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Liquefied Natural Gas Cryogenic Submersible Pumps

液化天然气（LNG）低温潜液泵

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Liquefied Natural Gas Cryogenic Submersible Pumps

1 Scope

This Standard specifies the terms and definitions, type and model, technical requirements, junction boxes, inspection and test, inspection rules, preparations before delivery, and seller's information of cryogenic submersible pumps for transporting liquefied natural gas (LNG).

This Standard applies to submersible centrifugal pumps for transporting liquefied natural gas (LNG) (hereinafter referred to as submersible pumps).

2 Normative References

The following documents are essential to the application of this Document. For the dated documents, only the versions with the dates indicated are applicable to this Document; for the undated documents, only the latest version (including all the amendments) is applicable to this Document.

GB/T 191 Packaging – Pictorial marking for handling of goods

GB/T 755-2019 Rotating electrical machines - Rating and performance

GB/T 1032-2012 Test procedures for three-phase induction motors

GB/T 1974 Tangential keys and keyways

GB/T 2828.1 Sampling procedures for inspection by attribute – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection

GB/T 3215-2019 Centrifugal pumps for petroleum, petrochemical and natural gas industry

GB/T 3216 Rotodynamic pumps – Hydraulic performance acceptance tests – Grade 1, 2 and 3

GB 3836.1 Explosive atmospheres – Part 1: Equipment – General Requirements

GB 3836.2 Explosive atmospheres – Part 2: Equipment protection by flameproof enclosures “d”

GB 3836.3 Explosive atmospheres – Part 3: Equipment protection by increased safety “e”

GB/T 4942.1 Degrees of protection provided by the integral design of rotating electrical machined (IP code) – Classification

GB/T 6391 Rolling bearings – Dynamic load ratings and rating life

GB/T 7306.2 Pipe threads with 55° thread angle where pressure-tight joints are made on the threads – Part 2: Taper internal and external threads

GB/T 7307 Pipe threads with 55° thread angle where pressure-tight joints are made on the threads

GB/T 9124 (all parts) Specification for steel pipe flanges

GB/T 9125 (all parts) Fasteners for pipe flange joints

GB/T 9126 Dimensions of non-metallic flat gaskets for pipe flanges

GB/T 9239.1-2006 Mechanical vibration – Balance quality requirements for rotors in a constant (rigid) state – Part 1: Specification and verification of balance tolerances

GB/T 13306 Plate

GB/T 19204 General characteristics of liquefied natural gas

GB/T 22670 Test procedures for converter-fed three phase cage induction motors

GB/T 22719.1 Interturn insulation of random-wound winding for AC low-voltage electrical machines – Part 1: Test methods

GB/T 29529-2013 Methods of measuring and evaluating noise of pumps

GB/T 29531-2013 Methods of measuring and evaluating vibration of pumps

JB/T 6880.2 Steel castings for pumps

JB/T 6913 Cleanliness of pump products

3 Terms and Definitions

For the purposes of this Document, the terms and definitions given in GB/T 3215-2019 and the following apply.

3.1 Sump

A sealed metallic container for installing submersible pumps.

3.2 Thermal transient working condition

The working conditions in which the fluid temperature in the pump changes due to compression, throttling, friction, etc.

a) Based on the center of the first-stage impeller of the submersible pump, the submerged depth shall not exceed 20m:

b) Medium temperature is no lower than -196°C, and no higher than -110°C:

c) The submersible pump operates within the range of 70%~120% of the rated flow.

5.1.3 The performance of the submersible pump is based on the specified speed.

5.1.4 The NPSH3 value at the specified point of the submersible pump shall not exceed the guaranteed NPSHR value.

5.1.5 During the operation of the submersible pump, the change of power supply voltage and frequency and its influence on the performance of the motor and the limit of temperature rise shall comply with the provisions of GB/T 755-2019.

5.1.6 Under specified operating conditions, the mean time between failures of submersible pumps shall be no less than 5000h.

5.1.7 The design of the submersible pump shall meet the following requirements:

--- Thermal transient working conditions shall comply with the provisions of GB/T 19204;

--- During the hydrostatic test, the maximum allowable working pressure of the pressure-bearing parts shall be less than 90% of the elastic limit stress of the materials used for the parts at 293K;

--- Connecting flanges, fasteners (nuts and bolts) and gaskets shall comply with the provisions of GB/T 9124 (all parts), GB/T 9125 (all parts) and GB/T 9126.

