature, ambient fluid flow rate, motor torque, input voltage, and input power frequency are controlled and output parameters amperage, speed, input kilowatts, power factor, and average winding temperature rise are measured.

A.3.7.2 Test procedures

A.3.7.2.1 General

This subclause provides the details of the motor performance and motor voltage for minimum current test procedures.

A.3.7.2.2 Motor performance test

To establish the motor performance parameters from 6.9.3.2, the motor shall be run in a test loop under the following conditions:

a) The cooling fluid (water) shall be maintained between 60°C and 71°C [150 °F (±10 °F)].

b) The flow rate shall maintain a fluid velocity by the motor between 0,27 m/s and 0,34 m/s (0,9 ft/s and 1,1 ft/s).

c) The input power frequency shall be 60 Hz (±1 %) with voltage THD < 5 %.

d) The inside diameter of the casing/liner in the immediate proximity of the motor shall not be larger than two times the diameter of the motor, and its diameter shall be reported.

The motor load shall be set at 100 % of rated output power, while energized at the voltage which yields the minimum current at 100 % output power. The motor shall operate for a minimum of one hour to allow time for the fluid in the test loop and the internal motor temperature to stabilize prior to obtaining the performance parameters. The amperage, voltage, speed, torque, input kilowatts, and power factor are measured and average winding temperature rise and efficiency are calculated. The average winding temperature rise is calculated according to the change in resistance of the stator winding between two states per A.3.7.3. The efficiency is calculated according to Formula (A.17):

$$\text{Efficiency} = (v_r \times \pi/30)(\tau\ (\text{Nm}))\ /\ (\text{Input (Kilowatts)} \times 1\ 000) \times 100 \qquad \text{(A.17)}$$

The viscosity of the motor fluid used in the test shall be estimated and reported using the temperature-viscosity curve for the fluid and the internal operating temperature of the motor calculated as the ambient fluid temperature plus the average winding temperature rise. The minimum viscosity allowed with this viscosity estimation method during testing shall be 4 cP.

A.3.7.2.3 Motor voltage for minimum current

To verify the optimum motor voltage for a specified power output rating, the motor shall be run in a test loop under the conditions described in A.3.7.2.2. The motor fluid used in the test shall be of the same fluid specification used for the motor performance test. The motor load is to be maintained at constant torque [calculated torque at 100 % output power assuming a rotation speed of 3 450 r/min, (±2 %)] or maintaining a constant power output of 100 % rated output power (±2 %), while energized at varying voltages. The voltage shall be varied and at each voltage point the amperage shall be recorded and data plotted until the minimum input current point is determined. The voltage at which the current is minimized is the motor test voltage for the motor performance test in A.3.7.2.2 and the motor voltage for minimum current in 6.9.3.1.

A.3.7.3 Requirements for determining motor winding temperature rise by measuring winding resistance change

A.3.7.3.1 General

The supplier/manufacturer shall have requirements and documented procedures for validating motor winding temperature rise. The average temperature of a winding can be determined by comparing the DC resistance of the winding at a specific temperature with the DC resistance at the temperature before the winding is initially energized at the start of the test. This method utilizes the characteristic of the conductor material, where in the temperature range of interest, the winding resistance changes in direct proportion to the winding temperature. This validation test shall be performed using the following procedure:

a) The first resistance measurement is taken before the motor is energized and loaded, with the winding temperature is stabilized while immersed in the test fluid. The winding resistance can be taken between any two line terminals, and the same two terminals are used throughout the test. The test fluid temperature shall also be recorded at this time.

b) After the motor has been energized and loaded and stabilized per A.3.7.2.1, the test fluid temperature is recorded again, and the motor is de-energized. At the moment motor is de-energized, a timing device is to be started. Within 15 s after the motor shaft stops rotating or within one minute after the motor is de-energized (whichever can be achieved first), the first resistance reading and the time it is taken is to be recorded.

c) An additional minimum of four winding resistance measurements along with the corresponding times of the measurements shall be recorded; these measurements shall be completed within the next two minutes. Test fluid circulation and temperature is to be maintained constant in the test loop after de-energizing the motor.

d) A curve shall be plotted of resistance versus time and the curve shall be extrapolated back to zero time to determine the resistance at the time of de-energization. The curve fit of the resistance data versus time shall have a sample coefficient of determination of 0,995 or greater. The average winding temperature shall then be determined according to the formula:

$$\text{Average Winding Temperature Rise } (^\circ\text{C}) = (R_f - R_b)/R_b \times (K + T_b) - (T_f - T_b) \quad \text{(A.18)}$$

where

R_f is the resistance of the winding at the time of motor de-energization, determined from an extrapolation of the five consecutive resistance readings taken after de-energization (ohms);

R_b is the resistance of the winding before the test is started at a known stable temperature (ohms);

K is 234,5 for copper conductor;

T_f is the temperature of the test fluid at the time of motor de-energization (°C);

T_b is the temperature at the time R_b is taken (°C).

A.3.7.3.2 Testing documentation

The following test information shall be recorded:

a) location of test;

b) date of test;

c) qualified person performing testing;

d) motor description including model, serial number, nameplate power, voltage, and ampere;

e) reference fluid test temperature;

f) motor fluid used in the test;

g) test data results.

A.3.7.4 Scaling of design validation

Scaling of motors is allowed within a motor model and series by using per-unitized performance data provided that the supplier/manufacturer shall test at minimum three different sizes of motors within the model and series and the temperature rise is within ±3 °C and other parameters as listed in Table A.3 are within ±3 % of the resulting testing values as prescribed in Clause 6. The allowable scaling range for a motor model and series shall be defined by smallest and largest horsepower motor within the three motors tested and results fall within the defined tolerances. Other conditions of motor scaling include the following:

a) If a motor model, series, and size is available in multiple voltage configurations, only one motor voltage configuration needs to be tested and the results shall be accepted for the other motor voltage configurations for that motor size.

b) Any motor configuration available for the motor model and series and size (such as upper tandem, centre tandem, lower tandem, single) can be used for the purposes of determining the performance rating.

c) Scaling is not permitted between motors which have different lamination geometry (such as differences in diameter, rotor/stator slot geometry).

Similar performance parameters can be expected on a per unit basis for motors constructed with equivalent magnet wire current density, ampere turns, lamination design and specification, output power rating per unit of rotor length, and having the same materials of construction within the electromagnetic region. See the following table for per-unitized motor performance parameters.

Table A.3 — Per unit motor performance parameters

Parameter	Per-unitized parameter
Efficiency	Percentage
Amperage	Percentage
Rotational speed	Revolutions per minute
% Power factor	Percentage
Winding temperature rise (°C)	Degree C

The supplier/manufacturer shall have documented procedures and acceptance criteria in place for the scaling of motors. All scaled motors shall have data reviewed and verified by a qualified person and documented within the design files for the component.

A.3.7.5 Motor operating internal temperature limits

The supplier/manufacturer shall have documented procedures and acceptance criteria to support the minimum and maximum motor operating internal temperature limits as indicated on the component data sheet as approved by a qualified person.

A.3.7.6 Locked rotor current, torque, and power factor

To establish the locked rotor current, torque, and power factor, the motor shall be tested under the following conditions:

a) The motor shaft should be locked against rotation, and the shaft locking mechanism shall include a torque measuring device.

b) The motor voltage and frequency shall be determined by the supplier/manufacturer to achieve full nameplate current.

c) The motor shall be energized under the above conditions, long enough to measure the motor amperage, torque, and power factor, and immediately shut down.

A.3.8 Power and motor lead extension cable

A.3.8.1 General

This subclause includes the general cable rating and selection criteria for main power cable and motor lead extension cables without pothead.

A.3.8.2 Cable ratings and selection criteria

A.3.8.2.1 General

The cable ratings and selection criteria such as, conductor size, voltage rating, temperature rating, chemical resistance, and ampacity coefficients shall be provided by the supplier/manufacturer. These ratings and selection criteria shall be validated by the supplier/manufacturer through documented procedures with acceptance criteria referencing established industry standards such as IEEE, ASTM, IEC, and NEMA as reviewed and approved by a qualified person who is other than the person who developed the original rating and/or selection criteria.

A.3.8.2.2 Conductor size

The supplier/manufacturer shall validate the cable conductor size through dimensional and resistive testing per D.3 and the results shall be reviewed and approved by a qualified person.

A.3.8.2.3 Acceptable minimum bending radius rating

To determine the minimum bend radius rating of finished ESP downhole cable, the supplier/manufacturer shall use the following testing procedure:

a) The cable sample length for this test can have any given length, however, 40 % to 60 % of the sample length shall be held as a control sample which is to be maintained at the reference temperature (±2 °C) and used for establishing a benchmark value. The remaining cable sample length shall be used for the bending test.

b) The cable sample used for the bending test shall be cooled in a cold chamber to the minimum handling temperature of the cable for a minimum of four hours.

c) The sample shall be bent over a cylindrical mandrel for three full bending cycles within a maximum of 2 min from the time the sample is removed from the cold chamber. The bending cycle shall correspond to a 180 ° curve of the cable over the mandrel to one side and another 180 ° curve to the opposite side of the cable. For flat cable constructions, the cable shall be bent along the minor cable axis.

d) The diameter of the mandrel shall be determined by minimum rated bend radius for the cable.

e) After the bending test is completed, the cable sample shall remain at the reference temperature (±2 °C) for a period of 24 h and then is subjected to tests as defined in C.9.2.2. The test results are considered acceptable if the voltage breakdown value is within 90 % of same tests performed on the control sample.

f) Testing is to be completed successfully on all three consecutive samples. Should one of the set of three samples fail original testing, then testing is to be performed with a new group of three samples.

A.3.8.2.4 Ampacity coefficient

A.3.8.2.4.1 General

The objective of this test is to validate the ampacity coefficient value of the cable.

A.3.8.2.4.2 Test equipment and procedures

The supplier/manufacturer shall use the following test equipment and procedures:

a) As a minimum, the test equipment shall comprise of the cable and equipment necessary to maintain electrical integrity of the connection. Test equipment shall pass the defined current through the device and allow for equal current among phases. Conductor temperature shall be physically measured or derived through calculation based on resistance measurements.

b) The sample length shall be a minimum of 30 cm (11,8 inches).

c) A minimum of three samples shall be tested. Samples can be modified for conductor temperature measurement purposes, provided the modification does not impact the performance of the sample.

d) The test for the temperature-rise shall be performed in air at atmospheric pressure and at the reference temperature (±2 °C or ± 3,6 °F).

e) Each sample shall be tested at a minimum of two amperages. The upper and lower test amperages to be used for testing are listed in Table A.4.

   — separate test samples do not need to duplicate the exact amperages used to test previous samples;

   — the amperage can be DC or AC (RMS);

   — on a given test, all three conductors shall have equal amperage such that the phase furthest from the average is no more than 1 % different than the average.

Table A.4 — Amperage test value by conductor size

Conductor size	Minimum upper amperage during test	Maximum lower amperage during test
2/0 AWG	190	47
1/0 AWG	151	38
1 AWG	118	30
2 AWG	94	24
25 sq. mm	70	18
4 AWG	59	15
16 sq. mm	45	12
6 AWG	37	10
10 sq. mm	28	10

f) The temperature of the air in the test chamber shall be monitored and adjusted so that the conductor temperature is within 10 °C (18 °F) of the maximum rated temperature of the cable.

g) The test conditions are considered stable when the conductor temperature and air temperature change no more than 1 °C (1,8 °F) in 30 min.

A.3.8.2.4.3 Construction of ampacity coefficient

A curve showing the expected temperature rise vs. amperage shall be constructed following the general form of temperature rise equals the ampacity coefficient multiplied by the square of the amperage in the device. The data points shall be curve fitted using a polynomial of the form:

$$\Delta T = c \times I^2 \quad \text{(A.19)}$$

The value of c is the resulting ampacity coefficient.

A.3.8.2.4.4 Test acceptance criteria

The calculated ampacity coefficient shall not be greater than the rated value by more than 5 %. The coefficient of determination for the polynomial curve using the calculated coefficient and the experimental data should be at least 0,9.

A.3.8.2.5 Voltage rating and temperature rating

A.3.8.2.5.1 General

The objective of this test is to validate the voltage and temperature ratings of the cable.

A.3.8.2.5.2 Test equipment and sample preparation

Validate the voltage and temperature ratings of the power and motor lead extension cable using the following:

a) As a minimum, the test equipment shall comprise the cable and test equipment necessary to age the cable under various conditions.

b) A minimum of 12 samples shall be required for testing. Three or more samples shall be tested at each of the following conditions:

   — unaged;

   — aged in nitrogen at maximum temperature rating or higher;

   — aged in water at maximum temperature rating or higher;

   — aged in mineral oil IRM902 (per ASTM D471) at maximum temperature rating or higher.

   Additional samples and additional temperatures are acceptable.

c) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test.

d) The length of the aged cable samples for testing shall be of a length sufficient that the cable sample shall be a minimum of 30 cm long after any contaminated ends of the cable have been cut off and the ends have been prepared for discharge testing.

e) The samples for aged testing shall be aged at the maximum operating temperature for the cable design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of ±2,5 °C (±4,5 °F) throughout the test. Additional tests performed at temperatures other than the maximum rated temperature of the cable shall follow the same testing criteria of having 9 aged samples (three samples aged in nitrogen, water, and mineral oil).

f) The pressure shall be greater than 700 kPa (101,5 psi) and less than 700 kPa (101,5 psi) above that which is sufficient to maintain water in liquid phase at the test temperature. The pressure shall be maintained at a single value, ±100 kPa (14,5 psi), throughout the test, prior to increasing the temperature by heating and shall be maintained via a regulator or similar device.

g) The aged samples shall age at the test temperature for a minimum of 28 days for all three samples aged in nitrogen, water, and mineral oil. If testing more than 9 aged samples, shorter times are acceptable for additional samples.

