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THE ICE CAPABILITY OF THE MULTIPURPOSE ICEBREAKER BOTNICA-FULL SCALE RESULTS

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ABSTRACT

The trials of the new Finnish multipurpose icebreaker Botnica were performed on the northern Gulf of Bothnia. The main part of this paper consists of the results from the ice trials and their analysis. The results are compared with the results obtained in the ice model tests performed for the ship during the project phase. The ice capability of the ship is compared with the data published from other icebreakers. In the beginning of the paper, the ship and her propulsion system are also briefly introduced, and the measuring system onboard as well as the ice measurements are described.

1. INTRODUCTION

Finland has experience about the multipurpose icebreakers since March 1993, when the icebreaker Fennica was delivered to the Finnish Maritime Administration. The sistership Nordica was delivered in January 1994. In wintertime these ships have assisted ship traffic to the Finnish harbours, which all freeze each winter. Outside the icebreaking season these ships are leased for offshore duties in the North Sea. A similar working profile was designed for the new icebreaker, which was ordered from Aker Finnyards Ltd in March 1997, the same shipyard which constructed the previous two multipurpose icebreakers, and delivered to the Finnish Maritime Administration in April 1998. The new ship was named Botnica and primarily it was designed for assisting merchant ships into the harbours of the Gulf of Finland.

In exceptionally severe winters, the fast ice in the eastern part of Gulf of Finland can reach the thickness of 90 cm, the long time average being 45 cm. However, each year ice is pressed against the Finnish coast by the wind which forms ridges which can be about 10 m thick. The channels, too, leading to harbours through the fast ice can be very heavy due to the busy traffic.

When planning the full-scale ice test program, the target was to test the ship in all the above mentioned ice conditions. Due to the early date of the tests in the middle of February, the test area was chosen to be the northern Gulf of Bothnia, where the ice conditions are always heavier than in the Gulf of Finland.

Another guideline was, when planning the test program, to repeat most of the tests performed in the ice trials of the multipurpose icebreaker Fennica [1]. The test programme should include, in addition to the typical speed tests in different ice conditions, turning tests in ice and tests where the propeller flow is used in ice breaking.

2. THE MULTIPURPOSE ICEBREAKER BOTNICA

The main dimensions and propulsion power of MSV Botnica are somewhat smaller than her predecessors MSV Fennica and MSV Nordica (Table 1), but her hullform is almost the same. The most important characteristics, having an influence on performance in ice, are in addition to the bow, having good icebreaking characteristics, the bow reamers and Azipod propulsion units (Figure 1).

