ITTC Quality System Manual

Recommended Procedures and Guidelines

Procedure

Propulsions Tests in Ice

7.5 Process Control

7.5-02 Testing and Extrapolation Methods

7.5-02-04 Ice Testing

7.5-02-04-02.2 Propulsions Tests in Ice

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Propulsions Tests in Ice

1. PURPOSE

- Definition of standards for performing propulsion tests in ice
- Assistance in making the test results from different test series and different laboratories more consistent.

2. PROPULSION TESTS IN ICE

The purposes of performing propulsion tests are generally

a) To determine the attainable speed, resistance and required propulsion power in specific ice conditions.
b) To determine the effectiveness of the combined hull-propulsion system in ice.
c) To investigate the ice interaction with appendages and propulsion system.

Most recommendations about conducting tests given in the procedure 7.5-02-04-02.1 “Ice resistance tests in level ice” are also valid for the case of propulsion tests.

In order to determine the required propulsion power in ice, the following three methods are commonly used:

- towed propulsion test in open water
- towed propulsion test in ice
- free running propulsion test in ice.

The pre-set values, measured data and results are listed in the flow chart in Figure 2-1 for each test type.

The model’s degrees of freedom may vary from one facility to another, but it is important that the principles of the test arrangements are presented. Basically, the model should be free to pitch, heave and roll in case of towed propulsion tests.

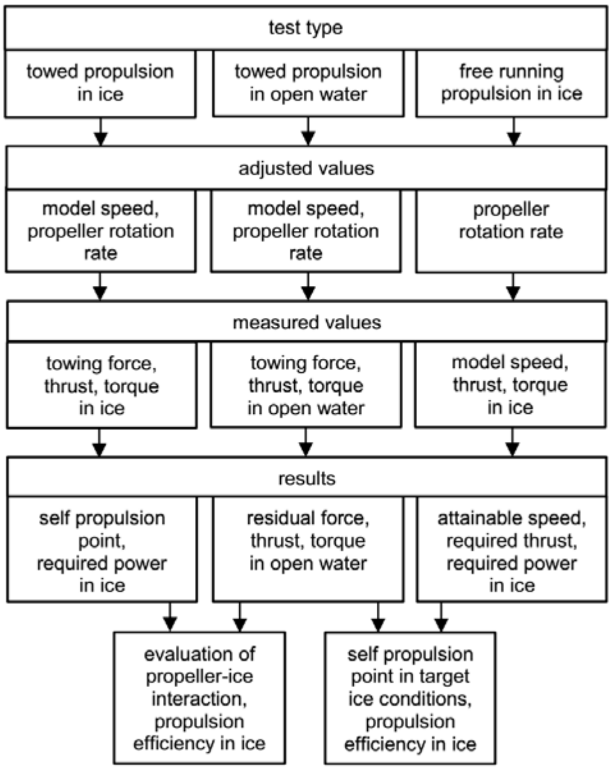

Figure 1 different test types with pre-sets, measurements and main results (top to bottom)

The quantities to be measured during propulsion tests are given in section 3.1. In addition to the direct measurements, collecting visual data is also important to observe the flow of ice pieces around the ship’s hull. Thus, underwater photographs and videos should be taken during each test. All hull appendages, such as rudders, nozzles, ice deflecting fins, which may have been omitted during resistance tests should be attached to the model. The test report should give sufficient description of their geometry and location.

Models of propellers and other propulsive devices should be correctly scaled. If stock propellers are used, their geometry should be as close as possible to the designated full scale design propeller. Propeller diameter and the clearance between the tip of the propeller and the hull are important parameters. Information about the number of propellers and propeller performance data as well as inward or outward turning should be included in the test report (compare ITTC recommended procedure for Propulsion/Bollard Pull Test 7.5-02-03-01.1 section 3.1.1.2).

Direction of propeller rotation may affect the ice load because of changes in the local flow conditions and motion of broken ice pieces. In order to scale the propeller inflow in an appropriate manner the propeller rotation rate should be matched with that from the self-propulsion point. The effective thrust (T_{eff} is the thrust (T) reduced by the thrust deduction fraction $(1 - t)$:

$$T_{\text{eff}} = (1 - t)T$$

The propeller speed control can be based on constant rotation rate, constant torque or constant power. The system may also include an active control which makes it possible to simulate the dynamic behaviour of the real propulsion machinery.