A.3.8.2.5.3 AC discharge testing

Validate the AC discharge of the power and motor lead extension cable using the following:

a) All samples, new or aged, shall be tested to full discharge (failure) in the same manner:

   — the discharge test temperature shall be 20 °C (±2 °C) [68 °F (±3,6 °F)];

— the test atmosphere shall be water.

b) The samples shall be prepared so that the cable ends are clean and well insulated from the electric ground and from the other phases. Following the aging tests, it is acceptable to cut away ends of cable that can be contaminated between the conductor and the insulation.

c) A water tank is to be prepared which is designed so that the water within the tank is grounded. The sample shall be bent so that some part of the cable is totally immersed in water while the cable ends are kept out of water. AC voltage shall be applied to one phase while the other two phases, cable armor and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V per second. All phases of all samples shall be tested with the same voltage increase rate within ±5 %.

d) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phase and ground. Then the test shall be completed a second time to measure the full discharge on the second attempt.

e) The process shall be repeated for all phases of a given sample.

f) The process shall be repeated for all samples.

A.3.8.2.5.4 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to verify the voltage and temperature rating of the cable. As a minimum, these criteria shall include the following:

a) Established criterion for un-aged discharge (failure) voltage.

b) The aged samples shall demonstrate a full discharge (failure) voltage greater than the voltage rating when exposed to maximum rated temperature for a minimum period of one year. Documented accelerated testing methods are acceptable.

A.3.8.2.5.5 Documentation

The supplier/manufacturer shall have testing results reviewed and approved by a qualified person. At a minimum, the following data shall be recorded:

a) cable model, type, and lot or batch number;

b) date of testing;

c) test temperature;

d) duration of aging;

e) first and second breakdown voltage or each phase of each sample;

f) accelerated test method used, if applicable.

A.3.9 Pothead

A.3.9.1 General

The supplier/manufacturer shall provide the rating of potheads.

A.3.9.2 Voltage rating and temperature rating

A.3.9.2.1 Test equipment and sample preparation

Validate the voltage and temperature ratings of the pothead using the following:

a) As a minimum, the test equipment shall comprise of the pothead, an attached section of cable and a device that simulates the pothead to motor connection sealing interface and pressure equalization characteristics of a seal chamber section. Test equipment shall be necessary to age the equipment under various conditions.

b) A minimum of 12 samples shall be tested. Three or more samples shall be tested at each of the following conditions:

   — unaged;

   — aged in nitrogen at maximum temperature rating or higher;

   — aged in water at maximum temperature rating or higher;

   — aged in mineral oil (IRM 902 per ASTM D471) at maximum temperature rating or higher;

   Additional samples and additional temperatures are acceptable.

c) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test.

d) The equipment shall be subjected to vibration at 1 G and 60 Hz in a radial direction for a period of not less than 6 h before use in the test. During the vibration conditioning procedure, the equipment does not have to be filled with fluid and can be vibrated at any temperature. No modifications to the equipment are allowable after exposure to the vibration.

e) The samples for aged testing shall be aged at the maximum operating temperature for the pothead design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of ±2,5 °C (±4,5 °F) throughout the test. Additional tests performed at temperatures other than the maximum rated temperature of the pothead shall follow the testing criteria of having 9 aged samples (three samples aged in nitrogen, water, and mineral oil).

f) The pressure shall be greater than 700 kPa (101,5 psi) gauge pressure and less than 700 kPa (101,5 psi) gauge pressure above that which is sufficient to maintain water in liquid phase at the test temperature. The pressure shall be maintained at a single value, ±100 kPa (14,5 psi), throughout the test, prior to increasing the temperature by heating and shall be maintained via a regulator or similar device.

g) The aged samples shall age at the test temperature for a minimum of 28 days for all three samples each aged in nitrogen, water, and mineral oil. If testing more than 9 aged samples, shorter times are acceptable for additional samples.

A.3.9.2.2 AC discharge testing

Validate the AC discharge of the pothead using the following:

a) All samples, new or aged, shall be tested to full discharge (failure) in the same manner:

   — the discharge test temperature shall be 20 °C (±2 °C) [68 °F (±3,6 °F)];

   — the test atmosphere shall be air with a humidity content less than 30 % relative saturation.

b) All aged samples shall undergo inspection or other testing method to confirm if there has been any fluid contamination into the sealing areas of the pothead. If the pothead sealing is found to have failed and the pothead is contaminated, the sample might not be used for discharge testing.

c) The samples shall be prepared so that the cable ends and pothead terminals are clean and well insulated from the electric ground and from the other phases. Following the aging tests, it is acceptable to cut away ends of cable that are contaminated inside the insulation.

d) AC voltage shall be applied to one phase while the other two phases, cable armor, pothead housing and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V per second. All phases of all samples shall be tested with the same voltage increase rate within ±5 %.

e) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phases and ground. Then the test shall be completed a second time to measure the full discharge on the second attempt.

f) The process shall be repeated for all phases of a given sample.

g) The process shall be repeated for all samples.

A.3.9.2.3 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to verify the voltage and temperature rating of the cable. As a minimum, these criteria shall include the following:

a) Established criterion for un-aged discharge (failure) voltage.

b) The aged samples shall demonstrate a full discharge (failure) voltage greater than the voltage rating when exposed to maximum rated temperature for a minimum period of one year. Documented accelerated testing methods are acceptable.

A.3.9.2.4 Documentation

The supplier/manufacturer shall have testing results reviewed and approved by a qualified person. At a minimum, the following data shall be recorded:

a) pothead model, type, and lot or batch number;

b) date of testing;

c) test temperature;

d) duration of aging;

e) first and second breakdown voltage or each phase of each sample;

f) accelerated test method used, if applicable.

A.3.9.3 Ampacity coefficients

A.3.9.3.1 Test equipment and procedures

Validate the ampacity coefficient rating of the pothead using the following:

a) As a minimum, the test equipment shall comprise the pothead, a device that simulates the motor connection, and equipment necessary to maintain electrical integrity of the connection. Test equipment shall pass defined current through the device and allow for equal current among phases. A minimum of one conductor temperature inside the pothead shall be physically measured or derived through calculation.

b) A minimum of three samples shall be tested. Samples can be modified for conductor temperature measurement purposes provided the modification does not impact the performance of the sample.

c) The test fluid for the temperature-rise test shall be water. The water in the test fixture shall circulate to maintain a constant temperature around the test equipment throughout the test.

d) Each sample shall be tested at a minimum of two amperages, subject to the conditions specified in Table A.4.

e) Separate test samples do not need to duplicate the amperages used to test previous samples.

f) The amperage can be DC or AC (RMS).

g) On a given test, all three conductors shall have equal amperage such that the phase furthest from the average is no more than 1 % different than the average.

h) The temperature of the test fluid shall be modified so that the conductor temperature is within 10 °C of the maximum rated temperature of the pothead. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus.

i) The pressure shall be no greater than 700 kPa (101,5 psi) above the pressure necessary to maintain water in liquid phase at test fluid temperature.

j) The test conditions are considered stable when the conductor temperature and fluid temperature change no more than 1 °C (1,8 °F), and the test pressure changes no more than 20 kPa (2,9 psi) in 30 min.

A.3.9.3.2 Construction of ampacity coefficient

A curve showing the expected temperature rise vs. amperage shall be constructed per A.3.8.2.4.3.

A.3.9.3.3 Test acceptance criteria

The acceptance criteria shall be per A.3.8.2.4.4.

A.3.9.4 Pothead differential pressure cycling performance

A.3.9.4.1 Test equipment and procedure

Validate that the pothead is capable of experiencing the rated pressure cycling performance using the following:

a) As a minimum, the test equipment shall comprise of:

   — the pothead and a device that simulates the motor connection;

   — a housing to contain test fluid exterior to the pothead/motor simulator and maintain and measure pressure;

   — a housing to contain test fluid interior to the simulator and maintain and measure pressure;

   — a device to measure temperature.

   NOTE For the purposes of this test, motor simulator does not require electrical integrity, it is only a test to determine the ability to seal.

b) A minimum of three samples shall be tested.

c) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test.

d) The equipment shall be subjected to vibration at 1 G and 60 Hz in a direction consistent with radial direction on the ESP when attached, for a period of not less than 6 h before use in the test. No modifications or repairs to the equipment are allowable after exposure to the vibration.

e) The test shall be at the maximum operating temperature for the pothead design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of ±2,5 °C (±4,5 °F) throughout the test.

f) The test shall use two test fluids. The fluid outside the device under test shall be water. The fluid inside the device under test shall be motor fluid with a viscosity of no more than 8 cP at test temperature. The two fluids shall be immiscible and clearly show contamination in either direction.

g) The test setup shall ensure that the test fluids are essentially free of debris and contaminants such as air or water throughout the test.

h) The test pressures shall be greater than 206,8 kPaa (30 psia) and sufficient to maintain water in liquid phase. The pressure(s) shall be changed throughout the test to achieve pressure cycles. It is acceptable to change either pressure outside the pothead/motor connection or the pressure inside the connection to change the pressure differential across the connection.

i) Once the stabilized test temperature is achieved, the maximum internal differential pressure shall be applied to the connection and held for a minimum of 5 minute. After the hold period, the pressure differential shall be changed to result in the maximum negative pressure differential rating. The rate of pressure change shall be no more than 6,9 kPa (1 psi) per second. The maximum negative pressure differential shall be held for a minimum of 5 minute. After the hold period, the differential pressure shall be changed until it reaches the maximum internal differential pressure rating. The rate of pressure change shall be no more than 6,9 kPa (1 psi) per second. The process shall be repeated to reach the rated number of pressure cycles or for 100 total cycles, whichever is greater.

A.3.9.4.2 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to validate the pothead differential pressure cycling performance rating as indicated on the component data sheet.

Testing shall be completed successfully on all three consecutive samples. Should one of the set of three samples fail the testing, then a testing shall be performed with a new group of three samples.

A.3.9.5 MLE Pothead thermal cycling performance

A.3.9.5.1 Test equipment and procedure

Validate the MLE pothead rated thermal cycling performance as reported on the component data sheet using the following:

a) As a minimum, the test equipment shall comprise of:

- the MLE pothead and a device that simulates the motor connection;
- a housing to contain test fluid exterior to the pothead/motor simulator and maintain and measure pressure;
- a housing to contain test fluid interior to the simulator and maintain and measure pressure;
- a device to measure temperature.

NOTE For the purposes of this test, motor simulator does not require electrical integrity.

b) A minimum of three samples shall be tested.

c) The samples used for testing purposes shall be standard equipment and not have any modifications that shall affect their performance in the test.

d) The equipment shall be subjected to vibration at 1 G and 60 Hz in a direction consistent with radial direction on the ESP when attached, for a period of not less than 6 h before use in the test. No modifications to the equipment are allowable after exposure to the vibration.

e) The test shall use two test fluids. The fluid outside the device under test shall be water. The fluid inside the device under test shall be motor fluid with a viscosity of no more than 8 cP at test temperature. The two fluids shall be immiscible and clearly show contamination in either direction.

f) The test setup shall ensure that the test fluids are essentially free of debris and contaminants such as air or water throughout the test.

g) The test pressures shall be greater than 206,8 kPaa (30 psia) and sufficient to maintain water in liquid phase. The exterior pressure should be maintained greater than the interior pressure with a pressure differential equivalent to the maximum negative pressure differential rating of the MLE pothead throughout the test.

h) Once the maximum test temperature is reached, the temperature should be held for a minimum of 5 min. After the hold period, the temperature shall be decreased until the temperature equals the minimum temperature for the thermal cycle rating. The rate of temperature change should be no more than 1 °C (1,8 °F) per minute. The minimum temperature shall be held for a minimum of 5 minute. After the hold period, the temperature shall be increased until it reaches the maximum temperature rating. The rate of temperature change shall be no more than 1 °C (1,8 °F) per minute. The process shall be repeated to reach the rated number of thermal cycles.

NOTE The purpose of this test is only to determine the ability to seal at the rated temperature range.

A.3.9.5.2 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to validate the MLE pothead rated thermal cycling performance as reported on the component data sheet. As a minimum, these criteria shall include the absence of leakage in either direction across the seal and the ability to hold the rated pressure differential in both directions.

Testing shall be completed successfully on all three consecutive samples. Should one of the set of three samples fail the testing, then a testing shall be performed with a new group of three samples.

Annex B
(normative)

Requirements for determining performance ratings as an assembled system

B.1 General

This annex provides supplier/manufacturers requirements for establishing performance ratings and related testing of the assembled ESP system. Testing shall be performed to the requirements of Clause 7, to an approved procedure with defined acceptance criteria, on calibrated equipment and by a qualified person. Testing results shall be documented and approved by a qualified person other than the person who performed the testing. All testing shall be performed to conform to the requirements of 7.2, 7.3, 7.4, 7.6, and 7.8 and to document procedures which include acceptance criteria with the results approved by a qualified person.

NOTE Results from design validation testing are not necessarily directly applicable for prediction of downhole performance during operation.

B.2 Method for determining system capabilities

B.2.1 Axial strength and bending tensile load

The supplier/manufacturer shall specify the axial strength, in terms of both maximum allowable tensile load and maximum allowable compressive load that the ESP system can be exposed to per the functional specification. Axial strength of the assembly under bending moment forces shall be determined by performing a stress analysis calculation which is performed and reviewed by a qualified person.

B.2.2 Surface temperature rating

The supplier/manufacturer shall specify the minimum and maximum well site ambient temperature conditions under which the ESP system can be installed. This rating shall be established based upon documented historical record of field installations and performance and/or full scale testing.

B.2.3 Amperage rating for the assembled ESP system

The supplier/manufacturer shall specify the maximum amperage rating for the assembled ESP system during operation, including start-up conditions. This rating shall be determined by the supplier/manufacturer's calculations based on the environment as defined by the functional specification and the supplier/manufacturer shall define the component which determines the rating.