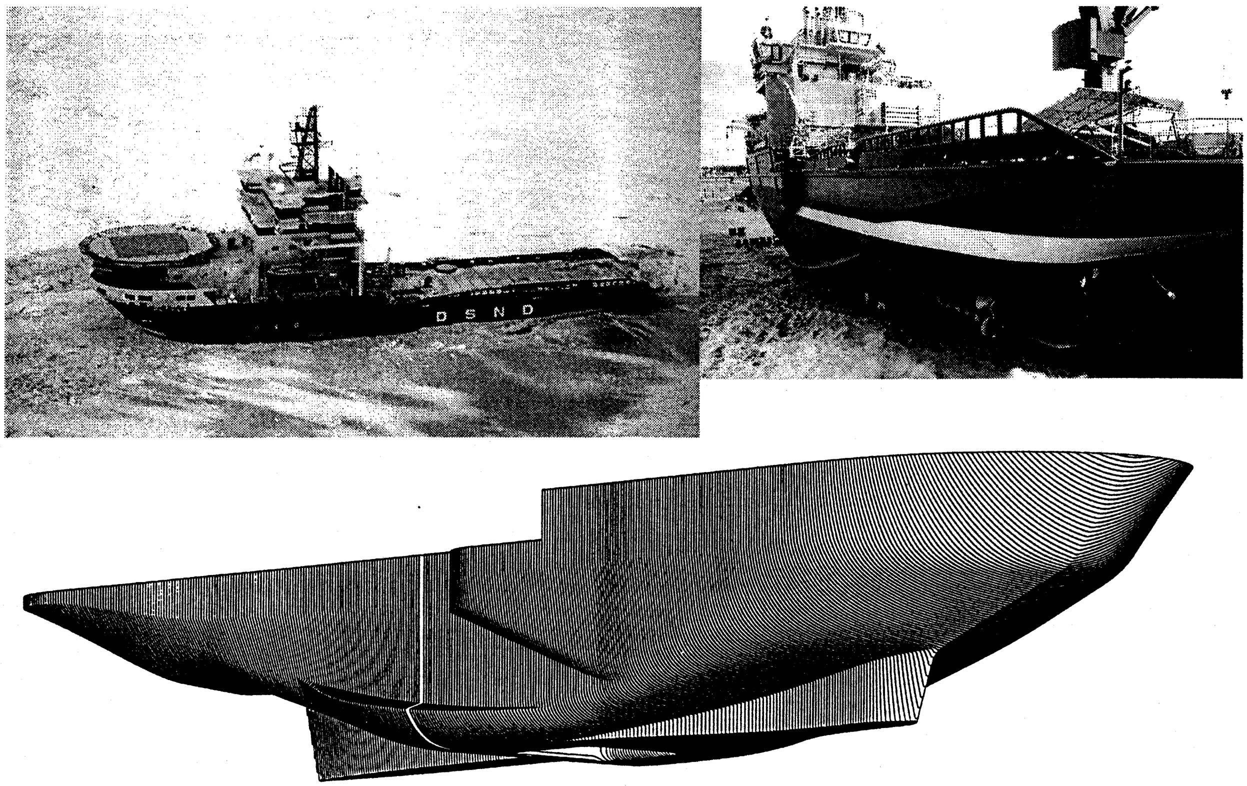


Figure 1 MSV Botnica in the ice trials (top, left), Azipod units (top, right) and hull form (bottom).

Table 1 Comparison of the principal dimensions and main data of MSV Botnica and her predecessors.

	MSV Botnica	MSV Fennica/MSV Nordica
Length o.a.	96,7 m	116,0 m
Breadth	24,0 m	26,0 m
Draught/deadweight		
■ Baltic	7,2 m / 1000 t	7,0 m / 1650 t
■ offshore	8,5 m / 2850 t	8,4 m / 4800 t
Machinery output	15000 kW	21000 kW
Speed	15 kn	16 kn
Bollard pull	117 t	234 t
Main propulsion units	Azipod azimuth thrusters 2×5000 kW (open propellers)	Aquamaster azimuth thrusters 2×7500 kW (in nozzle)

3. THE FULL-SCALE ICE TESTS PERFORMED

3.1 Measurements onboard and ice measurements

The measuring system onboard consisted of DGPS-equipment for measuring the ship position, gyro-compass for measuring the ships heading and isolation amplifiers for measuring the propeller speed and propulsion motor power as well as thruster steering angle signals coming from the bridge indicators. The motor power signal is based on a numerical model of the motor torque. This model is developed by the motor manufacturer. All the data was recorded with a PC equipped with a data acquisition card.

The ice measurements were performed by two ice groups. The first group performed the measurements and observations associated with the performance tests in level ice, the second one measured the profiles of the old channels and ridges. From the level ice the thickness of ice and snow as well as ice temperature were measured, the salinity of ice was determined from the ice samples taken by the ice group. The structure of the ice was recorded by photographing.

The thickness of the ice mass in the old channels and ridges was measured by coring holes. In channels the measurements were performed in sections which were perpendicular to the center line of the channel, in ridges, the transverse section was measured along the planned penetration line of the ship. The top profile of the ridge was measured by levelling.

The top profile of ice was also determined using laser profilometers. One unit was installed to a helicopter and one to the bow of the ship. The latter one provides information from the ice surface encountered and the former about ridge statistics in the area. A laser profilometer is a high-speed, high accuracy distance meter operating with frequencies up to 2000 Hz and is thus capable of producing almost continuous surface profile of ice. The onboard laser was used to measure the top profile of ridges rammed and also to deduce the freeboard of old channels. The freeboard was determined by identifying water level signatures from the data. The freeboard was converted isostatically to rubble thickness by using density 890 kgm-3 and porosity 0.1. The data was logged with a PC located on bridge from where also the frequency and other measurement parameters could be adjusted. The measurement frequency during the tests was 100 Hz.

