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Ships and marine technology — Hydraulic performance tests for waterjet propulsion system

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Foreword

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 8, *Ship design*.

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Ships and marine technology — Hydraulic performance tests for waterjet propulsion system

1 Scope

This document specifies the measurement and acceptance criteria and the test report of hydraulic performance tests for waterjet propulsion system of Class A and Class B.

The test methods for the waterjet propulsion pump with and without the inlet duct are both specified. This document is applicable to the hydraulic performance test of water jet propulsion under the specified test conditions. This document specifies the precision grade of Class A for hydraulic model tests of water jet propulsion and Class B for acceptance tests of small and middle-sized or intermediate test models.

In addition, this document specifies the test conditions of Class A and Class B, and recommendations and requirements for test equipment to ensure that the test can be carried out under the conditions of corresponding accuracy.

This document does not include miscellaneous parts of waterjet unit, such as steering and reversing gear, hydraulic system and control system.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, symbols and abbreviated terms

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
waterjet unit
unit that consists of *waterjet propulsion system* (3.2), steering and reversing gear, hydraulic system and control system which is able to steer and reverse the main body

3.2
waterjet propulsion system
propulsion system that consists of *waterjet pump* (3.3), nozzle and inlet duct (generally the impeller of waterjet pump is integrated with the nozzle) and that is able to drive the main body moving

3.3
waterjet pump
pump that transfers the energy of prime mover to water by rotating impeller

Note 1 to entry: The waterjet pump obtains a counter-acting force and drives the main body moving. It consists of impeller, guide vane, shell and shaft (hereinafter referred to as “pump”). The main types are mixed-flow type and axial flow type. The axial flow waterjet pump is one in which the liquid is discharged axially from the impeller. The mixed-flow waterjet pump is one in which the liquid is discharged from impeller with an angle α ($0° < \alpha < 90°$) to the shaft line, also called the inclined waterjet pump.

3.4
flow rate
Q
volume of liquid discharged by *waterjet pump* (3.3) per unit time

3.5
pump total head
H
algebraic difference between the outlet total head, H_2, and the inlet total head, H_1

Note 1 to entry: Pump total head is given by Formula (1):

$$H = H_2 - H_1 \tag{1}$$

where

H_1 is the inlet total head, expressed in Pa;

H_2 is the outlet total head, expressed in Pa.

Note 2 to entry: Unless otherwise specified, the baseline of the head is the waterjet propulsion shaft line.

[SOURCE: ISO 9906:2012, 3.2.15, modified — notes 1 and 2 to entry have been modified.]

3.6
pump power input
P
power transmitted to the pump by its driver

[SOURCE: ISO 17769-1:2012, 2.1.11.2, modified — note 1 to entry has been deleted.]

3.7
pump efficiency
η
proportion of the *pump power input* (3.6), *P*, delivered as pump power output, P_u, at given operating conditions

Note 1 to entry: Pump efficiency is given by Formula (2):

$$\eta = \frac{P_u}{P} \tag{2}$$

where

P_u is useful mechanical power transferred to the liquid during its passage through the pump, given by Formula (3);

$$P_u = \rho g Q H \tag{3}$$

[SOURCE: ISO 17769-1:2012, 2.1.12.1, modified — Formula (3) has been added and the symbols have been explained.]

3.8
type number
K

dimensionless quantity, defined by Formula (4):

$$K = \frac{2\pi n Q'^{1/2}}{(gH')^{3/4}} = \frac{\omega Q'^{1/2}}{(y')^{3/4}} \tag{4}$$

where

Q' is volume flow rate per eye, expressed in m^3/s;

H' is head of the first stage, expressed in m;

ω is expressed in time, like s^{-1}, and n is expressed in $60 \times min^{-1}$ form.

Note 1 to entry: The type number should be taken according to the maximum diameter of the first stage impeller.

3.9
net positive suction head
NPSH
pump inlet total head above the head, equivalent to the vapour pressure per unit volume liquid, i.e. pump inlet total head adds head equivalent to atmospheric pressure and subtracts head equivalent to the vapour pressure

Note 1 to entry: Net positive suction head is calculated by Formula (5):

$$NPSH = H_1 - z_D + \frac{p_b - p_v}{\rho g} \tag{5}$$

where

p_b is (absolute) atmospheric pressure, expressed in Pa;

p_v is (absolute) vapour pressure, expressed in Pa;

z_D is height of impeller inlet, expressed in m.

[SOURCE: ISO 17769-1:2012, 2.1.5.5, modified — definition has been modified; the symbols have been modified and the notes 2, 3 and 4 to entry have been deleted.]

3.10
guarantee point
operating performance of the pump which the supplier guarantees to be achieved under specified conditions

[SOURCE: ISO 17769-1:2012, 2.1.13.2, modified — note 1 to entry has been deleted.]