B.2.4 Dog leg severity limits for the assembled ESP system

The supplier/manufacturer shall provide the dog leg severity limits for the assembled ESP system determined using stress analysis calculations. The stresses in the ESP system are to be calculated and the stress value and the maximum allowable stress value for the ESP assembly shall be provided at the following:

a) the most severe dog leg point in the well survey from the surface to the pump setting depth;

b) the ESP assembly setting depth.

B.2.5 Deviation limits for the assembled ESP system

The supplier/manufacturer shall provide the maximum deviation angles reported as the number of degrees from vertical which the ESP assembly can be installed through and at which the ESP can be operated.

B.2.6 Minimum, maximum, and differential operating environment temperature rating for the ESP assembly

The supplier/manufacturer shall specify the minimum, maximum, and differential operating environment temperature rating for the assembled ESP system during operation, including start-up conditions. This rating shall be determined by the supplier/manufacturer's calculations based on the environment as defined by the functional specification and the supplier/manufacturer shall define the component(s) which determine(s) the rating. The differential operating environment temperature rating for the seal chamber section shall be calculated based on full contraction capacity utilization of the upper most chamber of the seal chamber section.

B.2.7 Maximum pressurization and depressurization rates

The supplier/manufacturer shall specify the maximum pressurization and depressurization rates for the assembled ESP system during operation, including start-up conditions. These rates shall be determined by the supplier/manufacturer's calculations based on the environment as defined by the functional specification and the supplier/manufacturer shall define the component(s) which determine(s) the rate values.

B.2.8 Power requirements (kVA and kW)

The supplier/manufacturer shall determine through calculations the required input power in kVA and kW at the wellhead to properly operate the assembled ESP system within the environment defined by the functional specification. The calculations shall include the motor kVA/kW requirements at the motor input terminals, and the additional requirements due to the losses in the cable and motor lead extension. This information is to be provided to the user/purchaser in response to the functional specification. The value reported shall not consider any kVA loses due to harmonic distortion.

B.2.9 Assembled ESP system motor fluid percentage utilization of each seal chamber contraction capacity

For each seal chamber or set of parallel chambers, the supplier/manufacturer shall report the percentage of nominal motor fluid contraction capacity that is used when the ESP system cools from the expected maximum ESP operating temperature to the expected minimum well static temperature (when the ESP is not operating) as defined in the functional specification.

To determine the oil volume relevant for a given chamber or set of parallel chambers, the calculations shall include the following:

a) the volume of the motor fluid in the motor(s);

b) the volume of oil in any of the seal chambers below the given chamber;

c) any additional volume of oil in additional component or device below the given chamber.

For a gravity-type chamber, the calculations shall also include the total volume of the chamber itself. For a positive seal type chamber, or set of parallel seal chambers, the volume shall also include the motor side of the positive chamber when the positive seal device experiences maximum internal differential pressure.

For the purpose of the calculations, the entire volume of motor fluid shall be considered to be at the estimated internal operating temperature of the motor for the application. The calculated contraction shall be the change in volume of the motor fluid that results between the estimated internal motor operating temperature and the minimum expected bottom-hole temperature of the well. This contraction volume shall be divided by the rated capacity for the chamber type or set of parallel chambers and corrected for operating deviation where applicable.

B.2.10 Minimum operating speed for assembled system

The supplier/manufacturer shall have a documented process to determine the minimum operating speed for the assembled ESP system for the environment defined in the functional specification. The supplier/manufacturer shall consider conditions such as, pumping fluid to surface, lubrication of bearings, motor fluid circulation, minimum start/break frequency, and downhole gauge requirements.

B.2.11 Maximum operating speed for assembled system

The supplier/manufacturer shall have a documented process to determine the maximum operating speed for the assembled ESP system for the environment defined in the functional specification. The supplier/manufacturer shall consider conditions, such as exceeding component ratings, erosional velocities, and well drawdown limitations.

Annex C
(normative)

Functional evaluation: single component

C.1 General

This annex contains requirements for the functional evaluation procedures that verify the ability of an ESP component to conform to the functional specification. Each component shall perform within the acceptance criteria defined. The results of each functional evaluation shall be documented and approved by a qualified person.

The failure of a component to conform to any specified criteria requires the functional evaluation to be halted. The functional evaluation testing can then be restarted at the beginning after the component is corrected. One exception is a supplier manufacturer defined testing system anomaly that causes no detrimental effect on the component, in that case the testing can continue from the point of interruption. Testing anomalies/interruptions shall be documented in the testing results.

All testing shall be in accordance with the supplier/manufacturer's documented procedures and performed by a qualified person. This testing shall be performed prior to delivery and/or transfer of ownership to the user/purchaser. All testing shall be performed to conform to the requirements of 7.2, 7.3, 7.4, 7.6, and 7.8 and to document procedures which include acceptance criteria with the results approved by a qualified person.

Previous documentation or testing applicable to existing components shall be accepted at its relevant grade. Components qualified to higher grades of functional evaluation shall be considered qualified for lower grades of functional evaluation.

For the purposes of the subsequent tables in Annex C, the term "In conformance with supplier/manufacturer specifications and acceptance criteria" requires component functional evaluation documentation availability and/or documented processes and procedures as approved by a qualified person.

C.2 Definitions

For the purposes of this annex, the following definitions apply.

C.2.1

insulation resistance test

high potential (Hipot) test reported as micro-amperage or micro-amperage per KV per 1 000 FT (cable)

C.2.2

conductor resistance test

low voltage resistance test to determine the resistance of a conductor

C.2.3

insulation discharge test

high-voltage test which is applied until the insulation breaks down/fails

C.2.4

minimum allowable bending radius insulation discharge

high-voltage test which is applied to a cable at its minimum allowable bending radius until the insulation breaks down/fails

C.3 Bolt-on discharge head

There are no functional evaluation requirements or grades for the bolt-on discharge head.

C.4 Pump and gas handler

There are three functional evaluation grades for the pump and gas handler component(s) as outlined in Table C.1.

Table C.1 — Functional evaluation grades for pump and gas handler

	F3	F2	F1
Hydraulic evaluation	Per API RP 11S2	Per F3 but with the addition of two additional test points taken at: 1. between minimum operating limit and BEP 2. between BEP and maximum operating limit	Per F2 with pass/fail criteria at ±3 % tolerance on flow and head ±5 % tolerance on power, a minimum of 93 % of published efficiency
Mechanical — shaft extension, shaft end play, and shaft side play	In conformance with supplier/manufacturer specifications and acceptance criteria	Per F3	Per F3
Mechanical — shaft total indicator run-out	In conformance with supplier/manufacturer specifications and acceptance criteria	Per C.10	Per C.10
Vibration	In conformance with supplier/manufacturer specifications and acceptance criteria	Per API RP 11S8, but for component outer diameter <15,24 cm (6 in): maximum peak velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s), for horizontal testing is 0,396 cm/s (0,156 in/s) For component outer diameter ≥15,24 cm (6 in); maximum peak velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s). All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz and limits above apply to any peak in the spectrum.	Per F2

C.5 Bolt-on intake

There is one functional evaluation grade for the bolt-on intake. The requirement is to functionally evaluate the shaft rotation, shaft extension, shaft end play, and shaft side play in conformance with supplier/manufacturer specifications and acceptance criteria.

C.6 Mechanical gas separator

There are two functional evaluation grades for the mechanical gas separator as outlined in Table C.2.

Table C.2 — Functional evaluation grades for mechanical gas separator

	F2	F1
Mechanical — shaft rotation	In conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical — shaft extension, shaft end play, and shaft side play	In conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical — shaft total indicator run-out	In conformance with supplier/manufacturer specifications and acceptance criteria	Per C.10
Mechanical — rotor	In conformance with supplier/manufacturer specifications and acceptance criteria	Rotor sub-components to be dynamically balanced per supplier/manufacturer specifications and acceptance criteria.
Vibration	In conformance with supplier/manufacturer specifications and acceptance criteria	Per API RP 11S8, but for component outer diameter <15,24 cm (6 in): maximum peak velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s), for horizontal testing is 0,396 cm/s (0,156 in/s) For component outer diameter ≥15,24 cm (6 in); maximum peak velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s). All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz and limits above apply to any peak in the spectrum. Supplier/manufacturer shall have a documented procedure to ensure that shaft radial support bearings are adequately lubricated during vibration testing.

C.7 Seal chamber section

There are three functional evaluation grades for the seal chamber section as outlined in Table C.3. If seal chamber section is integral to motor, please refer to C.8.

Table C.3 — Functional evaluation grades for seal chamber section

	F3	F2	F1
Hydrostatic evaluation — bag/bladder/ bellows, relief valves, mechanical seals, housing joints	Per API RP 11S7	Per F3	Per F3 and including a pressure bleed off test during the air test using a pressure gauge to ensure pressure holds for a minimum of 5 min.
Mechanical — power loss, shaft extension, shaft end play, and shaft side play	Per API RP 11S7	Per F3	Per F3 and loaded power loss per supplier/manufacturer specifications and acceptance criteria
Mechanical — shaft total indicator run-out	In conformance with supplier/manufacturer specifications and acceptance criteria	Per F3	Per C.10
Seal fluid — dielectric	In conformance with supplier/manufacturer specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Vibration	In conformance with supplier/manufacturer specifications and acceptance criteria	Per API RP 11S8, but for component outer diameter <15,24 cm (6 in): maximum velocity peak amplitude for vertical test is 0,508 cm/s (0,200 in/s), for horizontal testing is 0,396 cm/s (0,156 in/s) For component outer diameter ≥ 15,24 cm (6 in); maximum peak velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 n/s). All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz and limits above apply to any peak in the spectrum.	Per F2

C.8 Motors

C.8.1 General

There are three functional evaluation grades for the motor as outlined in Table C.4.

Table C.4 — Functional evaluation grades for motors

	F3	F2	F1
Hydrostatic evaluation — pressure test for leaks (vacuum or pressure)	In conformance with supplier/manufacturer specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical — standard idle/coast, kW	In conformance with supplier/manufacturer specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical — load test	No requirement	No requirement	Per A.3.7.3.1
Electrical functional testing — insulation testing, dielectric oil breakdown, phase imbalance	Per C.8.2	Per F3	Per F3
Mechanical — shaft extension, shaft end play, and shaft side play (if applicable)	In conformance with supplier/manufacturer specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Vibration	In conformance with supplier/manufacturer specifications and acceptance criteria	Per API RP 11S8, but for component outer diameter <15,24 cm (6 in): maximum peak velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s), for horizontal testing is 0,396 cm/s (0,156 in/s) For component outer diameter ≥15,24 cm (6 in); maximum peak velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s). All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz and limits apply to any peak in the spectrum.	Per F2

C.8.2 Electrical functional testing procedure

The purpose of this procedure is to verify the electrical integrity of the manufactured ESP motor. This test is typically performed at no load conditions. The test procedure shall be per supplier/manufacturer established procedures and acceptance criteria which, as a minimum, conforms to the following.

a) Clean all electrical connections.

b) Measure phase to phase resistance which shall be balanced within ±3 % of the average of the resistance of all three phase to phase measurements.

c) Test insulation resistance from phase to ground for all three phases (motor winding phases can be tied together or tested separately) using a DC source at (1,5 × {nameplate voltage} + 1 000) × 1,7. The motor housing temperature shall be between 10 °C and 40 °C and supplier/manufacturer shall have established acceptance criteria for either current leakage or minimum resistance.

d) Following motor rotational testing, test insulation quality from phase to ground. Test shall be performed with the motor housing temperature at a minimum of 40 °C with all three phases closed and at a minimum of 9 kV direct current and the motor housing temperature shall be recorded. The supplier/ manufacturer shall have established acceptance criteria for current leakage value.

e) Test di-electric strength of oil in conformance with ASTM D877 or ASTM D1816. Oil shall successfully test to a dielectric strength of a minimum of 20 kV direct current. This test shall be performed as the last step in the testing process and the oil sample is to be taken from the motor base end.

C.9 Cable and MLE

C.9.1 General

There are three functional evaluation grades for the cable and MLE as outlined in Table C.5.

Table C.5 — Functional evaluation grades for cable and MLE

	F3	F2	F1
Electrical — insulation resistance, EPDM, or polyethylene insulated cable	In conformance with supplier/manufacturer specifications and acceptance criteria	Per API RP 11S6 or IEEE 1018 or IEEE 1019	Per F2
Electrical — insulation resistance, other insulation types	In conformance with supplier/manufacturer specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Electrical — conductor resistance	In conformance with supplier/manufacturer specifications and acceptance criteria	Per D.3.4 and D.4	Per F2
Electrical — insulation discharge	No requirement	No requirement	Full AC discharge test (C.9.2)
Electrical — minimum allowable bending radius insulation discharge	No requirement	No requirement	Full AC discharge test per NEMA WC 53

C.9.2 Insulation AC discharge test

C.9.2.1 General

Perform a test for determining the voltage at which the insulation of an insulated conductor breaks down or fails by meeting the following requirements:

a) Supplier/manufacturer shall select three samples from the length of finished cable to be tested to full discharge (failure) in the same manner.

b) The discharge test temperature shall be 20 °C (±2 °C) [68 °F (±3,6 °F)].

c) The test atmosphere shall be water.

d) The samples shall be prepared so that the cable ends are clean and well insulated from the electric ground.

e) A water tank is to be prepared which is designed so that the water within the tank is grounded.

C.9.2.2 Testing procedure

Validate the insulation AC discharge using the following.

a) The sample shall be bent so that some part of the cable is totally immersed in water while the cable ends are kept out of water. AC voltage shall be applied to one phase while the two other phases are shorted to each other and the cable armor and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V per second. All phases of all samples shall be tested with the same voltage increase rate within ±5 %.

b) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phase and ground. Then the test shall be completed a second time to measure the full discharge on the second attempt.

c) Repeat the test on the other two samples.

d) Record the sample information and insulation breakdown voltages.

e) Testing results shall be interpreted within the limits set by the supplier/manufacturer.

