



International
Standard

ISO 6398-1

**Oil and gas industries including
lower carbon energy —
Submersible linear motor systems
for artificial lift —**

**Part 1:
Submersible linear motor**

*Industries du pétrole et du gaz, y compris les énergies à faible
teneur en carbone — Systèmes de moteurs linéaires submersibles
pour relevage assisté —*

Partie 1: Moteur linéaire submersible

**First edition
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Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols and abbreviations	4
4.1 Abbreviated terms	4
4.2 Symbols	4
5 Functional specification	5
5.1 General	5
5.2 SLM type description	5
5.3 Functional requirements	5
5.3.1 General	5
5.3.2 Application parameters	5
5.3.3 Environmental compatibility	7
5.3.4 Compatibility with related well equipment and services	8
5.4 User/purchaser selections	8
5.4.1 General	8
5.4.2 Design validation	8
5.4.3 Functional evaluation	8
5.4.4 Quality grades	9
5.4.5 Shipping, handling, and storage	9
5.4.6 Additional documentation or requirements	9
6 Technical specification	9
6.1 General	9
6.2 Design criteria	9
6.2.1 General	9
6.2.2 Design documentation	9
6.2.3 Materials	10
6.2.4 Dimensional information	11
6.2.5 Design verification	11
6.2.6 Design validation	11
6.2.7 Functional evaluation requirements	12
6.2.8 Design changes	12
6.3 Technical specification — SLM	12
6.3.1 General	12
6.3.2 Technical characteristics	12
6.3.3 Performance rating	12
6.3.4 Scaling of design validation	12
7 Supplier's/manufacturer's requirements	12
7.1 General	12
7.2 Documentation information	13
7.2.1 General	13
7.2.2 Delivery documentation	13
7.2.3 Operation's manual	13
7.2.4 Product qualification certificate	14
7.2.5 Product data sheet	14
7.3 Electrical nameplate	14
7.4 Permanent component identification	14
7.5 Quality	14
7.5.1 General	14
7.5.2 Quality grade requirements	15

ISO 6398-1:2024(en)

7.6	Raw materials	15
7.7	Traceability	16
7.8	Calibration systems	16
7.9	Examination and inspection	16
7.9.1	General	16
7.9.2	Weld	17
7.9.3	Dimensional inspection	17
7.10	Manufacturing non-conformity	18
7.11	Functional testing	18
8	Repair/redress	18
9	Shipping, handling, and storage	18
9.1	General	18
9.2	Storage	18
Annex A	(normative) Design validation performance rating requirements	20
Annex B	(normative) Functional evaluation	25
Annex C	(informative) Schematic of the test device	31
Annex D	(informative) Components of the submersible linear motor	34
Bibliography		35

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 document 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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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 4, *Drilling, production and injection equipment*.

A list of all parts in the ISO 6398 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been prepared by users/purchasers and suppliers/manufacturers of submersible linear motors and is intended for use in the petroleum and natural gas industries worldwide. This document provides requirements and information to both parties in the selection, manufacturing, testing and use of submersible linear motors. Further, this document addresses supplier specifications. This document provides the components composition diagram of the submersible linear motor, see [Annex D](#).

This document provides the required levels for design validation, quality control and functional evaluation, allowing the user/purchaser to select each level for a specific application. According to different components, design confirmation is divided into two grades; quality control is divided into two grades; and functional evaluation is divided into two grades. For grades of design validation, quality control and functional evaluation, grade 2 is the lowest grade, and higher grades have additional requirements. The user/purchaser may specify supplementary specifications for these grades.

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Oil and gas industries including lower carbon energy — Submersible linear motor systems for artificial lift —

Part 1: Submersible linear motor

1 Scope

This document provides requirements for the design, design verification and validation, quality control, functional evaluations and storage of submersible linear motor (SLM) systems.

This document is applicable to components of submersible linear motors including stators, movers and motor lead extension cables.

This document also specifies design validation performance rating requirements and functional evaluation for SLM.

Equipment not covered by this document includes pumps and other fittings, power cables and drive systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 10893-4, *Non-destructive testing of steel tubes — Part 4: Liquid penetrant inspection of seamless and welded steel tubes for the detection of surface imperfections*

ISO 10893-5, *Non-destructive testing of steel tubes — Part 5: Magnetic particle inspection of seamless and welded ferromagnetic steel tubes for the detection of surface imperfections*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ASTM E94, *Standard Guide for Radiographic Examination*

ASME BPVC, Section V, *Nondestructive Examination*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

bottom connection of stator

connecting part between the lower end of the *stator* (3.19) and the stator base

3.2

corrosive environment

environment that contains one or more corrosive agents

[SOURCE: ISO 8044:2020, 3.3]

3.3

cushion

terminal buffer for the *mover* (3.9) of a linear motor

3.4

design validation

process of proving a design by testing to demonstrate conformity of the product to design requirements and performance ratings

[SOURCE: ISO 15551:2023, 3.39]

3.5

design verification

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

[SOURCE: ISO 15551:2023, 3.40]

3.6

maximum operating temperature

maximum ambient temperature at which the *submersible linear motor* (3.26) can be operated as specified by the supplier/manufacturer