To derive the surface profile from the measured data a reference level must be constructed. The roll and pitch angles of the ship were also measured which in principle allow the determination of the vertical movement of the bow and its distance to water level. However, the reference level can also be determined directly from the data as it contains records from the sea surface.

3.2 Level ice performance

Level ice speed tests performed both ahead and astern are usually the most important tests to be performed for a new icebreaker, because they enable easy comparison with other icebreakers. However, the propulsion system of Botnica gives more possibilities to perform different tests, because full power can be used in both rotating direction of the propellers. In other words the tests can be performed either by the Azipod propellers in pulling mode, which is the normal mode, or in pushing mode, when the Azipod units are turned 180° and the rotation direction of the propellers is changed. Pushing mode, instead of turning the Azipod units 180°, is very handy in harbour maneuvering or in assistance operations, when the direction of movement has to be changed repeatedly. However, in pushing mode the propeller thrust is reduced because the propeller was optimized for pulling mode. Figure 2 clarifies the different propulsion modes. The resistance, both ahead and astern, was determined from the tests, in which the Azipod operated in the pulling mode. The determination of resistance in ice was based on the measurements of the ship speed and propeller rotation speed the procedure being as follows: First the advance coefficient was calculated from the measured values of the propeller rotation speed and the ship speed multiplied with the wake fraction. Then the propeller thrust corresponding the advance coefficient was determined from the K_T-curve of the Azipod units. The total resistance was obtained by multiplying the thrust with the thrust deduction fraction. The wake and thrust deduction fracions as well as the K_T-curve were determined with model tests performed in icefree conditions. The use of these values when determining the resistance in level ice was reasoned because according to ice model tests the propeller-ice interaction in level ice was quite infrequent for this ship.

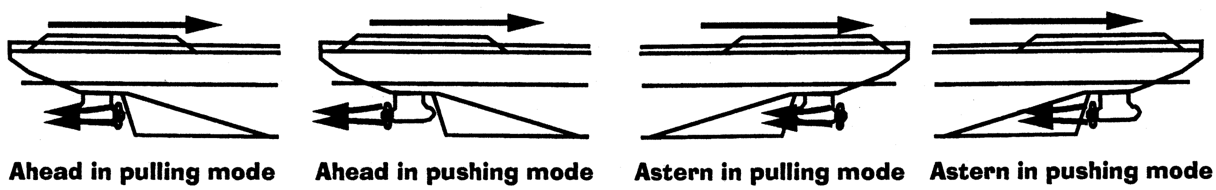


Figure 2 Azipod positions and propeller flow directions in different propulsion modes.

The level ice resistance tests were made in two ice fields, the thicknesses of which differed somewhat from each other. The thickness of ice in the thinner icefield varied between 55-65 cm and in the thicker icefield between 60-76 cm the average values being 61 cm and 71 cm, respectively. The average snow thickness in the both ice fields was 14 cm with a variation between 5-25 cm. The measurements were performed from the edge of the channel broken by the ship at the intervalls of about 100 m. For each test an effective ice thickness was determined which in addition to the ice thickness includes one third of the snow thickness. This thickness value having in the following the symbol H_{eff}, is used in this paper. The salinity of ice was about 0.2 % and as there was very little snow ice on top of the columnar grained ice, the flexural strength can be assumed to be about 500-600 kPa.

The ship reached in pulling mode with full power of 10 MW the maximum forward speed of 7,9 kn in the thicker ice (H_{eff} = 79 cm) and 9,4 kn in the thinner ice (H_{eff} = 65 cm). The maximum backing speed in the thinner ice (H_{eff} = 67 cm) was 7,2 kn. In the thinner ice the tests with full power were performed also in the pushing mode. The maximum speed ahead was 8,1 kn (H_{eff}= 66 cm), and astern 5,6 kn (H_{eff}= 67 cm).