5.1.8 The submersible pump shall be able to work at the maximum continuous speed. The maximum continuous speed shall meet the following requirements:

a) It is equal to the corresponding synchronous speed under the condition of the maximum supply frequency of the motor;

b) For variable-speed submersible pumps and fixed-speed submersible pumps that may overspeed, it shall be no lower than 110% of their rated speed.

5.1.9 Submersible pumps should have a stable head-flow curve for all application conditions.

5.1.10 The rated flow point of the submersible pump shall be within the range of 80%~110% of the flow rate of the best efficiency point of the provided submersible pump.

5.1.11 The enclosure protection level of the submersible pump shall be IP50 or above specified in GB/T 4942.1.

5.1.12 The rating of the submersible pump is the continuous rating based on the continuous

5.3.2.4 The length of the first pipeline threaded or welded to the shell should not exceed 150mm. For DN25 and smaller, it shall be at least Sch160 seamless pipe; and for DN40, it shall be at least Sch80 seamless pipe.

5.4 Rotor

5.4.1 The impeller shall be designed as a closed structure; and the inlet end of the blade shall be a round head.

5.4.2 The impeller and shaft shall be connected by key; and no pin shall be used to fix the impeller to the shaft. Clamping sleeves may be used with purchaser approval. During normal rotation, the fastening device shall use the resistance of the liquid to the impeller to keep the thread in a tightened state; and there shall be a reliable mechanical locking method (such as a pin and a corrosion-resistant set screw or a tongue washer). Cap screws shall have recess with rounded corners and reduced diameter to reduce stress concentrations.

5.4.3 All the keyways of the shaft shall have a fillet radius in accordance with GB/T 1974.

5.4.4 The shaft shall be machined and polished along its entire length; and the total indication runout should not exceed 40μm/m. The total runout over the full length of the shaft should not exceed 80 μm.

5.5 Wear rings and running clearances

5.5.1 Radial running clearances shall be used to limit internal leakage. A replaceable wear ring shall be installed in the shell. The impeller shall have integral wear surfaces, or replaceable wear rings.

5.5.2 The hardness difference between the impeller sealing ring of the submersible pump and the wear-resistant surface of the shell sealing ring is at least 50HBW.

5.5.3 If replaceable wear rings are used, they shall be located by means of locking pins, press fits of saddle screws (axial or radial), or spot welds. The diameter of the radial pin hole or threaded hole on the wear ring is no greater than 1/3 of the width of the wear ring.

5.5.4 The running clearance shall meet the following requirements:

--- When determining the internal running clearance of wear rings and rotating parts, the pumping temperature, suction conditions, properties of the liquid pumped by the pump, thermal expansion and seizure characteristics of the material, and pump efficiency shall be considered. The clearance shall be large enough to ensure the reliability of the work under all specified working conditions and to avoid seizure.

--- For copper alloy, aluminum alloy and stainless steel, the minimum diameter clearance given in Table 1 shall be used.

--- For non-metallic wear ring materials with very low or no tendency to seize, the vendor

5.6 Motor

5.6.1 The motor of the submersible pump shall be able to drive the submersible pump safely and reliably when submerged in the working medium, so that the submersible pump can provide the required flow and head.

5.6.2 The materials selected for submersible pump motor shall meet the following requirements:

--- The selected materials shall meet the requirements of their material standards and have valid material inspection reports;

--- It has the properties of low temperature resistance, durability, corrosion resistance, moisture resistance, mildew resistance, non-toxicity and flame retardancy.

The magnet wire for the stator winding of the submersible pump motor is made of special enameled round copper wire with low temperature resistance and corrosion resistance. Its surface insulation can, from room temperature to ultralow temperature and from ultralow temperature to room temperature, do not occur cracks caused by thermal stress, and ensure stable performance in the environment of liquefied natural gas (LNG) or liquid nitrogen; and can withstand the impact of ground withstand voltage, turn-to-turn withstand voltage and inverter output voltage dU/dt ≤ 1000 V/us. The ground withstand voltage shall be tested according to the requirements of Table 17 in GB/T 755-2019; and the turn-to-turn withstand voltage shall be tested according to the method specified in GB/T 22719.1.

The stator and rotor cores of submersible pump motor are made of special cold-rolled silicon steel sheets with low temperature resistance, high magnetic permeability, low loss and low hysteresis expansion rate; and the surface is coated with paint without peeling off or cracking in the environment of liquefied natural gas (LNG) or liquid nitrogen.