C.10 Measuring shaft runout

C.10.1 General

The purpose of this procedure is to define the method for measuring shaft Total Indicator Runout (TIR) on the top and bottom ends of ESP components. This procedure applies to the following components: pump or gas handler, seal chamber section, intake and mechanical gas separator.

This procedure does not apply to components with less than two journal bearings on the shaft.

The construction of some components shall not allow easy access to both ends of the shaft. In those cases only one end shall be measured.

This procedure measures total indicator runout at the ends of a shaft that is (typically) supported by journal type bearings that have a relatively loose fit. Measurement results shall be within the limits set by the supplier/manufacturer. The total indicator runout measured is twice the actual shaft deflection.

C.10.2 Procedure

The procedure is as follows:

a) Support the component on a flat surface that gives even support along the entire length of the component or on moveable stands that support the component at the two quarter points.

b) Mount a dial indicator base on the exterior of the component or on another stationary surface, as close to the end as practical. The indicator base can be magnetic or a clamp type. The indicator measurement precision shall be 0,02 mm or 0,001 inches.

c) Position the indicator probe such that it contacts the major diameter of the shaft splines. Shaft spline types, shaft extension, and indicator configurations vary considerably. A qualified person experienced in measuring shaft runout should supervise and approve the test setup.

d) Working from the end of the component that is opposite of the indicator setup, slowly rotate the shaft 360° while an observer notes the maximum deflection of the indicator. Components for which only one end of the shaft is accessible and short components, such as bolt-on intakes, shall require special care in rotating the shafts to avoid false readings.

e) Repeat steps a) through d) for the other end of the shaft, if applicable.

f) Total indicator runout for the component shall be reported for each end of the shaft.

Annex D
(normative)

Cable reference information

D.1 General

This annex covers detailed information and references pertaining to copper power cable conductors.

D.2 Metric conductors

D.2.1 Conductor properties

Unless otherwise specified, conductor sizes specified in metric sizes shall meet the requirements of IEC 60228 for conductor dimensions, resistance, resistance testing, and temperature correction.

D.2.2 Metric cable conductor dimension table

Table D.1 provides cable conductor dimensions for common cable construction types and shall be used to provide conductor size ratings per A.3.8.2.2.

Table D.1 — Cable conductor min and max dimensions for common metric sizes

Conductor				**Nominal weight**		**Maximum diameter of conductor**					
Size	**Area**					**Solid (class 1)**		**Stranded (class 2)**		**Stranded compact (class 2)**	
Trade name	cmil	in^2	mm^2	lb/kft	kg/km	in	mm	in	mm	in	mm
10 mm^2	19 644	0,015 5	10	59,7	88,5	0,146	3,7	0,165	4,2	0,157	4,0
16 mm^2	31 109	0,024 8	16	95,6	140	0,181	4,6	0,209	5,3	0,205	5,2
25 mm^2	49 305	0,038 8	25	149,2	222	0,224	5,7	0,260	6,6	0,256	6,5

D.2.3 Metric conductor resistance tables

Table D.2 provides cable conductor nominal resistance values for common cable construction types and shall be used as a quality check for various conductor sizes per D.2.1.

Table D.2 — Common copper metric conductor resistance values at 20 °C

Conductor size	**Maximum conductor resistance values at 20 °C**							
	Solid (Class 1)				**Class 2 stranded, circular, or compacted**			
	Bare		**Coated**		**Bare**		**Coated**	
Trade name	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
10 mm^2	0,558	1,83	0,561	1,84	0,558	1,83	0,561	1,84
16 mm^2	0,351	1,15	0,354	1,16	0,351	1,15	0,354	1,16
25 mm^2	0,222	0,727	0,224	0,734	0,222	0,727	0,224	0,734

Table data were sourced from reference documents and further requirements in D.2.1.

Table D.3 shows the resistance values of the same cables at 25 °C. This is for simplicity when comparing them to the values found in the references that use 25 °C as the reference temperature.

Table D.3 — Common copper metric conductor resistance values at 25 °C

Conductor size	Maximum conductor resistance values at 25 °C							
	Solid				7-Wire stranded or compact			
	Bare		Coated		Bare		Coated	
Trade name	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
10 mm^2	0,571	1,87	0,574	1,88	0,571	1,87	0,574	1,88
16 mm^2	0,359	1,18	0,362	1,19	0,359	1,18	0,362	1,19
25 mm^2	0,227	0,74	0,229	0,75	0,227	0,74	0,229	0,75

Table data were sourced from reference documents and further requirements in D.2.1.

D.3 AWG conductors

D.3.1 AWG conductor dimensions

D.3.1.1 General

Unless otherwise specified, conductor sizes specified in American wire gage (AWG) sizes shall meet the requirements in this subclause.

D.3.1.2 Solid conductors

Solid conductors shall be in accordance with ASTM B258.

D.3.1.3 7-wire stranded conductors

7-wire stranded conductors shall be in accordance with ASTM B8.

D.3.1.4 7-wire compact stranded conductors

7-wire compact stranded conductors shall be in accordance with ASTM B496 for AWG 2 and smaller.

For larger than AWG 2, 7-wire compact stranded conductors shall have a diameter of 92 % of the ASTM B8 requirements for the equivalent AWG size.

D.3.1.5 AWG cable conductor dimension table

Table D.4 provides cable conductor dimensions for common cable construction types and shall be used to provide conductor size ratings per A.3.8.2.2.

Table D.4 — Cable conductor nominal dimensions for common AWG sizes

Conductor				Nominal weight		Nominal diameter of conductor					
Size	Area					Solid		7-Wire stranded		7-Wire compact	
AWG	cmil	in^2	mm^2	lb/kft	kg/km	in	mm	in	mm	in	mm
6 AWG	26 240	0,020 6	13,3	79,4	118	0,162	4,11	—	—	—	—
4 AWG	41 740	0,032 7	21,1	126	188	0,204	5,19	0,232	5,89	0,213	5,41
2 AWG	66 360	0,052 1	33,6	206	306	0,258	6,54	0,292	7,42	0,268	6,81
1 AWG	83 690	0,065 7	42,4	260	386	0,289	7,35	0,328	8,33	0,298	7,57

Table D.4 *(continued)*

Conductor				Nominal weight		Nominal diameter of conductor					
Size	Area					Solid		7-Wire stranded		7-Wire compact	
AWG	cmil	in^2	mm^2	lb/kft	kg/km	in	mm	in	mm	in	mm
1/0 AWG	105 600	0,082 9	53,5	319,2	475	—	—	0,368	9,35	0,337	8,56
2/0 AWG	133 100	0,104 5	67,4	402,7	599	—	—	0,414	10,8	—	—

D.3.2 AWG copper conductor resistance

D.3.2.1 Solid bare conductors

Solid bare conductors shall be in accordance with ASTM B3.

D.3.2.2 Solid tin coated conductors

Solid tin coated conductors shall be in accordance with ASTM B33.

D.3.2.3 Solid lead coated conductors

Solid lead coated conductors shall be in accordance with ASTM B189.

D.3.2.4 7-wire stranded bare conductors

7-wire stranded bare conductors shall be in accordance with ASTM B8, Class A stranded conductors.

D.3.2.5 7-wire stranded tin coated conductors

For 7-wire stranded conductors where each individual wire is tin coated, the nominal resistance of the overall conductor shall be one seventh the resistance of an individual coated wire in accordance with ASTM B 33.

D.3.2.6 7-wire stranded lead coated conductors

For 7-wire stranded conductors where each individual wire is lead-coated, the nominal resistance of the overall conductor shall be one-seventh the resistance of an individual coated wire in accordance with ASTM B189.

D.3.2.7 7-wire compact stranded non-coated conductors

7-wire compact stranded non-coated conductors shall be in accordance with ASTM B496.

D.3.2.8 7-wire compact stranded tin coated conductors

For 7-wire compact stranded conductors where each individual wire is tin-coated, the nominal resistance of the overall conductor shall be one-seventh the resistance of an individual tin-coated wire in accordance with ASTM B33.

D.3.2.9 7-wire compact stranded lead coated conductors

For 7-wire compact stranded conductors where each individual wire is lead-coated, the nominal resistance of the overall conductor shall be one-seventh the resistance of an individual coated wire in accordance with ASTM B189.

D.3.2.10 AWG conductor resistance tables

Table D.5 provides nominal copper cable conductor resistance values for common AWG cable construction types and shall be used as a quality check for various conductor sizes per D.3.1.

Table D.5 — Nominal AWG copper conductor resistance values at 20 °C

Conductor size	Nominal conductor resistance values at 20 °C									
	Solid					7-Wire stranded or compact				
	Bare		Coated			Bare		Coated		
AWG	Ω/kft	Ω/km	Ω/kft	Ω/km	CF	Ω/kft	Ω/km	Ω/kft	Ω/km	CF
6 AWG	0,395 2	1,297	0,406 7	1,334	0,971 6	—	—	—	—	—
4 AWG	0,248 5	0,815	0,255 7	0,839	0,971 6	0,253 0	0,830 0	0,263 1	0,863 1	0,961 6
2 AWG	0,156 3	0,513	0,160 9	0,528	0,971 6	0,159 0	0,522 0	0,165 3	0,542 8	0,961 6
1 AWG	0,123 9	0,407	0,127 5	0,418	0,971 6	0,127 0	0,417 0	0,130 7	0,429 2	0,971 6
1/0 AWG	0,098 3	0,322	0,100 6	0,330	0,976 6	0,100 0	0,328 0	0,102 9	0,337 6	0,971 6
2/0 AWG	0,077 9	0,256	0,079 8	0,262	0,976 6	0,079 5	0,261 0	0,081 8	0,268 6	0,971 6

Table data sourced from reference documents and further requirements in D.3.2.1 through D.3.2.9.

Table D.6 shows the resistance values of the same cables at 25 °C. This is for simplicity when comparing them to the values found in the references that use 25 °C as the reference temperature.

Table D.6 — Nominal AWG copper conductor resistance values at 25 °C

Conductor size	Nominal copper conductor resistance values at 25 °C							
	Solid				7-Wire stranded or compact			
	Bare		Coated		Bare		Coated	
AWG	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
6 AWG	0,402 8	1,322	0,414 6	1,360	—	—	—	—
4 AWG	0,253 3	0,831	0,260 7	0,855	0,257 9	0,846	0,268 2	0,880
2 AWG	0,159 3	0,523	0,164 0	0,538	0,162 1	0,532	0,168 6	0,553
1 AWG	0,126 3	0,415	0,130 0	0,426	0,129 5	0,425	0,133 2	0,438
1/0 AWG	0,100 2	0,329	0,102 6	0,336	0,101 9	0,334	0,104 9	0,344
2/0 AWG	0,079 4	0,261	0,081 3	0,267	0,081 0	0,266	0,083 4	0,274

Table data were sourced from reference documents and further requirements in D.3.2.1 through D.3.2.10.

D.3.3 Resistance and temperature for copper AWG conductors

D.3.3.1 General

Temperature correction on resistance or conductivity of cable conductors shall be in accordance with temperature coefficients found in ASTM B193, based on conductor material and conductivity factor.

D.3.3.2 Temperature correction factor table for copper AWG conductors

Table D.7 shows the correction factors to correct measurements from measured temperature to 20 °C and the correction factor to calculate the nominal resistance at service temperature based on the value at 20 °C. The conductivity factors from the Table D.4 shall be used to determine the appropriate correction factor.

Table D.7 — Cable conductor temperature correction factors for copper AWG conductors

Temperature		Multiplication factors to...						
		correct measurement to 20 °C, based on conductivity factors				correct 20 °C value to service temperature, based on conductivity factors		
		100	97,66	97,16	96,16	100	97,66	97,16
°C	°F	unitless	unitless	unitless	unitless	unitless	unitless	unitless
0	32	1,085	1,083	1,083	1,082	0,921	0,923	0,924
10	50	1,041	1,040	1,040	1,039	0,961	0,962	0,962
15	59	1,020	1,020	1,019	1,019	0,980	0,981	0,981
20	68	1,000	1,000	1,000	1,000	1,000	1,000	1,000
25	77	0,981	0,981	0,981	0,981	1,020	1,019	1,019
30	86	0,962	0,963	0,963	0,964	1,039	1,038	1,038
35	95	0,944	0,946	0,946	0,946	1,059	1,058	1,057
40	104	0,927	0,929	0,929	0,930	1,079	1,077	1,076
45	113	0,911	0,912	0,913	0,914	1,098	1,096	1,096
50	122	0,895	0,897	0,897	0,898	1,118	1,115	1,115
55	131	0,879	0,882	0,882	0,883	1,138	1,134	1,134
60	140	0,864	0,867	0,867	0,869	1,157	1,154	1,153
65	149	0,850	0,853	0,853	0,855	1,177	1,173	1,172
70	158	0,836	0,839	0,840	0,841	1,197	1,192	1,191
75	167	0,822	0,826	0,826	0,828	1,216	1,211	1,210
80	176	0,809	0,813	0,814	0,815	1,236	1,230	1,229
85	185	0,797	0,800	0,801	0,803	1,255	1,250	1,248
90	194	0,784	0,788	0,789	0,791	1,275	1,269	1,267
100	212	0,761	0,765	0,766	0,768	1,314	1,307	1,306
120	248	0,718	0,723	0,724	0,726	1,393	1,384	1,382
140	284	0,680	0,685	0,686	0,688	1,472	1,461	1,458
160	320	0,645	0,650	0,652	0,654	1,550	1,538	1,535
180	356	0,614	0,619	0,621	0,623	1,629	1,614	1,611
200	392	0,586	0,591	0,593	0,595	1,707	1,691	1,688
220	428	0,560	0,566	0,567	0,569	1,786	1,768	1,764
240	464	0,536	0,542	0,543	0,546	1,865	1,845	1,840
260	500	0,515	0,520	0,522	0,524	1,943	1,922	1,917
280	536	0,495	0,500	0,502	0,504	2,022	1,998	1,993
300	572	0,476	0,482	0,483	0,486	2,100	2,075	2,070

D.3.4 Conductor resistance testing

D.3.4.1 General

Testing of the cable to determine its conductor resistance value shall be per ASTM B193.