3.7

motor lead extension cable

cable connected to the *pothead* (3.13) for splicing to the power cable

3.8

motor linear velocity

displacement of *mover* (3.9) running per unit time

3.9

mover

shaft-shaped component of the *submersible linear motor* (3.26) that carries on the back and forth movement in an operation

3.10

mover base

components with function of supporting the *mover* (3.9)

3.11

mover short joint

joints between *mover* (3.9) subs

3.12

mover straightness

maximum deviation distance between the *mover* (3.9) surface and the horizontal plane

3.13

pothead

power connector on the end of the *motor lead extension cable* (3.7) or power cable which mates to the motor

[SOURCE: ISO 15551:2023, 3.105]

3.14

qualified person

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

[SOURCE: ISO 15136-1:2009, 3.49]

3.15

rated power

output power of the *submersible linear motor* (3.26) under *rated voltage* (3.17), *rated current* (3.18) and *rated thrust* (3.16)

Note 1 to entry: Rated power is expressed in kW.

3.16

rated thrust

maximum *thrust* (3.27) value of the *submersible linear motor* (3.26) for long-term stable operation

3.17

rated voltage

optimal voltage of the *submersible linear motor* (3.26) for long-term stable operation

3.18

rated current

optimal current of the *submersible linear motor* (3.26) for long-term stable operation

3.19

stator

component of the *submersible linear motor* (3.26) that is usually composed of *stator core* (3.20), *stator electromagnetic winding* (3.21), inner cylinder and housing

Note 1 to entry: Generally, the *stator core* (3.20) and the *stator winding* (3.21) are placed in the oil filled sealing cavity composed of the inner cylinder and the shell.

Note 2 to entry: When the *submersible linear motor* (3.26) works, the stator remains stationary.

3.20

stator core

component of the *stator* (3.19) comprised of multiple steel lamination sheets through which copper or other electrical conducting material is wound and laminated to reduce eddy current loss

3.21

stator winding

conductive wire threaded through the *stator core* (3.20)

3.22

stator end cover

end cover at each end of a *stator* (3.19) sub

3.23

stator lead connector

lead connector of the series windings of the *stator* (3.19) of a *submersible linear motor* (3.26)

3.24

stator limit short section

joint that limits the *stator* (3.19) of a *submersible linear motor* (3.26)

3.25

stroke

maximum linear displacement of the *mover* (3.9) during operation

3.26

submersible linear motor

SLM

motor that directly converts electrical energy into mechanical energy for the linear motion needed to drive the plunger pump to do reciprocating work in a well

3.27

thrust

longitudinal acceleration force or deceleration force generated during operation of the *submersible linear motor* (3.26)

[SOURCE: IEC 62520-2011, 3.14]

3.28

top connection of mover

connecting part between the upper end of a *mover* (3.9) and the polished rod of a plunger pump

3.29

top connection of stator

uppermost connection part of the *stator* (3.19) sub in series

3.30

unique identifier

unique combination of alphanumeric characters to identify a specific component

[SOURCE: ISO 15136-1:2009, 3.70]

4 Symbols and abbreviations

4.1 Abbreviated terms

AWG American wire gauge

MD measured depth

NDE non- destructive examination

TVD true vertical depth

4.2 Symbols

K constant, is 234,5 for copper conductor

R_{UV} resistance value measured between U and V terminals of the winding

R_{VW} resistance value measured between V and W terminals of the winding

R_{WU} resistance value measured between W and U terminals of the winding

R_{med} sum of the three phase DC resistances

R_U U phase resistance of the winding

R_V V phase resistance of the winding

R_W W phase resistance of the winding

R_{mav} average of the three phase DC resistances

R	single phase resistance of the winding
ε_{mR}	imbalance rate of the three-phase DC resistance
$R_{\max}$	maximum value in R_U , R_V , R_W
$R_{\min}$	minimum value in R_U , R_V , R_W
R_f	resistance of the winding at the time of motor de-energization
R_b	resistance of the winding before the test is started at a known stable temperature
T_{av}	average winding temperature rise
T_b	temperature at the time R_b is taken
T_f	temperature at the time R_f is taken

5 Functional specification

5.1 General

The user/purchaser shall prepare a functional specification to order products that conform to this document and shall specify the requirements and operating conditions as appropriate. The user/purchaser shall specify the units of measurement for the data provided. This information is used by the supplier/manufacturer to recommend the SLM.

SLM is designed for specific applications, when used in a new/different application, re-evaluation is required to ensure that the system works properly. The process used for this re-evaluation shall be no less stringent than that required for the initial application.

5.2 SLM type description

The user/purchaser shall request a SLM on the basis of the production requirements.

5.3 Functional requirements

5.3.1 General

The user/purchaser shall specify the known and anticipated application parameters and requirements. Operational issues that can have an effect on the systems operation and durability, such as rated power, rated voltage, rated current, rated thrust, stroke, minimum and maximum strokes per minute and other issues, shall also be specified.

5.3.2 Application parameters

5.3.2.1 General

While installed, the SLM system shall perform in accordance with its functional requirements, which are typically determined based on application parameters. These parameters include, but are not limited to, those listed in [5.3.2.2](#) to [5.3.2.3](#).