Also starting tests were performed in the thicker ice field. The minimum power needed in pulling mode for continuous forward motion of the ship was 1,1 MW (H_{eff}= 73 cm) and only 0,9 MW astern (H_{eff} = 76 cm). When backing in the pushing mode the corresponding power was 2,7 MW (H_{eff} = 77 cm). Figure 3 presents the measured power values and Figure 4 the calculated total resistance values as a function of the speed.

Results from the model tests carried out for the ship model are also presented in Fig. 4. The model tests were performed in the ice tank of Ship Laboratory at the Helsinki University of Technology. The model tests were carried out in two phases; first the early design was completed with several variations of the vessel and after order, the final model tests were done to verify the final design in 60 cm thick ice. The presented model test results are extrapolated from the results of the latter test series. The prediction is seen to be quite accurate. The ice resistance in backing, obtained by extrapolation of model test results, is given in Fig. 4. Again a good match with full scale measurements is noticed, even tough more scatter exists in the data.

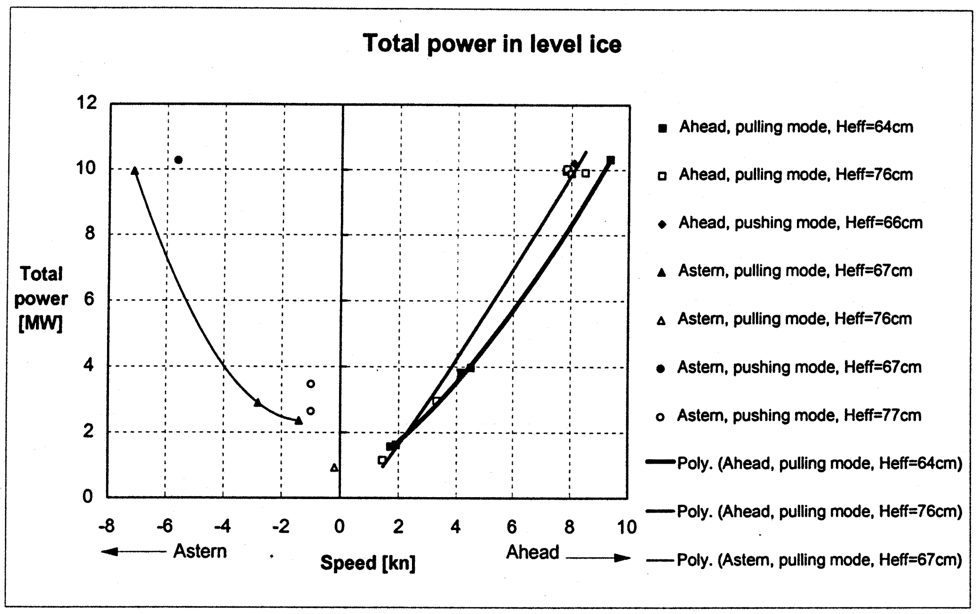


Figure 3 *Total propulsion power in level ice as a function of the speed. The speeds astern are denoted with negative values. Polynomial trendline curves were fitted to the datapoints from the tests in pulling mode.*