D.3.4.2 Allowable resistance

The resistance of single conductor and multiple-conductor parallel-lay cable shall be no more than the 102 % of the appropriate value in Table D.2 corrected to test temperature per D.2.

The resistance of multiple-conductor twisted assembly cable shall be no more than the 104 % of the appropriate value in Table D.2 corrected to test temperature per D.2.

D.4 Other conductor configurations

Conductor configurations other than those in D.2 and D.3 shall be in accordance with an appropriate standard or other requirement that consider dimensions and resistance and which shall be evaluated based upon supplier/manufacturer procedures and evaluation criteria and implemented by a qualified person.

Annex E
(informative)

Functional evaluation guideline — Assembled ESP system

E.1 General

The supplier/manufacturer should provide verifiable evidence that the components offered can be effectively assembled to meet the requirements of the application as defined by the user/purchaser. This should be determined through the series of tests described below and additional evaluations performed by a qualified person(s) assigned for the assembled ESP system evaluation.

User/purchaser should select the tests, testing parameters, and order of the testing as applicable to the project requirements. The objective of these tests is to verify the compatibility of the components, operational performance as designed, and system integration interfaces.

Testing should be performed to the requirements of Clause 7, to an approved procedure with defined acceptance criteria, on calibrated equipment and by a qualified person. Testing results should be documented and approved by a qualified person other than the person who performed the testing.

E.2 Mechanical compatibility test

This test verifies the mechanical compatibility and interface of the ESP system components. This testing can be performed horizontally or vertically in the supplier/manufacturer's facility. The user/purchaser should specify the specific components that are required for this test. During the testing, all equipment selected (ESP and auxiliary equipment) should be mechanically coupled and flanges fully secured. For components with rotating shafts, shaft end play, and rotation should be verified after mechanical make-up of each component in the assembly. This test is considered successful if all mechanical connections can be made up without damage and shaft settings (where measureable) are within the supplier/manufacturer specifications and the shafts of the entire assembly rotate freely. Rotation of the assembly shafts can be verified by measuring voltage generation from the motor while turning the upper most shaft in the made up assembly.

E.3 ESP assembly function test

The assembled ESP components (including ESP gauge if applicable) should be function tested at an operating frequency as defined by the user/purchaser at one or more points of the pump performance curve. If the ESP gauge is capable of measuring discharge pressure and flow, then the appropriate discharge head and flow meter couplings should be fitted to the top pump to allow the discharge pressure and flow meter lines to be made-up to the ESP Gauge. This test is intended to function test the ESP assembly only and, therefore, the surface drive, control system, and power cable utilized is at the supplier/manufacturer discretion. The supplier/manufacturer should provide test results in accordance with user/purchaser requirements.

E.4 Stack-up test

The objective of this static test is to verify the ESP system assembly and installation procedure is safe and fit for purpose. The pump is not started in this test. The stack-up test can mimic the rig floor activity and particular consideration should be given to unexpected "hold-up" points and clearance issues.

Additionally, evaluation of the activities on the rig floor allows the user/purchaser to find strengths and weaknesses in the procedure. This test can be extended by the user/purchaser to include operations such as running through hanger profile, assembling electric penetrators in the ESP packer, and set and release of ESP packer.

The information from this test can be used to refine the mechanical compatibility test and aid understanding of how the ESP system is handled and assembled such as where to spot spoolers, hang goose necks, and minimizing hazards.

E.5 System integration test (SIT)

The purpose of the System Integration Test is to verify the performance of a complete system. For the purpose of this test, the equipment utilized for test should be specified by the user/purchase as follows:

a) ESP components (excluding cable): should be either the specific serial numbered components intended for installation or components of the same model and design.

b) ESP cable: should be either the specific serial numbered cable intended for installation, cable of the same model and design, a load cell and/or electrical cable system simulator to mimic the cable system electrical characteristics, or a combination thereof.

c) Power equipment (such as adjustable speed drive (ASD), transformers, control systems): which should be either the specific serial numbered equipment intended for installation, equipment of the same model and design, other equipment that is suitable for the purposes of the test, or a combination thereof.

To ensure the system as a whole operates as designed and meets specification, the ESP should be functionally operated as per user/purchase requirements such as target flow rates, power supply frequency, operating frequencies, and test fluids.

The supplier/manufacturer in accordance with the user/purchaser should develop a rigorous test procedure to demonstrate that the system is fit for purpose through a series of tests that force the system into alarm and trip scenarios. These scenarios can be created within the ESP control system and externally depending on their nature [(such as operation or emergency shutdown (ESD)]. If the power supply is housed in module, then air pressure and volume should be verified to ensure conformance to design requirements.

E.6 Power test

The objective of this test is to verify that the power supply equipment is appropriately sized to start and run the ESP motor to full load conditions when connected to the correct power cable system, or if user/ purchaser agrees a load cell and/or electrical cable system simulator (the specific equipment to be utilized for this test should be in accordance with E.5). If the motor designed for the application is unable to achieve 100 % motor load in the test conditions, an alternative larger pump might be required for test, or a dynamometer can be substituted for the pump.

E.7 Calculating ESP system efficiency

ESP system efficiency can be calculated as the total amount of hydraulic power imparted into the fluid by the ESP pump divided by the electrical power required at the power cable at the wellhead. The calculation should incorporate all known PVT data to ensure best possible accuracy of the hydraulic power estimate used for the calculation.

Annex F
(informative)

Establishing recommended operating range (ROR) of ESP system

F.1 Recommended operating range (ROR)

F.1.1 General

This annex describes the factors to be considered for defining an ROR and establishes guidelines for creating the ROR. Some factors are application specific, while others shall apply to a certain stage design regardless of the application.

F.1.2 Considerations for ROR

F.1.2.1 Axial thrust forces

Axial thrust forces are application specific because, in addition to hydraulic stage design, thrust forces are affected by the fluid density, operating rotational speed, and number of pump stages. These factors should be considered when comparing the axial thrust forces generated compared to the thrust bearing load limits.

— Floater pumps: Axial thrust forces on floating pump impellers can cause excessive wear on thrust washers, especially when abrasive particles are present in the well fluid.

— Compression pumps: Axial forces on compression pump impellers are transferred to a thrust bearing, typically in the seal chamber section.

— Pumps with modular thrust bearings: Axial thrust forces are transferred to modular thrust bearings located in the pump section. Accelerated wear can occur on these bearings in excessive down thrust conditions, especially when abrasive particles are present in the well fluid.

— Pumps with hydraulic pistons for controlling axial thrust: Downthrust forces are equalized using a hydraulic piston in the top of the pump. Hydraulic piston size should affect the recommended operating range selection.

NOTE The ROR of a particular pump stage can vary depending on pump construction. A pump curve operating range can be extended beyond the efficient operating range of the pump depending on the thrust system supporting the pump, its construction type, and thrust curve.

F.1.2.2 Flow and pressure limits

Application specific limits to ROR can include flow or pressure limits such as a minimum flow required to cool the motor or a maximum pressure that should not be exceeded in the pump housing or maximum flow rate to prevent erosional velocities.

F.1.2.3 Power limits

Application specific limits to ROR can include constraints such as motor input power limits, motor operating temperature or amperage limits, and component shaft power limits.

F.1.2.4 Shape of head/flow rate curve

Centrifugal pump head vs. flow rate curves (per A.3.3.2) can show a droop, dip, or flat region in the body of the head curve. This condition is not application specific and is a characteristic of centrifugal pumps which require a decreasing head curve for an increasing flow rate in order to have stable flow rate control of the pump. When the head curve is flat or has a dip for a range of flow rates, the flow rate of the pump can be unstable.

Annex G
(informative)

Example user/purchaser ESP functional specification form

This annex provides a form which can be used by the user/purchaser to assist in specifying the functional requirements of the ESP system as required in Clause 5. This form is not necessarily inclusive of all requirements.

Company name	
Contact	
Well information (required)	
Operating environment: Coalbed methane ☐ Heavy oil ☐ Conventional oil ☐ Source water ☐ Other ☐	
Well Type: Vertical ☐ Directional ☐ Slant ☐ Horizontal ☐	
Well location: Onshore ☐ Offshore ☐ Subsea ☐	
Reservoir Type: Carbonate ☐ Shale ☐ Unconsolidated sandstone ☐ Coal ☐ Consolidated sandstone ☐	
Reservoir Recovery Process: Aquifer drive ☐ Solution gas drive ☐ Water flood ☐ Coal dewatering ☐ Thermal ☐	
Enhanced oil recovery: CO_2 flood ☐ WAG ☐ Polymer flood ☐	
Existing or planned power supply details: Generator ☐ Utility ☐ volts ______ Hz ______ KVA / Amp supply limitations ______________________________	
Existing or planned surface equipment: Switchboard ☐ 6-step ASD ☐ PWM ASD ☐ Filtered PWM ASD ☐ Medium voltage ☐ Space restrictions ☐	
Well information (if available)	
Well Profile: S-shaped ☐ U-shaped ☐ sinusoidal ☐ multilateral ☐	
Geothermal gradient / profile: please attach	
Previous production history: please attach	

Completion data (required)		**Units (circle one)**
Pump setting depth [PSD] (measured depth [MD])		m – ft
Pump setting depth [PSD] (true vertical depth [TVD])		m – ft
Existing or planned total well depth: TVD / MD	/	m – ft
Producing interval depth (top) TVD / MD	/	m – ft
Producing interval depth (bottom) TVD / MD	/	m – ft
Casing outside diameter		mm – in
Casing weight and grade		kg/m – lbm/ft
Casing connection type		
Minimum drift diameter through wellhead to bottom of ESP assembly		mm - in

Tubing outside diameter		mm – in
Tubing weight		kg/m – lbm/ft
Tubing grade		
Tubing thread/type/size		
Completion type: perforated casing ☐ open hole ☐		
Sand control: none ☐ slotted liner ☐ gravel pack ☐ sand screen ☐		
ESP system configuration: single ☐ Dual ☐ other ☐		
ESP deployment method: conventional tubing ☐ coiled tubing ☐ wireline ☐		

Completion data (if available)		**Units (circle one)**
Well deviation survey, (please attach) or as a minimum:		
Inclination at pump setting depth		Degrees
Dogleg severity at pump setting depth		degrees / 100ft or degrees / 30m
Maximum dogleg severity between wellhead and pump setting depth:		degrees / 100ft or degrees / 30m
Tubing inner coating type and thickness (if applicable)		
Completion thermal characteristics such as heat transfer coefficients for completion, insulated tubing/annulus or flowing temperature profile (please attach)		
Completion diagram (please attach)		

Operating and production information (required)		**Units (circle one)**
Well inflow performance expressed as a minimum: (please attach) - **expected flow rate such as stock tank flow rate or pump discharge rate** - **flowing pressure or fluid level at expected flow rate for a specified depth**		
Water cut		%
Tubing head pressure		kPa – psi
Casing pressure		kPa – psi
Minimum expected bottomhole temperature		C - F
Maximum expected bottomhole temperature		C - F
Reservoir static pressure - reference depth		kPa – psi m – ft
Total producing gas oil ratio		sm^3/sm^3 – scf/stb
Special operating conditions ; such as heavy completion fluids, sand face control, delayed start up, etc.		

Operation and production information (if available)		**Units (circle one)**
Sand cut		%
Wellhead flowing fluid temperature		°C – °F
Flowing temperature at reference depth **Reference depth**		°C – °F m - ft
Slugging tendency? **If yes, due to sand? gas? steam?**		Yes – No

Desired operating frequency range		Hz
Desired operating frequency at target rate		Hz
Please attach any materials, material requirements and dimensional limitations:		

Environmental compatibility (required)		**Units (circle one) or list units used**
Oil density at standard conditions or API gravity		
Oil viscosity at standard conditions		
Bubble point pressure at reservoir temperature		kPa – psi
Solution GOR		sm^3/sm^3 – scf/stb
Water PH		
Water density		
Water salinity / chloride concentration		Ppm
Gas specific gravity		
CO_2 (mole %)	**H_2S (mole %)**	

History of solids related problems such as plugging and erosion of downhole components?
Yes ☐ No ☐
If yes, please describe:
Sand morphology: (please attach) – refer to 5.3.3

History of scale related problems? **Yes** ☐ **No** ☐
History of paraffin deposition? **Yes** ☐ **No** ☐
History of asphaltene deposition? **Yes** ☐ **No** ☐

Foamy oil behaviour? **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:

Grade selections: Design validation, functional evaluation, and quality control (required)

Component	Selected Grades							
	Design Validation (Annex A)		Functional Evaluation (Annex C)			Quality Control (7.4)		
	V1	V2	F1	F2	F3	Q1	Q2	Q3
Bolt on discharge								
Pump and gas handlers								
Bolt on intake								
Mechanical gas separators								
Seal chamber sections								
Motor								
Cable, MLE and pothead								
Assembled ESP system	Annex B*		Annex E**					

- Greyed boxes indicate unavailable sections
- * indicates that component has no grade selections
- ** indicates an informative Annex

Other (if available):

Storage environmental conditions: please describe

Projected duration of storage:

Annex H
(informative)

Considerations for use of 3-phase low and medium voltage adjustable speed drives for ESP applications

H.1 General

This annex describes the considerations (electrical, mechanical, environmental, regulatory, and reliability) related to the application of low and medium voltage adjustable speed drives for ESP applications. The information supplied in this part of ISO 15551 is for ASDs driving a single downhole ESP motor assembly.