5.3.2.2 Well information

5.3.2.2.1 Requirement

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

- a) operating environment, such as corrosive environment of downhole heavy oil and conventional oil production applications;
- 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 or shale;
- e) reservoir recovery mechanism or process, such as water flooding, thermal recovery;
- f) production information, such as but not limited to fluid production, minimum expected well fluid flow rate, maximum expected bottom temperature, oil pressure, and casing pressure;
- g) existing or planned power supply details, such as generator/utility power, volts, frequency, kVA/Amp supply limitations;
- h) service-life expectation, such as days and repair cycle.

5.3.2.2.2 Supplemental Information

The following well information shall be specified, if available:

- a) well profile, such as inclination, "S shaped" and "U shaped";
- b) pertinent production history using SLM and other methods, such as other artificial lift methods or natural flow;
- c) anticipated sand production rate;
- d) potential for anticipated downhole wax formation;
- e) potential for anticipated downhole scale formation, including radioactive scales.

5.3.2.3 Completion information

5.3.2.3.1 Requirement

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

- a) proposed SLM setting depth in terms of MD and TVD of the upper end of the SLM mover;
- b) existing or planned total well depth, such as plug back depth in terms of MD and TVD;
- c) depth of producing intervals, top and bottom, in terms of MD and TVD;
- d) casing/liner size including outside diameter and mass, connection type and grade of production casing;
- e) minimum drift diameter through wellhead to bottom of the SLM assembly;
- f) production tubing size including outside diameter, mass, connection type, and grade;
- g) completion type, such as perforated casing or open hole.

5.3.2.3.2 Supplemental information

If a well deviation survey is not provided, it shall include, as a minimum, the following information:

- inclination and estimated dogleg severity at SLM setting depth;
- maximum dogleg severity between wellhead and setting depth for each casing or liner segment that the SLM has to pass through during installation.

5.3.3 Environmental compatibility

The user/purchaser shall specify the environmental compatibility requirements and preferred fluid property correlations by providing the following parameters:

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) CO₂ concentration (mole percentage);
 - ii) H₂S concentration (mole percentage);
- 2) specific gravity.

d) other:

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

Example of parameter tables that should be provided are shown in [Table 1](#).

Table 1 — Example of parameters should be provided when the user/buyer specifies environmental compatibility

oil		water		gas		other	
density	20 °C, 0,83 g/cm ³	pH	7,34	composition	CO ₂ : 12,79 %	composition	completion fluid 8,9 %
viscosity	50 °C, 12,3 MPa·s	density	0,9 g/cm ³		H ₂ S: 2,3 %		
bubble point pressure	13,3 Mpa	chloride concentra- tion/salinity	877 mg/l		other:		
solution gas-oil- ratio	200			specific gravity	0,892 5		

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 SLM conforms to the intended application.

5.3.4.2 Accessory equipment and well operation

The following topics shall be considered for the application:

- a) plunger pump: connection type with SLM, size and thread, etc.;
- f) dimension of chemical injection tubing/string line and injection point, such as above SLM, below SLM, annulus, tubing string;
- c) well intervention limitations, such as maximum allowable SLM length, maximum coiled tubing diameter;
- d) packer, location in the wellbore relative to SLM.

5.4 User/purchaser selections

5.4.1 General

The grades can vary by SLM as selected by the user/purchaser. General requirements and guidance on the selections available are provided in [5.4.2](#), [5.4.3](#) and [5.4.4](#).

5.4.2 Design validation

The user/purchaser shall specify one of the following two design validation grades as defined in [Annex A](#):

- V1: high grade;
- V2: basic grade.

5.4.3 Functional evaluation

The user/purchaser shall specify one of the following two functional evaluation grades as defined in [Annex B](#):

- F1: high level;
- F2: basic level.

5.4.4 Quality grades

The user/purchaser shall specify one of the following two quality grades as defined in [Clause 7](#).

- Q1: high level of quality;
- Q2: basic level of quality.

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.

5.4.6 Additional documentation or requirements

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

6 Technical specification

6.1 General

The supplier/manufacturer shall prepare a technical specification, which responds to the requirements in the functional specification set forth by the user/purchaser or which identifies in detail where variance(s) to the requirements in the functional specification exist or are offered.

The technical specification comprises three classes of information relating to obligation for disclosure of these documents by the supplier/manufacturer to the user/purchaser.

- Public information: this information should be identified as such and provided without restrictions (e.g. an ASTM material specification and published performance curves).
- Confidential information: this information should be identified as such (e.g. an engineering drawing) and may be either provided or made available for inspection.
- Trade secrets: this information should be identified as such (e.g. a secret formula or process); there is no obligation to disclose it to the user/purchaser.

The timing of disclosure may be governed by agreement between the supplier/manufacturer and the user/purchaser, considering the development time required. The documentation and disclosure requirements of this clause are separate from the requirements of other (sub)clauses, e.g. [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 document to be invalidated. The evidence supporting this shall be documented by the supplier/manufacturer.

6.2 Design criteria

6.2.1 General

The supplier/manufacturer shall demonstrate conformity to the design basis and performance rating(s) of the component as per [6.2.5](#) and [6.2.6](#). Manufacturing requirements are detailed in [Clause 7](#).

6.2.2 Design documentation

Documentation of the design process for SLM shall at least include:

- a) design criteria;

- b) engineering drawings and bill of materials;
- c) validation testing procedures, acceptance criteria, and approved results;
- d) design changes and design change justifications;
- e) technology readiness level assessment document.