If the motor is powerful enough and a constant rotation rate mode is selected, revolutions remain stable despite the ice load on the propeller. For ships without an over-torque capacity, this may not be realistic. In addition, crushing strength of model ice is much weaker than that of real ice. Generally most model basins are able to match flexural strength but not crushing strength at the same time. As a consequence, this type of propeller control may lead to inaccurate torques on the shaft.

A more realistic control system is a constant torque control, which keeps the shaft torque constant and decreases the rotation rate in case of exceedance of propeller ice interaction loads. However, to scale everything correctly in this case, the mass inertia and flexural stiffness of the whole propulsion train should be reproduced in model scale which can be difficult. Again control over the crushing strength of model ice is also difficult.

The methods described hereafter were originally developed for testing models in ahead operation in ice. Due to the strong influence of hull appendages and propeller – ice interaction their applicability to astern testing is limited.

The measurements in the propulsion test depend on the test type as shown in Figure 2-1. In the figure, F_X is the tow force, R_I is the ice only resistance, R_{IT} is the total resistance in ice, R_{OW} is the open water resistance and T_{eff} is the effective thrust. For both types of test, propeller rotation rate, torque and thrust (propeller and nozzle) from each propeller shaft and model speed are measured. For towed propulsion tests, the towing force is also measured.

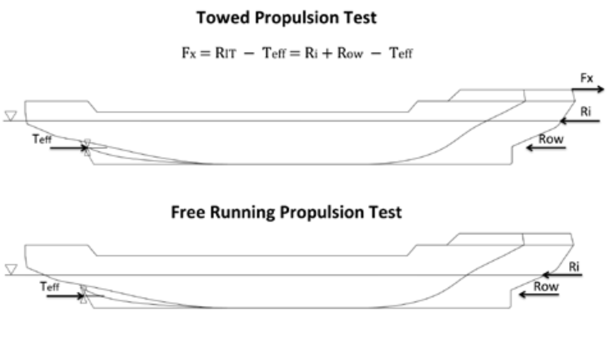

Figure 2 Forces acting on the model in towed propulsion test and free running propulsion test

2.1 Towed propulsion tests

During the towed propulsion test the model is towed at constant speed while the propeller rotation rate and thereby thrust is varied between values from near idling condition to a level close or above the maximum available power of the vessel or with constant rotation rate. If the test is carried out in open water called overload open water tests, overload restraining force should be matched with the ice resistance at the same speed of the model. The advantage of these tests is to obtain the power from the wide range of speed, propeller rotation rate in open water. The model should be in the ice condition to evaluate propeller ice interaction. Generally one or two representative ice sheets (including thickest tested ice) is used for this purpose.

The following equations (1) - (6) present how the ice resistance and propulsion tests in open water with a towed model can be used to find out resistance, self-propulsion-point and required power.

Total resistance can be obtained independently from resistance test in ice as specified in ITTC recommended procedure 7.5-02-04-02.1:

$$R_{IT} = R_I + R_{OW} \quad (1)$$

In overload tests in open water the towing force F_X is measured for different combinations of propeller rotation rate and model speed. The residual force F_{RES} is then determined from:

$$F_{RES} = R_{OW} - T_{eff} \quad (2)$$

For self-propulsion in ice ($F_X = 0$) the following equality must be fulfilled

$$T_{eff} = R_{IT} = R_I + R_{OW} \quad (3)$$

$$\Rightarrow F_{RES} = R_{OW} - R_{IT} = -R_I \quad (4)$$

In some basins the residual force $-F_{RES} = T_{eff} - R_{OW}$ is referred to as net thrust meaning the available thrust to overcome additional resistance due to ice. It should be noted that during towed tests with varying propeller rate F_{RES} and F_X usually take both positive and negative values.

Propeller rotation rate, thrust and torque at self-propulsion can be obtained from the results of the overload test in open water.