4 Measurement and acceptance criteria

4.1 General

The basic parameters of the waterjet hydraulic performance tests directly obtained from the measurement are flow rate, pressure, torque and speed of rotation. The derived parameters calculated from the basic parameters are head, shaft power and efficiency. All of these parameters shall meet the acceptance criteria specified in this clause.

Table 1 gives the acceptance level of pump head, flow rate, shaft power and efficiency. All acceptance criteria are expressed as percentages of guarantee values. The test equipment shall meet the measuring precision requirements. The measuring apparatus and their calibration should be confirmed. Both the purchaser and manufacturer shall be entitled to have representatives present at all tests. The date of the test shall be mutually agreed by the purchaser and manufacturer. Acceptance criteria shall meet the requirements in Table 1 and if applicable, any agreements between the purchaser and manufacturer.

Table 1 — Acceptance criteria for Class A and Class B

Quantity	Class A %	Class B %
Flow rate	±1,5	±2,0
Speed of rotation	±0,2	±0,5
Torque	±1	±1,4
Pump total head	±1	±1,5
Pump power input	±1	±1,5
Pump efficiency	±2,25	±2,9

A guarantee point may be detailed in a written contract, a customer-specific waterjet performance curve, or similar written and project specific documentation.

If not otherwise agreed upon between the purchaser and the manufacturer, the following should apply.

a) The acceptance grade should be in accordance with the grades given in Table 1.

b) Tests should be carried out on the test stand of the manufacturer's works with clean, cold water, using the methods and test arrangements specified in this document.

c) The waterjet performance should be guaranteed between the waterjet's inlet connection and outlet connection.

d) Pipe and fittings (bends, reducers, and valves) outside the waterjet are not a part of the guarantee.

The combination of manufacturing and measurement tolerances in practice necessitates the usage of tolerances on tested values. The tolerances given in Table 1 take into account both manufacturing and measurement tolerances.

The performance of a waterjet varies substantially with the nature of the liquid being pumped. Although it is not possible to give general requirements and guidelines in which clean, cold water can be used to predict performance with other liquids, it is desirable for the parties to agree on empirical rules to suit the particular circumstances.

For batch products, the number of waterjets which are tested should be agreed between the purchaser and manufacturer.

4.2 Measurement range

The flow rate is measured within the range of 80 % to 110 % of the best efficiency point or duty point at identical speed of rotation.

The variation between the measured speed of rotation and specified speed of rotation should be within ±20 % for Class A and the range from 60 % to 120 % for Class B.

4.3 Stable operating conditions of measuring systems

The test should be carried out on the test stand which meets the corresponding precision grade. The test stand may be the manufacturer's test works, or a test stand mutually agreed between the purchaser and the manufacturer. The precision grade of the test equipment is decided by the measuring system. The flow rate, inlet and outlet pressure, speed of rotation, torque, which are naturally fluctuating when measured in the tests, as well as the signals, are automatically recorded or the statistical records accumulate. The readings of delivered signals should satisfy the stable condition.

If the design or operation of the pump causes a large fluctuation in the measured value, a buffer device may be installed in the measuring instrument or its connecting pipeline, to reduce the fluctuation to the range given in Table 2 for measurement. Buffer devices should be symmetrical and linear, like capillaries, which should provide integral values that contain at least one complete fluctuation period.

Table 2 — Permissible amplitude of fluctuation as a percentage of mean value of quantities being measured

Measured quantity	Permissible amplitude of fluctuations	
	Class A %	Class B %
Flow rate	±2	±3
Differential head	±3	±4
Pressure	±2	±3
Pump power input	±2	±3
Speed of rotation	±0,5	±1
Torque	±2	±3
Temperature	0,3 °C	0,3 °C

Several sets of readings should be taken for each operating point considered. The arithmetic mean of the mean values from all sets of readings for each quantity should be taken as the actual value given by the test for the operating conditions considered. This actual value is used to ensure that the overall tolerance of the measuring system meets the uncertainty requirement of the corresponding grade. A minimum of three sets of readings should be taken at unequal intervals at the chosen point and the mean value of each quantity and the efficiency derived from each set of readings should be recorded. The variation of quantities shall meet the requirement of Table 3 (see ISO 5198).

Table 3 — Limits of variation between repeated mean values of the same quantity (based on 95 % confidence limits)

Number of sets of readings	Flow rate, pump total head, torque and pump power input	Speed of rotation
	%	%
3	0,8	0,25
5	1,6	0,5
7	2,2	0,7
9	2,8	0,9

4.4 Evaluation of flow and head

Guarantee point evaluation should be performed at the rated rotational speed. It is not necessary to recalculate the test points based on rotational speed in cases where the test rotational speed is identical to the rated rotational speed. For tests in which the test rotational speed is different from the rated rotational speed, each test point should be recalculated to the rated rotational speed, using the affinity laws.