6.2.3 Materials

6.2.3.1 General

Metallic materials such as mover, stator and lead extension cable of SLM shall be as specified in this document; non-metallic materials can be implemented according to other relevant documents. All materials shall be specified by the supplier/manufacturer and shall be appropriate for the requirements in the functional specification. The supplier/manufacturer shall have documented specifications for all materials in critical subcomponents. All materials used shall conform with these specifications.

Critical subcomponents should at least include: stator core, stator housing, stator winding, motor lead extension cable, mover and top connection of mover.

The supplier's/manufacturer's specifications shall define for metallic materials (if applicable):

- a) chemical composition;
- b) mechanical property:
 - tensile strength;
 - yield strength;
 - hardness;
 - residual stress;
- c) electrical properties:
 - 1) resistivity or conductivity;
 - 2) insulating property;
 - 3) high temperature resistance;
- d) magnetic properties:
 - 1) magnetic permeability;
 - 2) core loss.

The mover shall be of sufficient strength that the profile and connection can withstand the combined torsional and axial loads within the specified operational range. The material strength shall be reconsidered for the special application. The resulting design verification shall be approved by a qualified person.

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

6.2.3.2 Welds

Welds shall be specified appropriate to the material, function, and service of the component and/or assembly; and weld identification and examination shall be in accordance with the specified quality grade. Requirements shall be in accordance with the supplier/manufacturer's specifications as defined in [Clause 7](#).

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. Coatings and surface treatments addressed by this subclause are limited to those that provide performance enhancements for erosion, anti-friction and corrosion of subcomponent materials, which are designed to be in direct contact with production fluids as specified in the design basis. The supplier's/manufacturer's specifications shall specify, where applicable, the characteristics and acceptance criteria of the coatings or surface treatments including but not limited to:

- a) basic coating type and surface treatment composition;
- b) corrosion resistance;
- g) effective surface hardness;
- h) minimum and maximum coating thickness;
- i) roughness.

6.2.4 Dimensional information

Dimensional information shall be provided for the SLM supplied. Analysis may be required to calculate stress in deviated or severely curved wells.

The supplier/manufacturer shall specify:

- a) maximum OD of the SLM;
- b) total length and mass of the SLM;
- c) maximum inclination and dogleg severity that can maintain SLM normal operation at SLM setting depth.
- d) dimension information and connection type of the motor lead extension cable;
- e) schematic diagram of components including dimension information for external fittings.

Dimensional information of the motor lead extension cable shall at least include the nominal cross-sectional area of the conductor (in mm²) and AWG.

6.2.5 Design verification

Design verification shall be performed by the supplier/manufacturer to verify that the product design conforms to the supplier's/manufacturer's design basis. Design verification activities are conducted to ensure that the design outputs meet the design basis input requirements. Design verification includes documented activities, such as review of design calculations, product testing and comparison with similar designs and historical records of defined operating conditions. Empirical methods and/or physical testing used in design verification shall be fully documented and supported with drawings and material specifications. All design verification documentation shall be included in the product design file and shall be approved by a qualified person other than the design's originator.

6.2.6 Design validation

Design validation testing shall be performed to verify that the SLM design conforms to the performance rating as per [Annex A](#). Design validation activities are conducted to ensure the component performance meets the intended application or use as defined by the supplier's/manufacturer's design basis. 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](#), which provides a detailed description of the two validation grades (V1 and V2) in this document. [Annex C](#) provides the schematic of the machine performance test device for reference during the design validation process.

6.2.7 Functional evaluation requirements

Functional evaluations shall be performed in accordance with [Annex B](#) and shall be approved by a qualified person to verify that each SLM meets the supplier's/manufacture's documented requirements. The results of these evaluations shall be documented and shall become a portion of the quality documentation for the product. [Annex C](#) provides the schematic of the high temperature resistance test device and the hydrostatic test device for reference during the functional evaluation process.

6.2.8 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 design change. A substantial design change is a change to the design identified by the supplier/manufacture that affects the performance of the product in the intended service condition. A design that undergoes a substantive design change becomes a new design requiring design verification as specified in [6.2.5](#) and design validation as specified in [6.2.6](#).

6.3 Technical specification — SLM

6.3.1 General

The SLM shall be compatible with related well equipment and services as defined in [Clause 5](#).

While installed and operated in accordance with the functional specification, the SLM shall perform in accordance with the functional specification.

The supplier/manufacture shall prepare the technical specification for the SLM that responds to the functional requirements.

The supplier/manufacture shall provide to the user/purchaser the data as defined in [7.2](#).

6.3.2 Technical characteristics

The SLM shall convert input electrical power to mechanical energy for the linear motion needed to drive the mover to do the reciprocating work at the required design stroke, strokes per minute and thrust.

6.3.3 Performance rating

The supplier/manufacture shall provide the following performance characteristics in accordance with [Annex A](#):

- a) rated thrust;
- b) imbalance rate of the DC resistance of the winding;
- c) winding temperature rise;
- d) minimum and maximum strokes per minute.

6.3.4 Scaling of design validation

The design of the SLM shall not be scaled.

7 Supplier's/manufacture's requirements

7.1 General

This clause contains the detailed requirements to verify that each component manufactured meets the requirements of the technical specifications. Design validation performance rating requirements by component are addressed in [Annex A](#).