For the purposes of this International Standard, adjustable speed drive (ASD) is the term used to describe this device. This device is also commonly known in the industry as a variable speed drive (VSD) or a variable frequency drive (VFD).

An ASD offers the flexibility to control the rotational speed of an ESP. The basic function of an ASD for ESP applications is to convert input three-phase, fixed frequency and fixed voltage to output three phase, adjustable frequency and adjustable voltage.

H.2 Definitions

For the purposes of this annex, the following definitions apply.

H.2.1

distortion factor

harmonic factor

measure of the distortion of a period signal away from a perfect sinewave

Note 1 to entry It is calculated as the ratio of the root-mean-square total of the harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percent of the fundamental.

H.2.2

total demand distortion

TDD

measure of the distortion of a current profile relative to its full load value

Note 1 to entry It is calculated as the ratio of the root-mean-square total of the harmonic content to the full load value, expressed as a percentage. Using this measure, rather than THD, allows for higher current THD when load is low.

H.2.3

total harmonic distortion

THD

common term used to define either voltage or current distortion factor

Note 1 to entry See H.2.1.

H.3 Design and selection considerations

When using an ASD for an ESP application, the following are issues that shall be taken into consideration during the selection and design of the system:

a) The ASD shall be designed, manufactured, and tested in accordance with the latest applicable standards of the final destination of use such as IEC, UL, and NEMA.

b) Electrical noise immunity shall be in accordance with local standards such as IEC 61800-3.

c) The user/purchaser shall consider the maximum allowable current total demand distortion (TDD) and voltage total harmonic distortion (THD) on the input of the ASD as described in IEEE 519. The properties of the incoming power system shall impact the harmonic distortion generated by the ASD. Establishing the maximum allowable ASD TDD and THD is important to help minimize electrically induced degradation of the electrical and mechanical power supply systems.

d) The user/purchaser shall consider the maximum allowable current TDD and voltage THD on the output of the ASD and ensure that the ASD, accessories (such as transformers), and power system shall meet these criteria. In establishing the maximum output THD, the user/purchaser shall consider the entire power system, its equipment and set-up from the output of the ASD to the downhole electrical system. Establishing the maximum allowable ASD output TDD and THD is important to minimize electrically induced degradation of the electrical insulation system and mechanical sub-components of the downhole ESP equipment.

e) There can be substantial value in including electrical systems engineering in the design phase. See H.8 for documentation needed from the manufacturer for the design and integration of the ASD.

f) Application of transient voltage surge suppressors (TVSSs) can be considered to the input and possibly the output to limit high voltage transients. If utilized, the TVSS shall be matched to the application so that output TVSS would be set to the maximum output voltage.

g) If the ASD is designed as a regenerative drive (meaning designed to allow power flow in both directions), then the ASD can include DC Bus regulation to reduce the possibility of drive over-voltage trips due to regenerative conditions.

h) Physically segregated terminal blocks can be provided for control and power wiring. This is important to limit interference induced from the power circuit into the control circuit.

i) The ASD's efficiency shall be provided at full load and speed and can be provided at other loads and speeds to assist the user/purchaser in evaluating the ASD efficiency.

j) User/purchaser can consider grounding the power supply system that provides the input power for the ASD to protect the ASD.

k) The ASD shall allow for grounding on the ESP side of the ASD or step-up transformer, if used.

H.4 Input power

When using an ASD for an ESP application, the following are issues that shall be taken into consideration regarding the input power.

a) The ASD shall operate with input voltage having up to 10 % voltage THD based on the calculation methods detailed in IEEE-519, with the exception of the point of measurement. The point of measurement of the THD shall be appropriate based on the type of ASD used.

b) ASD input harmonic current distortion shall be reported by the supplier/manufacturer for the ASD operating at 100 % and 50 % output current with 5 % impedance.

c) The user/purchaser or system designer shall consider input commutating reactance (source series reactance from the ASD all the way back to the source) for all ASD applications. The ASD can have the option to increase the system reactance in case the system reactance is too low.

d) The user/purchaser or system designer shall evaluate ASD input interaction with its source, especially with local generators and their controls. This is to minimize and prevent damage to the power supply system.

e) There can be substantial value for the user/purchaser to evaluate whether source transformer heating effects exist due to harmonics from the ASD(s) and, if necessary, mitigate with proper techniques.

f) At a minimum, the ASD shall tolerate variations of the nominal input voltage of ±5 % and maintain consistent nominal power output per the ASD nameplate.

H.5 Output power to ESP

The ASD should include all required equipment to ensure a suitable output voltage and current waveforms to ensure successful operation of the ESP system based on specific application requirements.

The ASD should be able to function properly for a variety of output filters (such as sinewave and/or dV/dt filters) installed at the drive output terminals. If the ASD uses filters on the output, then the ASD shall have a protection circuit to detect a filter malfunction and take appropriate protective action.

The ASD should be designed to produce greater than 100 % of rated output current for 1 min in order to support hard starting and short-term downhole load variations.

H.6 Accuracy of measurement

The user/purchaser or system designer should provide the supplier/manufacturer the requirements for accuracy of measurement of electrical information so this can be addressed in the ASD design.

H.7 Control functions

ASD's should have capability to determine the frequency (Hz) of the free spinning ESP motor in any direction and resume operation in proper rotation without damaging the downhole equipment.

ASD's should have the capability to reverse direction of an energized ESP motor by a controlled ramp down to a safe minimum frequency, reverse of direction, and ramp up of ESP to desired operating frequency in the opposite direction without damaging the downhole equipment.

Frequently accessed ASD programmable parameters can be adjustable from a digital operator keypad physically located on the ASD.

It is recommended that the ASD local control panel has the ability to be secured from unauthorized access.

ASD can include hard start functionality (such as rocking start mode, voltage boosting). This function is designed for assistance in starting equipment that is difficult to start.

The ASD should be programmable or self-adjusting for operation under the following conditions:

a) Operate ASD with motor disconnected.

b) Controlled shut down for phase-to-phase short circuit.

c) Operate ASD with one phase shorted to ground.

d) Multiple programmable stop modes, such as ramp, coast.

e) Multiple acceleration and deceleration rates, independently adjustable for controlled start-up, shut-down, and operational changes.

f) Ability to compensate for loss of its external control (such as shut down, continue operating, and operate in a pre-defined safe mode).

g) Capability to automatically restart after a trip with programmable features, such as number of restart attempts, time delay between restart attempts, and interlocking to ensure that the system is unable to re-start if the trip fault or process control remains open.

h) Multiple adjustable set points that lock out continuous operation at frequencies which can produce mechanical resonance. Frequency and bandwidth should be programmable.

i) Programmable output current under-load/overload from 0 % to 110 % with programmable time delays.

j) Independent torque limits for starting and running conditions.

k) Minimum and maximum frequency limit, to restrict operation outside of those limits.

l) Emergency stop (e-stop) hard wired into the drive such that when this contact is open, the drive should not run and cannot be overridden by any local or remote re-start commands.

m) Output current control mode which maintains a specified current set point and allows frequency to automatically vary to maintain a stable motor current within a programmable maximum and minimum frequency range.

n) External input control mode to allow frequency to vary to maintain a specified auxiliary input (such as flow rate, pressure) within a user programmable maximum and minimum frequency range.

At a minimum, the following functions setups and adjustments should be available from the local keypad and remotely through a communications port:

a) start/Stop command;

b) speed command;

c) motor direction selection;

d) maximum and minimum speed limits;

e) acceleration and deceleration rates;

f) critical (skip) frequency avoidance;

g) multiple attempt restart function;

h) multiple preset ramp speeds adjustment;

i) programmable analogue and digital input/output;

j) proportional/integral process controller;

k) speed control mode (such as constant frequency control, current control, pressure control);

l) motor voltage optimization — during fixed speed mode, allow for manual or automatic voltage optimization to minimize current draw.

H.8 Minimum input and output functionality

As a minimum, the ASD should interface with the following input and output signals which should be supplied in the appropriate electrical signals for the intended location of use:

a) programmable digital input (Form C contacts, sinking, or sourcing logic);

b) programmable digital output (Form C contacts);

c) analog input, 10 bits, 4 mA to 20 mA;

d) programmable analog output, 10 bits, 4 mA to 20 mA;

e) analog reference: +15 VDC source — 20 mA;

f) logic reference: +24 VDC source — 8 mA.

The supplier/manufacturer of the ASD should specify the number of each of the above inputs and outputs that are available in the ASD being supplied.

H.9 Protective functions

The ASD should provide certain protective functions to protect and permit operation of the ASD and ESP during operational fluctuations.

The overvoltage protection setting should be specified by the supplier/manufacturer and selected to prevent damage to the ASD. The overvoltage setting should be 110 % of system nominal input voltage. The overvoltage protections should shutdown and isolate the ASD by opening an upstream contactor or breaker (equipped with a shunt trip). The ASD should continue operating at the commanded speed during overvoltage conditions that do not exceed the overvoltage trip setting.

ASD should include the following protective features as a minimum:

a) DC link overvoltage/undervoltage: ensures that the peak voltages on the power semiconductors stay within their ratings. DC Link undervoltage protection is specific to certain ASD topologies.

b) Inverter fault: protects the ASD in the event of a fatal inverter fault, such as high current shut-down.

c) Input phase insensitive: required for SCR front ends to match the input phase rotation with the drive hardware/software, unless this configuration intelligence is built-in. A diode front end ASD does not require this feature.

d) Serial communication loss detection: detects loss of external communication between ASD and an external network or an internal bus communication loss between processors.

e) Short circuit protection: protects the ASD in the event of a short circuit to ground.

f) Input voltage phase loss/phase unbalance: detects loss of a phase or severely unbalanced phases which causes significant current increases on the other two phases.

g) Over current and under current protection: detects over load and under load conditions. At a minimum, there should be threshold and time limit adjustments for each. For an over load shutdown, the shut down time should follow an I2T algorithm where the time is inversely proportional to the square of the current increase.

h) Adjustable motor current limit: allows current to be varied from 10 % to 150 %.of ASD rating

i) Critical frequency avoidance: allows for avoiding specific frequencies and dead bands around each to prevent equipment operation in known harmful vibration frequencies.

j) Motor stall: detects a non-rotating motor or one in a high slip condition.

k) Logic voltage failure: detects and shuts down ASD in an orderly fashion in the event of a low voltage failure.

l) Back spin protection: detects an ESP back spin and delays restart by a restart timer or by monitoring back spin and allowing restart once it is safe to do so.

m) Thermal monitoring: detects variance from the temperature thresholds of the power semiconductors and heat sinks and control boards

H.10 ASD information to be provided to user/purchaser

The supplier/manufacturer should provide to the user/purchaser the following information which is typically used during the power system design phase. This information can be required prior to purchasing of ASD for design evaluation of the ASD and final documentation should be provided with delivery of ASD to the user/purchaser.

a) Dimensioned outline drawing.

b) Power and control connection diagram(s).

c) Descriptive bulletins (general product literature).

d) Product data sheet.

e) ASD input harmonic current distortion for the ASD operating at 100 %, 75 %, 50 %, and 25 % output current versus load and speed at a specified source impedance. Voltage THD and current TDD should be provided as a minimum. Individual harmonic currents can be available upon request.

f) ASD voltage sag ride-through capability information.

g) ASD under voltage protection trip level and time delay.

h) Details of the ASD overvoltage protection as defined, including the overvoltage protection setting and time delay and its variable limits.

i) Details of the ASD switching (carrier) frequency range, if adjustable and the ASD's de-rating verses switching frequency.

j) Information showing minimum allowable AC line reactance.

k) Amperage, voltage, kVA power, and kW/HP power rating.

l) Input power factor and efficiency versus load and speed.

m) Output filters available and limitations, such as for cable length.

Annex I
(informative)

Analysis after ESP use

I.1 General

This annex covers the recommended documentation process for determining the root cause of an ESP failure through analysis after its use. Analysis after ESP use is paramount to evaluate the inherent reliability of operational practices and/or equipment and to help determine potential areas for reliability improvement. It is not realistic to expect that all failures of a product or process can be eliminated and, therefore, another goal of analysis after use is to identify the most likely causes of failure and then identify appropriate action to mitigate the effects of those failures. Identification of the failure root cause can lead to operational and/or equipment modifications which ultimately can result in improved run life performance.

Throughout the analysis after use process, documentation should be collected and then reviewed as a whole to attempt and provide a complete overview of the system condition and use from installation to final inspection. This information should then be reviewed by the appropriate qualified persons from within the user/purchaser and/or supplier/manufacturer organizations to determine the root cause of failure and assign the failure code(s) as described in I.5. All observations, sample collections, and documentation should be performed by a qualified person.

I.2 Definitions

For the purpose of this annex, the following definitions apply:

I.1.1

failed item

item that can no longer perform it's required function

I.1.2

failure

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

I.1.3

failure descriptor

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

I.1.4

failure cause

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

I.1.5

fretting

special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force

I.1.6

item

component, device, subcomponent, functional unit, equipment, or system that may be individually considered

I.1.7

required function

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

I.1.8

reason for pull

motive for the ESP assembly being pulled from the well

I.**1.9**

primary failed item

failed component within the ESP system responsible for initiating the failure of the ESP system

I.1.10

primary failed descriptor

failure descriptor associated with the primary failed item

I.3 Documentation immediately after ESP failure is detected

When the ESP equipment has failed, it is important that all relative information recorded during its operation is collected as soon as possible to preserve the evidence needed for a root cause analysis investigation. The following items, if available, are needed:

a) all motor controller/ASD operational data;

b) amperage charts or amperage data;

c) downhole monitoring data;

d) SCADA and/or production historian data;

e) histories of choke settings inclusive of choke setting at time of failure;

f) history of actions taken prior and after the shutdown (ie. number of restart attempts);

g) well ESP installation history, inclusive of previous ESP installation, pull, and failure reports from the same well;

h) chemical treatment history;

i) initial sizing and design reports;

j) installation reports (other than reports provided by ESP installer);

k) any daily field reports that can detail sequence of events or equivalent;

l) the most recent downhole schematic (including the completion profile); wellbore profile to include pump setting depths (MD and TVD) and maximum dogleg severity;

m) most recent ESP run report as supplied by ESP installer;

n) any/all well intervention history.