The acceptance criteria of flow rate should be applied to its guarantee point at the guarantee head, and vice versa.

If there is no special requirement, the guarantee pump total head, H_G, is usually measured under the condition of guarantee flow rate of Q_G. It shall meet the acceptance requirements that the absolute value of the deviation between the head and the guarantee pump total head H_G is not greater than the head tolerance value. If the purchaser and the manufacturer agree, the method of determining guarantee flow rate, Q_G, under guarantee pump total head, H_G, may also be used.

4.5 Evaluation of efficiency or power

If the efficiency or power has been guaranteed, it should be evaluated against the applicable acceptance grade tolerance factor, i.e. the same as for Q/H in the following manner.

After a best-fit test curve ($Q-H$ / $Q-\eta$ / or $Q-P$ curves) is drawn and smoothly fitted through the measured test points, an additional straight line should be drawn between the origin (0 rate of flow, 0 head) and the guarantee point (rate of flow/head). If necessary, this line should be extended until it crosses the fitted test curve. The intersection between the smoothly fitted test curve and this straight line should form a new point of rate of flow/head, which is used for evaluation of efficiency or power. The measured input power or calculated efficiency at this point should be compared against the guarantee value and the applicable power or efficiency tolerance factors.

NOTE 1 The line from the origin method is used when evaluating the guarantee efficiency or power because it best retains the waterjet characteristics if the impeller diameter is changed. Additionally, this method always gives one single point of reference for evaluation.

NOTE 2 The tolerance limits for flow and head can be reduced as a result of adding a power guarantee.

5 Measurement uncertainty

5.1 General

Every measurement is inevitably subject to some uncertainty, even if the measuring procedures and the instruments, as well as the methods of analysis, fully comply with the recommendations and requirements of this document.

5.2 Statistical evaluation of overall measurement uncertainty

5.2.1 Evaluation of the random uncertainty

The random uncertainty due either to the characteristics of the measuring system or to variations of the measured quantity, or both, appears directly as a scatter of the measurements. Unlike the systematic uncertainty, the random component can be reduced by increasing the number of measurements of the same quantity under the same conditions.

A set of readings not less than three should be taken at each test point.

5.2.2 Evaluation of the systematic uncertainty

After all the known errors have been removed by zero adjustment, calibration, careful measurement of dimensions, proper installation, etc., there remains an uncertainty which never disappears. This uncertainty cannot be reduced by repeating the measurement if the same instrument and the same method of measurement are used. Permissible relative values for the systematic uncertainty in this document are given in Table 4.

Table 4 — Permissible relative values of the instrumental uncertainty, e_s

Measured quantity	Maximum permissible systematic uncertainty (at guarantee point)	
	Class A %	Class B %
Flow rate	±1,0	±1,5
Pump total head	±1,0	±1,0
Outlet pressure	±0,9	±1,0
Inlet pressure	±0,5	±1,0

Table 4 *(continued)*

Measured quantity	Maximum permissible systematic uncertainty (at guarantee point)	
	Class A %	Class B %
Suction head for NPSH test	±0,9	±1,0
Driver power input	±0,9	±1,0
Speed of rotation	±0,35	±1,4
Torque	±0,9	±2,0

5.2.3 Overall uncertainty

The value for overall uncertainty, *e*, is given by the derived quantity of systematic uncertainty and random uncertainty. Permissible values of overall measurement uncertainty, *e*, are given in Table 5.

Table 5 — Permissible values of overall uncertainties, *e*

Quantity	Class A %	Class B %
Flow rate	±1,5	±2,0
Speed of rotation	±0,2	±0,5
Torque	±1,0	±1,4
Pump total head	±1,0	±1,5
Motor power input	±1,0	±1,5
Pump power input (derived by torque and speed of rotation)	±1,0	±1,5
Pump power input (determined from the motor power input and the efficiency of the motor)	±1,3	±2,0

5.2.4 Determination of overall uncertainty of efficiency

The overall uncertainty of efficiency is divided into the amount calculated from the torque and the speed of rotation, or the amount calculated from the pump input power.

Using the values given in Table 5, the calculations lead to the results given in Table 6.

Table 6 — Resulting greatest values of the overall uncertainties of efficiency, *e*

Quantity	Class A %	Class B %
Overall efficiency (computed from Q, H, P_{gr})	±2,0	±2,9
Pump efficiency (computed from Q, H, M, n)	±2,0	±2,9
Pump efficiency (computed from Q, H, P_{gr} , η_{mot} η_{mot})	±2,25	±3,2

5.3 Conversion

5.3.1 Conversion to the guarantee conditions

The quantities required to verify the characteristics guaranteed by the manufacturer are generally measured under conditions different from those on which the guarantee is based.