7.2 Documentation information

7.2.1 General

The supplier/manufacturer shall establish and maintain documented information that relates to the requirements of this document. Documented information shall be maintained to demonstrate conformity to specified requirements. All documented information shall be legible and may be in any type of media, such as hard copy or electronic.

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

Design documents (see 6.2.2), data and component data sheet(s) shall be retained for 10 years after date of last manufacture of that component.

Delivery and manufacturing related documentation shall be retained 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 at least include:

- a) name and address of the supplier/manufacturer;
- b) product identification;
- c) dimension and mass of the product;
- d) functional evaluation documentation according to the specified functional grade;
- e) quality documentation according to specified quality grade;
- f) design validation grade;
- g) type of motor oil inside the stator;
- h) electrical nameplate information.

7.2.3 Operation's manual

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

- a) product illustration, indicating the main components and important dimensions of the submersible linear motor;
- b) handling and storage guidelines;
- c) installation and removal guidelines;
- d) operating and troubleshooting guidelines, including precautions for safe and environmentally acceptable operation;
- e) maintenance guidelines;
- f) safety guidelines.

7.2.4 Product qualification certificate

When required by the quality grade or the user/purchaser, product qualification certificates shall be supplied. The product qualification certificate shall state that the product meets the following requirements:

- a) quality grade;
- b) design validation grade;
- c) functional evaluation grade;

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

7.2.5 Product data sheet

When required by the quality grade or the user/purchaser, a component data sheet shall be supplied, and shall provide the following information:

- a) quality grade;
- b) design validation grade;
- c) functional evaluation grade;
- d) rated power;
- e) rated voltage;
- f) rated current;
- g) rated thrust;
- h) maximum operating temperature;
- i) stroke;
- j) minimum and maximum strokes per minute;
- k) motor linear velocity;
- l) critical dimensions (see [7.9.3](#));
- m) connection type to the motor lead extension cable, such as tape-in or plug-in.

7.3 Electrical nameplate

The SLM should have a nameplate made of durable materials or engraved on the stator housing. The nameplate information should include at least the rated voltage in volts, the rated load current in amperes, the frequency, the power factor (PF), the service factor (SF), strokes per minute (SPM), the number of phases, horsepower to kilowatts (HP/kW) output, and the frame size if pertinent.

7.4 Permanent component identification

Important components shall be permanently marked with the unique identifier.

7.5 Quality

7.5.1 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's/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 subcomponent supplied as conforming to the requirements of this document.

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

7.5.2 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. 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](#), subcomponent by defining sample size refers to the percentage of subcomponents to be inspected per heat or batch lot with a minimum of 1 %. Where the percentage of subcomponents 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.

Conformity 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 in accordance with this document.

Table 2 — Quality grade requirements summary for SLM

property	Q2	Q1
Material certificate (see 7.6)	Per supplier/manufacturer	100 % of subcomponents excluding: — common hardware — process materials — shipping materials/ equipment
Dimensional inspection (see 7.9.3)	Per supplier/ manufacturer	Critical dimensional inspection
Welds (see 7.9.2)	Visual inspection as per 7.9.2.2	Non-destructive examination for 100 % of components as per 7.9.2.3 , 7.9.2.4 , 7.9.2.5 or 7.9.2.6 or 7.9.2.7
Documentation (see 7.2)	Per supplier/manufacturer	product qualification certificate, operator's manual, product date sheet
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/subcomponents (not including common hardware) and not 100 % of the component/subcomponent itself (such as surface area).		

7.6 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 conformity to the chemistries and properties defined in the supplier's/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.

7.7 Traceability

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

For Q2 quality grade, traceability shall be in accordance with supplier's/manufacture's documented procedures. For Q1 quality grade, all subcomponents 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 components shall allow for traceability of the component 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 document when it leaves the supplier/manufacturer's inventory.

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. The supplier's/manufacture's procedures shall be based on ISO/IEC 17025. See also ANSI/NCSL Z540.3

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

Calibration intervals shall be established based on repeatability and degree of usage. Intervals may be lengthened or shortened based on documented repeatability, amount of usage and calibration history, but the interval shall not exceed one year.

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 conformity to the defined acceptance criteria. Each measured parameter shall be documented 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 shall be 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/manufacture or user/purchaser, NDE and inspections shall be performed and accepted according to the supplier's/manufacture's documented specifications. The supplier's/manufacture's documented specifications shall include the requirements defined in this subclause and acceptance criteria.

NDE instructions shall be detailed in the supplier's/manufacture's documented procedures and conform with this document. All NDE instructions shall be approved by a qualified ISO 9712 Level II examiner and performed by a qualified person. Personnel performing and accepting NDE shall be qualified in accordance with the supplier's/manufacture'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.

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 subclause.

7.9.2.2 Visual inspection

All visible welds shall be visually inspected and documented 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.

The implementation of visual inspection requires documented procedures that include specific acceptance criteria and with approved and documented results. Visual inspection requires that 100 % of the accessible/visible surfaces to be inspected.

7.9.2.3 Radiographic inspection

Radiographic inspections shall meet the requirements of ASTM E94.

7.9.2.4 Ultrasonic inspection

Ultrasonic inspections shall meet the requirements of ASME BPVC, Section V, Article 5.

7.9.2.5 Magnetic particle inspection

Magnetic particle inspections shall be in accordance with ISO 10893-5. See also ASTM E709.