I.4 Evidence collection during pull and wellsite dismantle

I.4.1 General

Prior to pulling the equipment, all parties should be advised that the pulling of the failed equipment is an integral part of determining the cause of failure. Any unusual events, or items, should be documented in writing and photographed. All key electrical readings should be checked and recorded prior to commencing pulling operations. Samples of any debris observed internally or externally on components should be placed in clean containers and labelled with the location on the ESP assembly where they were taken.

Prior to commencing the pull, the user/purchaser should review how the seal chamber section should be pressure checked at the well site. This information cannot be collected after the seal chamber section has been disconnected from the motor interface.

I.4.2 Recommended pull observations

The following items are recommended to be observed throughout the pulling of the ESP assembly and data or observations recorded.

a) Unique identifiers (such as serial numbers) of each ESP component.

b) Electrical readings from cable megger test:

- through the top of the feed-through prior to removing from the wellhead;
- after disconnecting the lower pigtail;
- after disconnecting any downhole electrical penetrators, if applicable;
- after disconnecting from motor.

c) Mechanical and electrical condition of the wellhead feed through mandrel and connection to lower pigtail. Document whether there was some amount of slack left for thermal expansion.

d) Mechanical and electrical condition of cable. Look for signs of damage, such as electrical blowouts, signs of decompression, and recording the physical location (pipe tally).

e) Number of retrieved cable bands/clamps and their condition. Compare with number installed to determine if any are left in the wellbore.

f) Mechanical and electrical condition of any/all splices in the cable, inclusive of the motor lead extension (MLE) to cable splice and any other field attachable or pig tail connections. If any splice is suspected of being a problem, the location of the splice should be recorded and it is recommended to be cut approximately 1 m (2 ft to 4 ft) above, and below, the splice and retrieved for further evaluation.

g) Mechanical and electrical condition of any additional electrical penetrator mandrels.

h) Condition of pothead entry point. The pothead should not be disconnected in the field. The MLE is recommended to be cut 0,5 m to 1 m (1 ft to 3 ft) above the pothead connection.

i) Discoloration of any component which would evidence extreme temperature such as blue/black colouring, paint blistering, and melted lead from the MLE.

j) Debris build up on any component. Collect samples of any debris that is found and place in clean container and label with details of where it was collected from the ESP assembly.

k) Note if intake is plugged with debris or if intake screen collapsed. Collect samples of any debris that is found and place in clean container and label with details of where it was collected from the ESP assembly.

l) Any corrosion of cable and/or equipment.

m) Obvious signs of impact or bending to housings or cable.

n) Note any/all electrical arcing damage and exact location.

o) Signs of MLE damaging/marking housings due to vibration.

p) Any obvious signs of tubing damage (such as corrosion, holes, and collar splits).

I.4.3 Recommended observations from well site disassembly

I.4.3.1 General

All components prepared for shipment off the well site should be performed per Clause 9. Any fluid or debris samples collected should accompany the ESP components to the location of testing and further dismantle.

During ESP laydown process, the following items should be observed and the data should be recorded.

a) Prior to laydown:

- while the ESP assembly is still fully assembled and hanging in the rig derrick, attempt to turn ESP pump shaft to determine if the assembly shafts turn with a normal amount of resistance;
- any discoloration and/or damage of the housings (such as mechanical or corrosion);
- If housings were coated, record any signs of degradation or damage.

b) After laydown:

- inspect all shaft couplings and adapters, record any signs of damage/abnormalities and keep with components for further additional inspection;
- Shaft rotation observations:
  - shaft rotation from top end of the top pump before disassembling and record if shaft rotates with a normal amount of resistance;
  - as components are disconnected from assembly, the shaft rotation of each component should be re-checked from the bottom end to determine if the shaft rotates with a normal amount of resistance and also observing if shaft rotates at top end while rotating at the bottom end;
  - shaft side play (radial stability) at each end of component.

I.4.3.2 Pump(s)/discharge head

The following should be taken into account with respect to pump(s) and discharge head.

a) Note if pump or pump common hardware show or demonstrate evidence of corrosion.

b) If the pumps were shimmed with loose shims in the couplings (as in some compression type pumps), place the shims in a plastic bag and label appropriately. Do not remove shaft extension screws or captive shims.

c) Examine O ring(s) and other seals at flange connection points for any signs of deformation or damage. Ensure that the O ring(s) and other seals remain with the discharge head for future examination.

I.4.3.3 Intake and mechanical gas separator

The following should be taken into account with respect to intake and mechanical gas separator.

a) Observe condition of the shaft and note if the shaft position is abnormal.

b) If the intake has a screen, observe the condition of the screen noting any signs of deformation or damage.

c) Examine O ring(s) and other seals at flange connection points for any signs of deformation or damage. Ensure that the O ring(s) and other seals remain with the intake and/or mechanical gas separator for future examination.

I.4.3.4 Seal chamber section

The following should be taken into account with respect to seal chamber section.

a) It is critical that the shaft seals be checked prior to disassembly of the seal chamber section to motor interface.

   — Using the pressure checking equipment as required for the type of equipment being utilized, check to confirm if any pressure is contained between the seal chamber section to motor interface point. Thereafter, check various points throughout the seal chamber section (should be mandated by the type of seal chamber section being utilized) to confirm shaft seal integrity.

   — If a shaft seal is found to be leaking, document the location of the leak.

b) Collect fluid samples before disassembling the seal chamber section from the motor. Observe for well fluid contamination and document. It is important that any labyrinth chambers be drained prior to laying horizontal.

c) When vent/drain plugs are removed, check and document presence and condition of sealing washers (such as over-compressed or normal).

d) When disconnected from the intake, observe if there is any debris in the head of the seal chamber section.

I.4.3.5 Motor(s)

The following should be taken into account with respect to motor(s).

a) Provided the MLE pothead remains connected to the motor, prepare the electrical conductors and take electrical readings through the pothead.

b) Record if motor fluid has a “burnt” smell.

c) Collect an oil sample from the base of the motor. If tandem motors were installed, collect a sample at the connection point when disassembling the motors as well. Observe for well fluid contamination and record. If sample is collected through drain plugs, check and document presence and condition of sealing washers (such as over-compressed or normal).

d) For tandem motors, observe the electrical connection point between the motors. Make note of any unusual conditions such as bent connection terminals and cracked insulators.

e) Rotate the motor shaft; determine if shaft rotates with a normal amount of resistance.

f) Observe condition of oil in head of motor for any debris and/or signs of metal particles.

I.4.4 ESP component dismantle

I.4.4.1 General

The dismantling of ESP components is recommended to be conducted in a controlled environment where extensive observations can be completed. Functional evaluations can be required along with equipment dismantling in order to fully to determine a components condition. Documentation from component assembly and function tests performed prior to installation can be made available for comparison purposes.

The following provides the general recommended observations and data to be recorded when dismantling ESP components.

a) Condition of the pump housing (such as scale buildup, corrosion, mechanical damage, and straightness).

b) If housings were coated, record any signs of degradation or damage.

c) Check rotation and note whether it turns free, hard, rough, or stuck. Note the condition of shaft and splines, including wear or twisting, corrosion, or other mechanical damage.

d) Head and base measurement for the shaft settings and how they compare to the manufacturer's original specifications.

e) Shaft's axial movement and how it compares to the manufacturer's original specifications.

f) Total indicator run-out (per C.10) and how it compares to the manufacturer's original specifications.

g) Observe all components for discoloration that would indicate wellbore fluid damage or possible heat damage.

h) Condition of shaft in terms of straightness or twisting and noting any signs of heat or abnormal wear.

i) Condition of all O rings and other seals for any signs of deformation, damage, or leakage of fluid past the O ring and other seals.

j) As ESP components are dismantled, continue to collect fluid samples, as available.

I.4.4.2 Pump and gas handler

The following provides the recommended observations and data to be recorded when dismantling pump and gas handler.

a) Signs of heat that would result from spinning diffusers.

b) After head and base are removed, record the condition of the threads and base bushing (such as wear, plugging, corrosion, and erosion).

c) If the pump has a threaded bearing support, record the distance from the end of the housing to the top of the bearing support to determine the gap between the head and support.

d) Condition of the radial support bearing(s) (such as wear, corrosion, and erosion) and if one-sided wear is noted.

e) Condition of the stage bushings and sleeves at the head, base, and, selectively, at intermediate points along the length for wear, cracks, or abrasive indications.

f) If the impeller and diffuser stack were difficult to pull from the housing.

g) If any diffusers show signs of spinning on the exterior.

h) Condition of impellers (such as signs of thrust, abrasive wear, and/or radial wear), especially for the pads, bores and hubs and if one-sided wear noted.

i) Selectively remove thrust washers and check for thickness and brittleness. Note the type of thrust washers and compare with a new washer. Confirm the same type of thrust washers were used throughout the pump.

j) If any debris is found in the pump, collect a sample for further analysis and testing.

k) Layout the pump components from the head to the base. Record the dimensional measurements of the pump subcomponents at the head, base and selectively at intermediate points along the length for wear and compare with original manufacturing specifications.

l) Material type of the bushings and sleeves and the spacing of any abrasion resistant (AR) bearings.

m) Observe the shaft splines for straightness and coupling engagement. If a coupling is only partially engaged, damage can be noted at the upper end of the spline.

n) If the shaft utilizes shim nuts, remove and measure with a caliper.

o) Condition of the shaft surface, noting issues such as pitting, galling, erosion beneath the shaft sleeves, and one-sided wear.

I.4.4.3 Gas separators

The following provides the recommended observations and data to be recorded when dismantling the mechanical gas separator.

a) After the respective internal parts are removed, record the condition of the ID as well as internal parts noting any erosion, corrosion, or other abnormalities.

b) Condition of all bearings, bushings, and sleeves noting wear (one-sided or concentric), presence of debris, and general condition. Collect samples of any debris for possible further analysis.

c) Observe condition of intake screen, if applicable. Note presence of debris or screen damage or if screen is missing.

I.4.4.4 Seal chamber section(s)

The following the recommended observations and data to be recorded when dismantling seal chamber section.

a) Condition of vent holes, noting any plugging and debris.

b) Look for any stress damage in all coupling splines/pins, if applicable.

c) Results of testing (by pressure testing or other means) each housing connection point to verify integrity. Give particular attention to lockplates and/or joint welds, if utilized.

d) Check shaft head and base bushing radial side play and how it compares to the manufacturer's original specifications.

e) Pressure test results for each mechanical shaft seal.

f) Check for presence and condition of drain/fill/vent valve/plug seal washers. If lead gaskets are utilized as sealing element, look for any areas where the lead gasket was not properly deformed (compressed) for a possible leak path or where the lead gasket might have been fully extruded due to being over-tightened.

g) Condition of each mechanical seal bellows, spring, runner and seat, observing for wear, scoring, chipping, or broken face. Note the condition of the elastomer in terms of pliability, stiffness, and hardness.

h) Inspect each chamber for corrosion or condition of threads contamination and provide a description of fluid samples taken from each chamber.

i) Condition of each bag/bladder/bellows (internally and externally) and bag/bladder/bellows clamp/retainers. Note the amount and type of fluid located inside the bag/bladder/bellows and on the outside of the bag/bladder/bellows. If bag/bladder/bellows is air or pressure tested for integrity (after dismantle), record results.

j) Observe the base bushing for any wear such as scoring, one-sided wear, or galling.

k) Observe the thrust bearings and both sides of the runner for any signs of damage or deformation such as operating in well fluid, up thrust, down thrust, uneven wear, deflected thrust runner, scoring, excessive heat, and fretting.

l) Observe the shaft splines for straightness and coupling engagement. If a coupling is only partially engaged, damage can be noted at the upper end of the spline.

m) If the shaft utilizes shim screws, record caliper measurements of each.

n) Condition of the shaft surface, noting issues such as pitting, galling, erosion beneath the shaft sleeves, one-sided wear, or scoring.

I.4.4.5 Motor(s) (includes the MLE and pothead)

The following provides the recommended observations and data to be recorded when dismantling the motor.

a) Results of motor housing pressure test.

b) Pressure test results and observations of the pothead for signs of heat, O ring (and other seal) damage, surface damage to sealing areas, or elastomer integrity.

c) Condition of motor head pothead connection area and note if any evidence of fluid tracking.

d) Check for presence and condition of drain/fill valve/plug plug seal washers. If lead gaskets are utilized as sealing element, look for any areas where the lead gasket was not properly deformed (compressed) for a possible leak path or where the lead gasket might have been fully extruded due to being over-tightened.

e) Observation of motor fluid conditions such as clear, dark, or emulsified, metal/brass/debris shavings and record dielectric strength measurements.

f) Results of electrical check of the motor without the pothead connected; and if tandem motors, results of the individual electrical tests of each motor.

g) Condition of thrust bearings and runner face, noting any indication of scoring, smearing, or galling.

h) Observations of any abnormal wear of the head bushing and any signs of damage or leak paths to the O ring (and other seal) sealing area.

i) Signs of galling on the motor head threads.

j) Observations of any physical or electrical damage to the lead wire.

k) Record any visible signs of a burn in the stator and end coils.

l) Condition of rotor string such as straightness, discoloration, signs of warping, and rotor strike.

m) Condition of rotor bearings.

n) Condition of slot liner.

o) Condition of thrust washers for wear and pliability.

p) Dimensional measurements of the rotors and rotor bearings and how they compare to the manufacturer's original specifications.

q) Condition of head and base bushing such as abnormal wear, grooving, or one-sided wear.

r) Condition of all electrical connection points, noting any arcing or burns.

s) Condition of sleeve surfaces, noting any signs of discoloration, wear, and scoring.

t) Observations of oil holes in shaft, noting any signs of plugging.