An alternative method would be the towed propulsion test in ice. From this test following relation between towing force, resistance and thrust can be obtained:

$$F_X = R_I + R_{OW} - T_{eff} \quad (5)$$

F_X – is the towing force

Again at self-propulsion point the towing force must be zero ($F_X = 0$):

The required propeller rate n_{req}, thrust T_{req} and corresponding torque Q_{req} can be obtained from the self-propulsion point and used to derive the required propeller shaft power P_{Dreq} (equation 6):

$$P_{Dreq} = 2\pi Q_{req} n_{req} \quad (6)$$

To obtain the self-propulsion point in target ice conditions R_{IT} and R_I are required as the corrections for deviating ice properties are commonly applied to the resistance.

It is noted that torque values can be derived from both ice and open waters using overload tests. Propulsion tests in ice can simulate a realistic view of interaction between ice and propulsors since the presence of ice can influence propeller performance (such as ice milling, blockage and proximity effect). For heavy propeller ice interaction case, direct use of ice torque which is mainly from ice milling may lead to inaccurate value due to inappropriate scaling of propulsion unit and crushing strength of model ice. Additional overload tests in open water at the same speeds could be useful to evaluate the extent of ice impact to the propulsion system as an index.

The reporting of propulsion tests should include time histories of the measured V, the towing force F_X, propeller rotation rate, n, propeller thrust, T, and torque, Q, (see Figure 2-3) as well as statistical data (maxima, minima, mean value and standard deviation) of these signals. The length of the test section should also be mentioned. Propeller performance curve should also be included in the report.

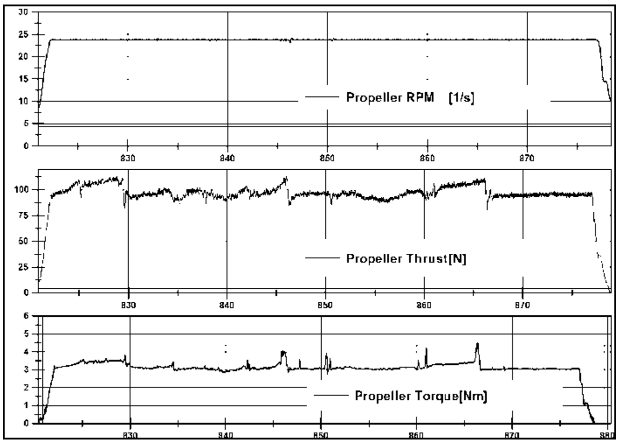

Figure 3 Time series of rpm, propeller thrust and torque

Although both towed propulsion test in ice and overload test in open water are widely accepted methods to evaluate the ship powering in ice, it allows large deviations from the self- propulsion point as the model is forced to maintain the speed. If the model motions, breaking pattern, and propulsion behaviour are out of a realistic range (such as ice ramming scenario due to thick ice in full scale), the test results cannot be used to interpolate the actual ice breaking performance. The towed propulsion tests should therefore be in the range of the designs capability. This may be estimated using theoretic predictions. Additionally tests with a free running model in ice can be carried out to cross check the towed propulsion results.

2.2 Free Running Propulsion Tests

If the model is free, no towing force is applied. The speed of the model then depends on the propeller thrust which is not necessarily constant. In order to achieve a representative mean speed it is important to have a sufficiently long test section. It is difficult to provide any guidance on selecting a proper length for this type of test, as the steadiness of the speed depends on too many variables. Care must be taken to plan long enough test run because it is recommend having at least two ship lengths after achieving stabilized speed.

If self-propulsion tests are performed with a free running model, deviations of ice properties must be within a small range. In order to ensure a steady model speed, the thrust and total resistance must be kept in balance. Any variation in ice properties causes also a change in model speed and thereby a change in propeller inflow and propeller-ice interaction.

When the ice thickness and properties are within a very small range, the resistance and model speed are not varying. Quantities to be measured are the same as in the propulsion test with a towed model, except the towing force.

The main result of a free running propulsion tests in ice is attainable speed at a certain propeller rate. If required ice resistance can be obtained from additional overload tests in open water at different combinations of speed and propeller rotation rate (Figure 4). The towing force at the same propeller rate and model speed as in the free running ice test will equal the ice resistance without open water resistance. This method can also be applied in tests astern.