7.9.2.6 Liquid-penetrant inspection

Liquid-penetrant inspections shall be in accordance with ISO 10893-4. See also ASTM E165.

7.9.2.7 Gas-penetrant inspection

Gas-penetrant inspections shall meet the requirements of ASME BPVC, Section V, Article 5.

7.9.3 Dimensional inspection

7.9.3.1 General

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

7.9.3.2 Critical dimensional inspection

The supplier/manufacturer shall have documented procedures performed by qualified personnel for the critical dimension(s) to ensure conformity with the supplier's / manufacturer's design criteria and specifications prior to final assembly documentation of the final measurements shall be provided to the user/purchaser.

Critical dimensional features shall at least consist of the following:

- a) mover straightness;

- b) cylindricity of mover permanent magnet and spacer ring;
- c) mover OD;
- d) thread of the short connection on the mover;
- e) maximum OD of the SLM;
- f) total length of the SLM;
- g) length and diameter of the motor lead extension cable;
- h) dimensions of external connectors.

7.9.3.3 Other dimensional inspection

The supplier/manufacturer may deem other dimensions to be critical based on the unique nature of the design.

7.10 Manufacturing non-conformity

The supplier/manufacturer shall establish and maintain documented procedures to ensure that a component that does not conform to specified requirements is prevented from being delivered or installed. This control shall provide for the identification, evaluation, documentation and disposition of a non-conforming component.

Non-conforming components or subcomponents dispositioned for rework shall be reinspected to the same requirements as the original component or subcomponent. Non-conforming components or subcomponents dispositioned for use as-is are acceptable for Q2 quality grades provided that the dispositioned component or subcomponent is evaluated and approved by a qualified supplier/manufacturer person. Responsibility for review and authority for disposition of non-conforming components and subcomponents shall be defined by the supplier's/manufacturer's documented procedures.

7.11 Functional testing

Functional evaluation testing shall be successfully performed by the supplier/manufacturer on each SLM manufactured. Functional test results shall be documented, dated, and signed by qualified personnel performing the test. The testing details and acceptance criteria shall be defined by the supplier's/manufacturer's documented procedures. Functional evaluation testing shall conform to requirements of [Annex B](#).

8 Repair/redress

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

9 Shipping, handling, and storage

9.1 General

SLM shall be handled, stored and shipped according to the documented processes and specifications of the supplier/manufacturer to prevent contamination of the equipment and damage from normally anticipated loads.

9.2 Storage

SLM products shall be stored in accordance with the requirements provided in the product operator's manual to prevent damage to the product.

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

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

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

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Annex A (normative)

Design validation performance rating requirements

A.1 General

This annex defines the validation grade requirements which include multiple individual validation procedures(s), process(s) and test(s) and provides the supplier/manufacture requirements for establishing the performance ratings as defined in [Clause 6](#). The supplier/manufacture shall document the validation test procedures and results in a design validation file conforming to the requirements of [7.2](#). The design validation 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 the design validation requirements of this document have been met. All testing shall be performed to conform to the requirements of [Clause 7](#) and the document procedures that 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 document provides two grades of design validation for the SLM:

- V1: Highest grade – satisfies the applicable functional, technical and manufacturing requirements of this part of 6398-1. The V1 design validation file shall include all the design validation requirements, methods, calculations and test results used to validate the design.
- V2: Basic grade – satisfies the applicable functional, technical and manufacturing requirements of this part of 6398-1. The V2 design validation file has no specific requirements of the design validation requirements, methods, calculations and test results used to validate the design. Validation grade V2 is a designation provided to accommodate that documentation of design validation of the applicable component may be determined from previously documented experience gained from manufacture of a component and/or internal design basis documentation.

Products 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 listed in [Table A.1](#).

Table A.1 — Design validation performance rating requirements

Requirement	V2	V1
Rated thrust	Per supplier/manufacture	As per A.3.1
Winding temperature rise	Per supplier/manufacture	As per A.3.3
Imbalance rate of the DC resistance of the winding	Per supplier/manufacture	As per A.3.2

A.3 Method for determining performance ratings

A.3.1 Rated thrust

A.3.1.1 General

The supplier/manufacture shall provide the rated thrust of SLM according to the functional requirements and operating conditions specified in the functional specification.

The rated thrust may be validated in accordance with the test method provided in this subclause. If any other method of validation is used, the supplier/manufacture shall reach an agreement with the user/purchaser and provide documented information on the validation process.

A.3.1.2 Method

- a) To perform the SLM rated thrust test, as shown in [Figure C.4](#), first connect the SLM mover to the thrust sensor and then connect it to the thrust detection device through the connector. Then lower the temperature sensor into the simulated well after tying it tightly in the middle of the SLM.
- b) Inject circulating water into the simulated well at the minimum expected flow speed provided by the user/purchaser.
- c) Start the SLM and thrust loading device according to the strokes per minute specified by the user/purchaser, and gradually increase thrust after stable operation. When it reaches the rated thrust given by the supplier/manufacture, operate the device for 2 h. If the rated thrust is not reached when it comes to SLM's upper limit, the test stops.
- d) Continue to increase thrust until the SLM can no longer push.

A.3.1.3 Documentation and reporting

The following testing information shall be documented:

- a) location of the test;
- b) date of the test;
- c) qualified person performing testing;
- d) test data results.