The vacuum pressure impregnated paint for the stator winding of the submersible pump motor is a low-temperature-resistant, corrosion-resistant, Class-F and above special insulating varnish. The insulating varnish layer covered on the surface of the stator winding after impregnating paint shall be able to prevent cracking caused by thermal stress during the process from room temperature to ultra-low temperature and from ultra-low temperature to room temperature.

The insulating material used in the stator slot and coil end of the submersible pump motor is Class-F and above heat-resistant; and the performance test of the insulating material can be carried out in the low temperature environment of liquid nitrogen. During the test, the insulating material is soaked in liquid nitrogen for 10 h above; it is required that the insulating material has no obvious changes such as foaming in appearance; meanwhile it shall have low temperature toughness, moisture resistance, mildew resistance and flame retardancy at low temperature; so as to ensure that it has high enough mechanical strength at low temperature.

The shaft of the submersible pump motor shall be made of stainless steel with a tensile strength of no less than 500MPa, an elongation after fracture of no less than 20%, a yield strength of no less than 200MPa and went through quenched and tempered or solution treatment.

The cables for submersible pump motor shall have the characteristics of low temperature resistance and corrosion resistance. Soak the cables in the liquid nitrogen environment for more than 2 hours. Under the condition of the minimum bending radius allowed by the cables, perform a bending test immediately after taking them out. The insulation layer on the surface of the cables shall not be damaged.

5.6.3 The submersible pump motor shall be connected to an external power supply through an explosion-proof junction box.

5.6.4 In the liquefied natural gas (LNG) or liquid nitrogen environment, when the insulation resistance of the submersible pump motor stator winding to the casing is corrected to 25°C, it shall be no lower than 25MΩ. The measurement of insulation resistance shall be carried out according to the provisions of GB/T 1032.

5.6.5 When the three-phase power supply is balanced, the deviation between any phase of the three-phase no-load current of the submersible pump motor and the average value of the three phases shall be no greater than 10% of the average value.

5.6.6 Under no-load conditions, the submersible pump motor shall be able to withstand an overspeed test of 1.2 times the rated speed for 2 min. After the test, there shall be no permanent abnormal deformation or other defects that hinder normal operation.

5.6.7 The submersible pump motor can meet the service requirements of the submersible pump at low temperature.

5.7 Rotor balancing

5.7.1 The critical speed of the submersible pump rotor is to be at least 10% higher than the maximum continuous operating speed of the pump.

5.7.2 The submersible pump rotor assembly shall be subjected to a dynamic balance test, and the dynamic balance test shall meet the following requirements:

--- The half-key method is used to calibrate the dynamic balance of the motor; the speed shall reach at least 2/3 of the rated speed; and the quality level of dynamic balance shall be no lower than the requirements of Gl.6 in GB/T 9239.1-2006;

--- The quality level of dynamic balance of submersible pump rotor assembly at rated speed shall be no lower than the requirements of Gl.6 in GB/T 9239.1-2006.

NOTE: Submersible pump rotor assembly includes all rotating parts such as inducer, impeller, motor rotor, rotor shaft, balancer and key, etc.

5.8 Bearings

The rolling bearing life shall be calculated according to GB/T 6391; and the rolling bearing shall be able to work continuously for at least 20 000 h under normal working conditions.

f) Rated power, in kilowatts (kW);

g) Rated frequency, in hertz (Hz);

h) Rated voltage, in volts (V);

i) Rated current, in ampere (A);

j) Specified rotational speed, in revolution per minute (r/min);

k) The number of phases;

l) Manufacturer's serial number;

m) Year and month of exit-factory;

n) The mass of the submersible pump, in kilograms (kg);

o) Product execution standard number.

5.11.4 The submersible pump shall be provided with a turning marking in an obvious place; if there is a terminal connection marking, it shall be marked in order to facilitate connection by section.

6 Junction Box

6.1 The selection of the explosion-proof grade of the junction box shall meet the explosion-proof requirements of the application.

6.2 The rated current of the junction box of the submersible pump shall be no less than the maximum working current of the pump.

6.3 The structure, test and marking of the junction box shall comply with the provisions of GB 3836.1~3836.3.

6.4 The surface roughness *R*α of the flameproof junction box shall be no greater than 6.3μm.

6.5 The junction box shall be marked with "Ex" and a warning plate with the words "It is strictly forbidden to open the cover with power on" in an obvious position.