I.5 Failure cause analysis

I.5.1 General

A failure cause analysis is performed to identify and document the circumstances that led to the failure, that is, the failure cause or root cause. This analysis is normally a series of questions (reason for pull, what was the primary failed item, what was the description of that item, and what was the cause of that failure) which is supplemented with the data collected in I.3 and I.4, helps to arrive at a reasonable root cause.

I.5.2 Reason for pull

The reason for pull is the main evidence of the downhole equipment failure. It is usually a result of an abnormal operating condition as detected by the downhole or surface monitoring systems, or a well test. Table I.1 lists standard industry nomenclature used for documenting general and specific reason for pull.

Table I.1 — Reason for pull nomenclature

Reason for pull: general	Reason for pull: specific	Description
Downhole instrumentation measured/detected	High motor winding temperature	Suspected failure indicated by abnormal downhole instrumentation measurements
	High vibration	
	Low motor oil dielectric capacitance	
	Pump discharge pressure	
Electrical	High current	Suspected failure indicated by abnormal electrical measurements or events such as relay tripping or blown fuses
	High voltage	
	Low current	
	Low impedence/resistance	
	Low voltage	
	Phase unbalance	
	Short circuit	
	Current leakage	
Flow	Low flow to surface	Suspected failure indicated by abnormal flow rate measurements
	No flow to surface	
Maintenance/repair	Casing repair	System pulled to conduct maintenance or repair on the well or on other downhole equipment
	Tubing repair/replacement	
	Sand control repair	
	Other downhole equipment repair/replacement	
	Clean out	
	Proactive ESP replacement	
Recompletion	Change artificial lift method/resize ESP system	System pulled to recomplete the well
	Converting well	
	Change/modify producing zone	
	Stimulation	
	Other	
Suspend	Permanent abandonment	System pulled due to the well being suspended
	Temporary abandonment	
	Shut-in	

Table I.1 *(continued)*

Reason for pull: general	Reason for pull: specific	Description
Other	Other	System pulled due to other reasons
	Economics	
	Logging well	

I.5.3 Primary failed item

The primary failed item is the component responsible for initiating the failure of the ESP assembly. Thus, it is the root failed item in the sequence of interrelated events that lead to an ESP failure. Tracing back this sequence of events and identifying the primary failed item normally requires some in-depth investigation. Table I.2 lists standard industry nomenclature used for documenting primary failed item.

Table I.2 — Primary failed item nomenclature

	Downhole ESP components					
Primary failed item	**Pump and gas handler**	**Intake and mechanical gas separator**	**Seal chamber section**	**Motor**	**Cable, MLE, and pothead**	**Other ESP items**
Sub-components	— Head/discharge — Base/intake — Housing — Shaft — Coupling — Screen — Shaft support bearing — O-rings (and other seals) — Thrust washers — Diffusers — Impellers — Retaining rings — Fasteners	— Head — Base — Housing — Shaft — Coupling — Intake ports/screen — Discharge ports/screen — Radial bearings — Inducers section — Separation section/rotor — Retaining rings — Fasteners	— Head — Base — Housing — Shaft — Coupling — Thrust bearing assembly — Bag/bladder/bellows chamber assembly — Mechanical seals — Relief valves — Labyrinth chamber assembly — O-rings (and other seals) — Motor fluid — Fasteners	— Head — Base — Filter — Housing — Shaft — Coupling — Thrust bearing assembly — Rotor bearing assembly — Stator — Rotors — Motor fluid — O-rings (and other seals) — Retaining rings — Y-point/leads — Fasteners	— Wellhead penetrator assembly — Pigtail — power cable — Packer penetrator — MLE — Splices — Pothead connector assembly — Fasteners	— Downhole sensors/instrumentation — Shroud — ESP assembly — Other ESP system component

I.5.4 Failure descriptor

The failure descriptor is the apparent, observed cause of failure of the primary failed item. These observations are typically made during the pull or dismantle of the ESP component(s). They are the main symptoms or perceptible signs of damage to the ESP components or their subcomponents that might have resulted in the system failure. Table I.3 lists possible failure descriptors for the main ESP components and subcomponents.

Table I.3 — Failure descriptor nomenclature for components and subcomponents

Category	Failure descriptors		Comments
Electrical	— Failed hipot test — High impedance/resistance — Low impedance/resistance	— Open circuit — Short circuit — Phase unbalance	Failures related to the supply and transmission of electrical power.
External	— Coated – external — Coated – internal — Contaminated	— Stuck closed — Stuck open — Plugged	Failures caused by external events or substances, such as paraffin, asphaltene, scale, sand, or iron sulfide
Material	— Brittle — Burn — Corroded — Discoloured — Eroded / pressure washed	— Hardened — Melted — Overheated — Swollen — Worn	Usually related to the physical characteristics of the material such as colour, hardness, or finish.
Mechanical	— Bent — Broken/fractured — Buckled — Burst/ruptured — Collapsed — Cracked — Damaged — Dented — Disconnected — Failed pressure test — Failed vibration test — Faulty clearance or alignment	— Leaking — Loose/spinning — Low efficiency — Punctured — Scratched — Squashed/flattened — Stuck — Torn — Twisted — Vibration/rub marks — Vibration/unbalanced	Usually the result of force, pressure, or torque.
Other	— Maintenance discard — Missing	— Other	

I.5.5 Failure causes

The failure cause is associated with the circumstances during design, manufacture, or use which has led to a failure. Identification of the failure cause normally requires some in-depth investigation to uncover the underlying human or organizational factors as well as the technical cause. Table I.4 lists standard industry nomenclature used for documenting possible causes of failure.

Table I.4 — Nomenclature for possible causes of failure

Failure cause: general	Failure cause: specific		Comments
System design/selection	— Equipment selection — Equipment selection – materials — Improper data used in design/selection	— Equipment selection – pressure capability — Equipment selection – volumetric capacity — System configuration	— Improper system design/selection including use of improper data or errors in calculations — Improper equipment selection — Improper material selection
Manufacturing	— Equipment testing — Fabrication problem	— Materials selection — Quality control — Mechanical design	— Improper mechanical design of parts or components — Improper fabrication or assembly of parts or components — Improper equipment testing or quality control

Table I.4 *(continued)*

Failure cause: general	Failure cause: specific		Comments
Storage and transportation	— Packaging or restraints — Storage	— Transportation	— Improper or inadequate equipment handling during storage or transportation
Installation	— System assembly — Improper well cleanout process — Installation – ESP field service	— Installation – service rig — Reran damaged equipment	— Improper procedures during installation or well preparation — Improper system assembly, including cable splices and flange connections — Improper evaluation or used equipment before reuse
Operation	— Enhanced recovery method or production strategy — Inadequate monitoring	— Operating procedures — Operation of other wells in field — Well treatment	— Improper operating procedures or inadequate monitoring
Reservoir or fluids	— Asphaltene — Bottom hole temperature — Free gas — Sand — Reservoir failure — Corrosive fluids	— Scale — Paraffin — Water cut — High inflow — Low or no inflow	— Unexpected reservoir conditions, leading to 1) plugging by scale, paraffin, asphaltene, sand, or other causes or 2) lower/higher productivity, higher GOR, or water cut — Reservoir fracturing, subsidence, etc.
Completion	— Failure or perforations/liner/openhole — Failure or improper sand control system	— Wellbore completion failure — Non-ESP downhole failure	— Failure of the wellbore completion such as casing, tubing, packer, safety valve, or liner
Other	— Weather/oceanographic — Natural disaster — Power disruption/lightening	— Poor power quality — Surface equipment failure	— Weather, war, terrorist attack — Failure of instrumentation or control
Normal or expected wear and tear	— Normal or expected wear and tear		— Equipment run life met or exceeded run life expectations

Annex J
(informative)

Downhole monitoring of ESP assembly

J.1 General

This annex provides considerations for downhole monitoring of ESP assemblies. Downhole monitoring in this case refers to a gauge that is attached to the ESP system, generally to the motor (at non-drive end), however, sensors and fittings such as, vibration and discharge pressure can be distributed around the ESP system as required to facilitate appropriate measurements. Communication to surface is generally by either dedicated signal line or superimposed on the ESP motor power cable.

Downhole monitoring systems can provide numerous important parameters for evaluating both the well and ESP system performance. Monitoring the downhole parameters shall assist in determining if the ESP is operating within its specified limits. Downhole monitoring systems assist in protecting the pumping system and help ensure the reservoir and completion should deliver to their fullest potential. The data collected from the downhole sensor can be transmitted to a surface control system such as the ASD or a Scada system which can then be used to control the ESP or other surface flow control devices to help maintain a desired downhole production condition.

NOTE Downhole monitoring systems generally require specific surface equipment design to operate with the downhole gauges and this surface equipment might not interchange across gauge manufacturers.

J.2 Downhole gauge typical parameters

The following is a list of typical parameters that are monitored by downhole gauges.

a) Pump intake pressure: this pressure measurement can be used to monitor the static and flowing pressure near the intake of the pump (typically installed at the base of the ESP motor) to allow for well productivity calculation, help maintain ESP operation above a minimum pressure to protect the pump from a pump-off condition and assist with validating PVT assumptions.

b) Pump discharge pressure: this pressure gauge is typically installed with a pump intake pressure gauge. This pressure measurement can be used to monitor the discharge pressure of the ESP during operation to allow for a differential pressure calculation which can be used to evaluate the pump operating conditions. This measurement can also assist in determining if a failure or other flow restriction that has occurred in the production tubing string.

c) Pump intake fluid temperature: this temperature measurement can be used for monitoring various production conditions such as assisting in validating PVT assumptions, fluid viscosity calculations, to provide necessary data for subcool calculations (steam floods/steam assisted gravity drainage), determining production tubing failures which can cause fluid recirculation in the wellbore and changes in operating environment temperature which might have a negative impact on the run life of the ESP system.

d) Pump discharge fluid temperature: this temperature measurement can be used in assisting in determining if free gas is passing through the ESP pump and also to monitor the health of the ESP pump by monitoring changes in the differential temperature across the ESP pump. This measurement can also be used to assisting with validating PVT assumptions.

e) Motor fluid/winding/end coil temperature: this temperature measurement can be used to monitor the internal temperature of the ESP motor to allow for operational control of the ESP motor within its internal temperature limitations. The sensor can provide motor fluid temperature, motor winding or motor end coil temperature or both depending on its design and placement.

f) Vibration: this measurement provides data to enable a trend analysis of ESP vibration at the sensor location over time. It is important to note that, typically, vibration sensors in most ESP downhole monitoring systems are designed to provide a vibration acceleration overall measurement but not vibration spectrums, therefore, the vibration data provided by the sensor can only be used for trending not for detailed vibration condition.

g) Current leakage: this measurement is typically performed by the downhole sensor surface equipment rather than by the downhole gauge itself. This measurement can provide the end user with information regarding the DC current leakage value which can be used to ascertain the electrical integrity of the electrical system.

Annex K
(informative)

Information on permanent magnet motors for ESP applications

K.1 General

This informative annex describes the considerations related to the application of permanent magnet (PMM) motors for ESP applications and is limited to switched DC motors that are constructed with a wound stator and rotors that are constructed using permanent magnets.

K.2 Design and selection considerations

When using a PMM for an ESP application, the following should be taken into consideration during the selection and design of the system.

a) Input power requirements:

- Non-typical ASD or other surface equipment can be required depending on supplier/manufacturer design.
- Power cable length might be a constraint.

b) Output power (torque):

- The PMM operates with torque being directly proportional to current supplied at any given frequency.

c) Operating speed:

- The PMM is a synchronous machine and, therefore, shaft speed is proportional to the rotation of the magnetic field in the stator as a function of the power frequency.
- The PMM can require a specific stator construction depending on the required shaft speed needed for the application.

d) Motor efficiency and heat transfer to the well fluid:

- The current density in the stator can be equivalent to that of a comparable induction motor and, if so, the stator resistive losses should be similar on a length basis.
- Because the PMM stator is shorter than a comparable induction motor, stator core losses can be lower in the PMM.
- There are no resistive power losses in the PMM rotor.
- The PMM rotor generates little heat that should pass through the stator.
- As the PMM design is able to operate efficiently with an increased airgap (space between the ID of the stator and OD of the rotor), the windage (fluid shear) losses in the motor fluid are greatly reduced.

e) Power limitations:

- In a PMM there is no “voltage saturation” level, however, it is possible the motor wire can be overheated to the point of insulation failure due to presence of resistive losses in the motor wire.

— Although there is no rotor saturation, it might be possible to power the stator to a magnetic flux level that would de-magnetize the rotor. Resistive losses would likely result in overheating and winding failure before that could occur.

f) Protection:

— Underload protection: The PMM motor has no “idle saturation” factor so as its loading is reduced, the current shall decrease proportionally. Thus, a PMM by nature shall have a relatively flat power factor curve as opposed to an induction motor which shall have a power factor curve that drastically falls off as its load is decreased. Therefore, it is easier to detect a change in load using amperage with a PMM than a conventional induction motor at low motor loads.

— Motor cooling (fluid flow past motor): As with induction motors, PMM’s require a flow of fluid past the motor for cooling to prevent overheating.

g) PMM system installation and pulling:

— During installation and pulling operations of PMM systems, an electrical safety device or procedure shall be used to protect personnel at surface from any voltage generated by the motor. While installation of a PMM system is similar to the installation of induction motor systems, a PMM can generate higher voltage levels when the shaft is rotated and precautions should be taken to prevent damage to personnel and equipment on the surface. The PMM controller shall also be designed to monitor backspin and alert the operator when it is safe to enter a junction box.

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