A.3.1.4 Test results

Test results shall be reviewed and approved by a qualified person other than the originator. This test shall confirm that, as a minimum, all the design validation requirements of the rated thrust have been met the requirements of purchaser/user.

According to the test method in this subclause, the thrust under stable state shall not be less than the requirements of the purchaser/user for SLM rated thrust.

A.3.2 Imbalance rate of the DC resistance of the winding

A.3.2.1 General

The supplier/manufacture shall provide the imbalance rate of the DC resistance of the winding according to the functional requirements and operating conditions specified in the functional specification.

The imbalance rate of the DC resistance of the winding may be validated in accordance with the test method provided in this subclause. If any other method of validation is used, the supplier/manufacture shall reach an agreement with the user/purchaser and provide documented information on the validation process.

A.3.2.2 Method and calculation

A.3.2.2.1 General

The DC resistance of the winding shall be measured in the actual cold state (the testing SLM shall be placed indoors, so that the temperature difference between the winding temperature and the room shall not exceed 2 K).

A.3.2.2.2 Method

The validation test shall be performed using the following procedure:

- check the appearance of the motor lead extension cable for damage;
- applicable resistance tester shall be selected according to the DC resistance of SLM winding;
- measure the resistance of each two terminals of the motor lead extension cable respectively, when measuring, the mover of the motor should be stationary.

NOTE The DC resistance of the winding test in other tests can be measured at other temperature states according to the specific test requirements.

A.3.2.2.3 Calculation

The validation calculations should be performed using the following procedure:

- The sum of three-phase DC resistances in ohms (Ω) shall be calculated according to [Formula \(A.1\)](#).

$$R_{\text{med}} = \frac{R_{UV} + R_{VW} + R_{WU}}{2} \quad (\text{A.1})$$

- The three-phase DC resistance in ohms (Ω) shall be calculated according to [Formula \(A.2\)](#).

$$\begin{aligned} R_U &= R_{\text{med}} - R_{VW} \\ R_V &= R_{\text{med}} - R_{WU} \\ R_W &= R_{\text{med}} - R_{UV} \end{aligned} \quad (\text{A.2})$$

- The average of the DC resistances of the three terminals in ohms (Ω) shall be calculated according to [Formula \(A.3\)](#).

$$R_{\text{mav}} = \frac{R_{UV} + R_{VW} + R_{WU}}{3} \quad (\text{A.3})$$

- The winding in ohms (Ω) shall be calculated according to [Formula \(A.4\)](#).

$$R = \frac{1}{2} R_{\text{mav}} \quad (\text{A.4})$$

- The imbalance rate of the DC resistance of the winding in per cent shall be calculated according to [Formula \(A.5\)](#).

$$\varepsilon_{\text{mR}} = \frac{R_{\text{max}} - R_{\text{min}}}{R} \times 100 \% \quad (\text{A.5})$$

A.3.2.3 Documentation and reporting

The following testing information shall be documented:

- location of the test;

- b) date of the test;
- c) qualified person performing testing;
- d) ambient temperature of test;
- e) DC resistance of the three-phase winding and calculated value of imbalance rate.

A.3.2.4 Test results

Shall be reviewed and approved by a qualified person other than the originator. This test shall confirm that, as a minimum, all the design validation requirements of the DC resistance of the winding have been met the requirements of purchaser/user.

In general, the imbalance rate of the DC resistance of the winding measured according to this test method shall not be less than the requirements of the purchaser/user.

A.3.3 Winding temperature rise

A.3.3.1 General

The supplier/manufacturer shall provide the winding temperature rise according to the functional requirements and operating conditions specified in the functional specification.

The winding temperature rise may be validated in accordance with the test method provided in this subclause. If any other method of validation is used, the supplier/manufacturer shall reach an agreement with the user/purchaser and provide documented information on the validation process.

A.3.3.2 Method and calculation

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.

The validation test shall be performed using the following procedure.

- a) In accordance with [Figure C.4](#), the mover is connected to the thrust sensor, then connected to the thrust testing device, and then put into the testing well.
- b) The first resistance measurement shall be taken before the SLM is energized and loaded. The winding resistance may 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.
- c) Inject circulating water into the simulated well at the minimum expected flow speed provided by the user/purchaser.
- d) Start the SLM and the thrust loading device according to the working conditions specified by the buyer/user. After the operation is stable, start to increase the thrust gradually. When the rated thrust given by the user/purchaser is reached, stop increasing the thrust. After the operation is stable for 1 hour, record the test fluid temperature once every half an hour. When the temperature rise is less than 1 K every half hour, or less than 2 K every hour, record the temperature of the test fluid again, and power off the SLM. When the SLM loses power, the timing device starts. Within 15 s after the SLM stops working or within 1 min after the SLM is powered off (whichever comes first), record the first resistance reading and the elapsed time;
- e) 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 shall be maintained constant in the test loop after de-energizing the motor.