7 Inspection and Test

7.1 Visual inspection

Check the following visually or with an appropriate gage:

--- Dimensions and interfaces of the submersible pump;

--- Whether the cable lead-out intact;

--- Check the plate information of the submersible pump;

--- Whether to carry out degreasing treatment, etc.

7.2 Electrical inspection

The explosion-proof grade of electrical components shall be consistent with the classification of the hazardous location where it is located; and the explosion-proof certificate shall be checked to see if it meets the requirements of the use site.

7.3 Test

7.3.1 Material test

The materials of the main parts of the submersible pump shall be subjected to physical and chemical tests; and the composition and metallographic structure shall meet the requirements of 5.10 and/or corresponding material standards.

7.3.2 Balance test

The balance test of the submersible pump shall be carried out according to the provisions in 5.7.

7.3.3 Hydrostatic pressure test

Use clean cold water or the liquid containing anti-rust agent specified by the purchaser to carry out the hydrostatic pressure test on the pressure-bearing parts. The test pressure is 1.5 times the maximum allowable working pressure of the submersible pump; and the pressure holding time shall be no less than 5 min.

7.3.4 Performance test

7.3.4.1 The performance test shall use liquid nitrogen or liquefied natural gas (LNG) as the test medium; and other test mediums may also be used upon negotiation between the manufacturer and the purchaser.

7.3.4.2 The performance test of the submersible pump shall be carried out in accordance with the provisions of GB/T 3216.

7.3.4.3 The test speed of the submersible pump is in principle the specified speed. If the speed cannot reach the specified speed due to the test equipment, the test is allowed to be carried out within the range of 1 ± 20% of the specified speed. The test results can be calculated according to formulas (1) ~ (3).

5.1 of GB/T 1032-2012.

7.3.11 Motor characteristic test

7.3.11.1 No-load characteristic test

The type inspection shall be carried out according to the provisions in Clause 8 of GB/T 1032-2012. During the exit-factory inspection, the motor shall run under no-load, at rated voltage and frequency; and the no-load current and no-load input power shall be measured.

NOTE: Remove the impeller during the test to measure the no-load characteristic curve, and allow the test to be carried out at room temperature.

7.3.11.2 Motor overspeed test

Motor overspeed test shall be carried out according to the provisions of 12.8 in GB/T 1032-2012.

7.3.11.3 Working characteristic test

The working characteristic test shall be carried out according to the provisions of Clauses 10 and 11 in GB/T 1032-2012.

8 Inspection Rules

8.1 General

8.1.1 The inspection procedure of the submersible pump shall be negotiated between the manufacturer and the purchaser.

8.1.2 The manufacturer of the submersible pump shall provide the following information:

a) necessary or required material certification, such as the material manufacturer's test report;

b) Test data and test results proving that the requirements of the technical specifications have been met;

c) Other information specified by the purchaser or required by the applicable codes and provisions.

8.2 Inspection classification

Submersible pump inspection is divided into two categories: exit-factory inspection and type inspection.

8.3 Exit-factory inspection

When submersible pumps are produced in batches, exit-factory inspection shall be carried out one by one, including submersible pumps used for type inspection.

8.4 Type inspection

In order to verify whether the submersible pump can meet all the requirements of the technical specifications, the inspection is called type inspection. In one of the following situations, type inspection shall be carried out:

a) Trial type identification of new products and old products transferred to factory;

b) After the product is formally produced, there are major changes in structure, material and process, which may affect product performance;

c) Submersible pumps produced in batches are regularly sampled and tested (at least once a year);

d) Resuming production after a long-term suspension of production;

e) There is a large difference between the inspection result and the previous type inspection;

f) The national quality supervision agency proposes a type inspection requirement.

8.5 Sampling

The sampling method shall comply with the provisions of GB/T 2828.1. A sampling plan for normal inspection can be adopted, the inspection batch is the monthly (daily) output of the product or the batch size of an order, and the inspection level is the general inspection level II, and an acceptable quality level (AQL) is 4.0. It can also be determined through negotiation between the supplier and the purchaser.

8.6 Inspection items

Table 2 specifies the minimum inspection items to be carried out for submersible pumps. If other inspection items are required, they shall be agreed upon by the manufacturer and the purchaser.

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