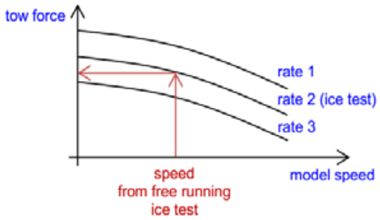

Figure 4 Ice resistance from free running test in ice and overload test in open water

2.3 Propeller/ice-interaction

When using equations (1) - (6), it is assumed that the average value of propeller rotation rate is the same in open water and in ice condition. The difference in thrust $dT_{\mathrm{eff}} = T_{\mathrm{I}} - T_{\mathrm{OW}}$ and torques on propeller shaft $dQ = Q_{\mathrm{I}} - Q_{\mathrm{OW}}$ should be measured at the same average speed and rotation rate in ice and in open water. A so-called ice efficiency coefficient of propulsion in ice has been presented (cf. 17th ITTC 1984). It is defined with the following equation:

$$\eta_{\mathrm{I}} = \frac{1 - \dfrac{dT_{\mathrm{eff}}}{T_{\mathrm{eff}}}}{1 - \dfrac{dQ}{Q_{\mathrm{OW}}}} \qquad (7)$$

A standardised index on the frequency or intensity of propeller-ice- interaction would be very useful. Due to the stochastic nature of propeller ice interaction, depending on ice properties and speed of the vessel, it might be useful to recommend a set of different indices instead of one.

Different indices for propeller ice interaction were already proposed in the past. Some quantify the number of ice impact events or time of propeller ice interaction in relation to the undisturbed operation time or distance. Additionally, some proposals were made to quantify the increase in torque either by comparing the mean values or the standard deviations in ice and open water as shown in equation (8).

$$\text{Torque ratio} = \frac{Q_{\mathrm{I}}}{Q_{\mathrm{OW}}} \qquad (8)$$

Where the Q_I is torque measured in ice and the Q_{OW} is torque measured in open water at the same condition.

The reliability of these indices depends on the length of the test runs, correct ice piece size, ice buoyancy, relative to the fluid, friction, and other mechanical properties of model ice including crushing and compressive strength. For most model ice types simultaneous similarity of all those properties influencing the ice impact on the propellers is usually not achieved.

3. PARAMETERS

3.1 Parameters To Be Measured

Definition of variables

Ice Efficiency Coefficient	(-)	η_{I}
Residual Force	(N)	F_{RES}
Towing Force	(N)	F_{X}
Propeller Rate	(1/s)	n
Delivered Power	(W)	P_{D}
Propeller Torque	(Nm)	Q
Propeller Torque in Ice	(Nm)	Q_{I}
Propeller Torque in Open Water	(Nm)	Q_{OW}
Total Resistance in Ice	(N)	R_{IT}
Ice Resistance Only	(N)	R_{I}

Open Water Resistance	(N)	R_{OW}
Thrust Deduction Factor	(-)	t
Thrust	(N)	T
Effective Thrust	(N)	T_{eff}

4. VALIDATION

4.1 Uncertainty Analysis

Not yet available

4.2 Benchmark Tests

1. Report of Committee on Ships in Ice-Covered Water (16th 1981 pp. 363-372)
   (g) Catalogue of Available Model and Full Scale Test Data (16th 1981 pp. 370-371)
2. Standard Model Tests (Ice)
   (17th 1984 pp.591-601)
   (1) Model Tests with R-Class Icebreaker
   (2) Propulsion Tests
   (3) Full Scale Prediction
3. Reanalysis of Full Scale R-Class Icebreaker Trial Results (18th 1987 pp.528-531) To Get Reliable Full-Scale R-Class Data CCGS "Pierre Radisson“ and CCGS “Franklin“
4. Retest of R-Class Icebreaker Model at a Different Friction Level (18th 1987 pp.532-543)
   (1) Resistance Tests (18th 1987 pp.532-540)
   (2) Self Propulsion Test (18th 1987 pp.540-543)
5. Comparative Test Program with R-Class Model (19th 1990 pp.526-531))
6. Comparative Test Program with Basic Offshore Model Structure
   (19th 1990 pp.534-540)
7. Basic Cylinder Tests(20th 1993 pp.470-481)
8. Repeatability Tests for Quality Control (20th 1993 pp.488-490)
9. Model Propulsion Tests in Ice (21st 1996 pp.252-263)