- f) 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 rise shall then be determined according to [Formula \(A.6\)](#).

$$T_{av} = [(R_f - R_b) / R_b \times (K + T_b)] - (T_f - T_b) \quad (A.6)$$

A.3.3.3 Documentation and reporting

The following testing information shall be documented:

- a) location of the test;
- b) date of the test;
- c) qualified person performing testing;
- d) fluid temperature of test;
- e) resistance temperature rise curve drawn after the test;
- f) temperature rise values calculated from the curve and measurement

A.3.3.4 Test results

Test results shall be reviewed and approved by a qualified person other than the originator. This test shall confirm that, as a minimum, all the design validation requirements of the winding temperature rise have been met the requirements of purchaser/user.

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Annex B (normative)

Functional evaluation

B.1 General

This annex contains requirements for the functional evaluation procedures that verify the ability of a SLM to conform to the functional specification. Two functional grades are defined, the user / purchaser shall select the required functional evaluation grade(s).

All testing shall be in accordance with the supplier's/manufacture's documented procedures and shall be performed by a qualified person. This testing shall be performed prior to delivery and/or transfer of ownership to the user/purchaser. Test parameters, acceptance criteria and test sequence shall also be agreed upon by user/purchaser and supplier/manufacture prior to performing functional evaluation.

All testing shall be performed to conform to the requirements of [Clause 7](#), and to document procedures which include acceptance criteria with the results approved by a qualified person.

Qualified to higher grades of functional evaluation shall be considered qualified for lower grades of functional evaluation.

B.2 Functional evaluation grades of the SLM

The user/purchaser shall specify the functional evaluation grades of the SLM detailed in [Table B.1](#). Two functional evaluation grades defined by this document:

- F1: high level;
- F2: basic level.

Table B.1 — Functional evaluation grades

	F2	F1
Insulation resistance test,	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per B.3
AC resistance voltage test	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per B.4
High temperature resistance test	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per B.5
Hydrostatic testing	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per B.6

B.3 Insulation resistance test

B.3.1 General

This clause specifies the requirements for the procedures, documentation and reporting, test results of the SLM insulation resistance test.

Insulation resistance test is a conventional test used to evaluate the insulation performance of SLM. Insulation resistance test is usually performed to achieve the following purposes:

- a) evaluate the quality of SLM produced;
- b) verify the safety requirements of procedures and standards;
- c) check whether there is a failure in the SLM or determine the failure cause(s).

B.3.2 Testing procedures

- a) Select the megger according to the operating voltage of the SLM in [Table B.2](#).

Table B.2 — Megger specifications expressed in Volts (V)

The operating voltage of the SLM	Megger specifications
<500	500
500 to 3 000	1 000
>3 000	2 500

- b) Test the insulation resistance of any phase to the housing or the conductor connected with the housing.
- c) The winding shall be discharged to earth after testing.

B.3.3 Documentation and reporting

The following testing information shall be documented:

- a) location of the test;
- b) date of the test;
- c) qualified person performing testing;
- d) description of the SLM, including type, serial number and rated voltage;
- e) ambient temperature and humidity of the test;
- f) testing voltage and insulation resistance values.

B.3.4 Test results

Unless otherwise agreed between the user/purchaser and supplier/manufacturer, the insulation resistance shall be more than 1,000 M Ω under 25 °C, the insulation resistance measured at other temperature shall be in accordance with the conversion coefficient in [Table B.3](#).

Table B.3 — Temperature coefficients of SLM insulation resistance at different temperatures

Temperature, °C	Temperature coefficient
100	188
90	94
80	47
70	23,5
60	11,8
50	5,6
If the insulation resistance value is measured at a temperature exceeding 100 °C, temperature coefficient should be determined in accordance with the requirements of the user/purchaser.	
NOTE The insulation resistance measured at a certain temperature is multiplied by the temperature coefficient to obtain the corresponding insulation resistance value at 25 °C.	

Table B.3 (continued)

Temperature, °C	Temperature coefficient
40	2,8
30	1,4
25	1
20	0,76
10	0,395
0	0,183
If the insulation resistance value is measured at a temperature exceeding 100 °C, temperature coefficient should be determined in accordance with the requirements of the user/purchaser.	
NOTE The insulation resistance measured at a certain temperature is multiplied by the temperature coefficient to obtain the corresponding insulation resistance value at 25 °C.	

B.4 AC voltage withstand test

B.4.1 General

This clause specifies the requirements for the procedures, documentation and reporting, test results of the SLM AC voltage withstand test.

The purpose for the AC voltage-withstand test is to evaluate the ability of the SLM to withstand overvoltage.

B.4.2 Testing procedure

- testing voltage: 1 000 V plus twice the input voltage; and the minimum voltage is 1 500 V;
- connect all motor lead extension cable terminals with wires in the phase-to-phase sequence: A-B, B-C, and C-A; ground the motor housing, and then connect one terminal from the motor lead extensions and the motor housing to the two terminals of the AC voltage test instrument, respectively;
- connect the mover and other non-test parts with the housing;
- the voltage shall start at less than half of the test voltage and be increased at a rate of no more than 5 % of the full test voltage to the full test voltage; the time for the voltage to increase from half value to full value shall be no less than 10 s; and the full value test voltage shall be hold for 1 min.
- when the voltage is reduced to zero, the insulation resistance test shall be carried out in accordance with [B.5.2](#).

B.4.3 Documentation and reporting

The following testing information shall be documented:

- location of the test;
- date of the test;
- qualified person performing testing;
- testing instrument;
- testing voltage and holding time;
- ambient temperature and humidity of the test;
- insulation resistance value and testing voltage.