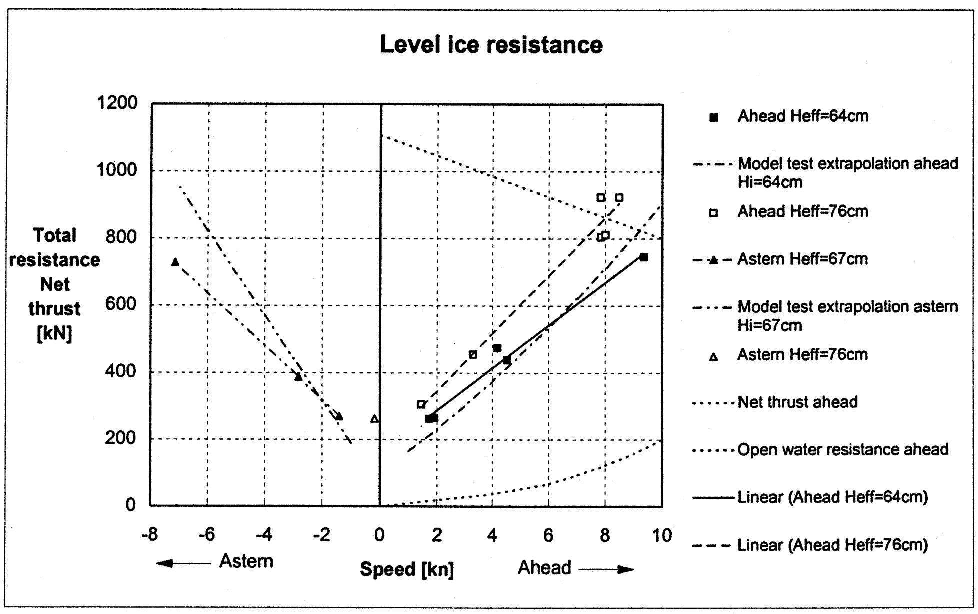
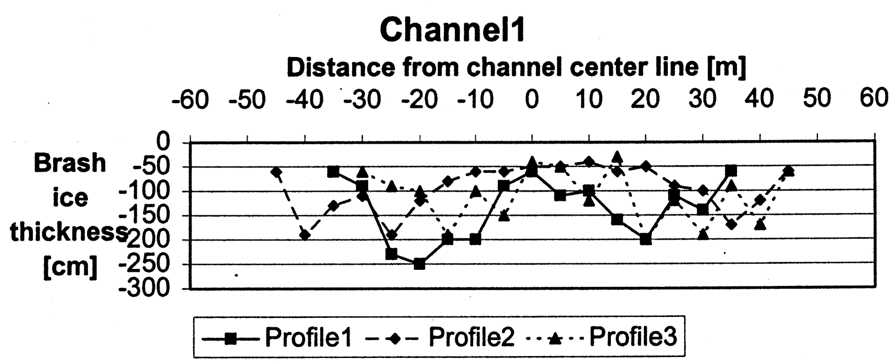


Figure 4 *Total resistance in level ice as a function of the speed. The speeds astern are denoted with negative values. In the figure also the curves of net thrust and open water resistance are included. "Net thrust" is the total thrust of the Azipod units multiplied with the thrust deduction factor (1-t).*

3.3 Resistance in old channels

Two channel legs were profiled for the channel performance tests. The first, Channel 1 (Figure 5 top), situated north from Hailuoto in the fairway to port of Oulu and the second, Channel 2 (Figure 5 bottom), in the fairway connecting the ports of Oulu and Kemi. The channels are at their heaviest in the second half of March so during the tests, in mid February, the brash ice thickness in the channels had not yet grown into its maximum, especially in Channel 1. Channel 2 was thicker, narrower and consolidated. The average thickness values for the channels, measured along the ship track with the laser profilometer are for channels 1 and 2 108 cm and 145 cm, respectively. Similar resistance tests ahead and astern as in level ice were performed in the channels and corresponding graphs for the total power and total resistance both ahead and astern are presented in Figures 6 and 7 respectively.



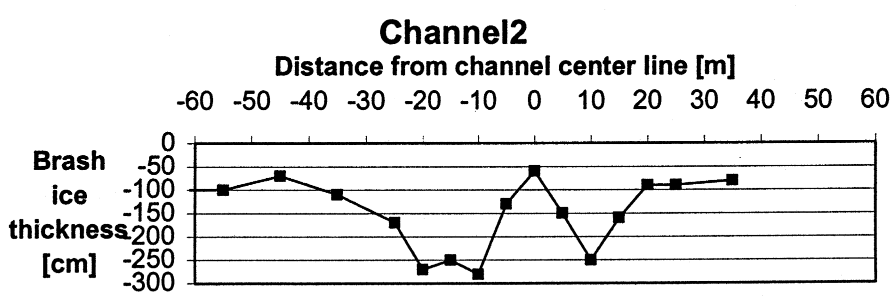


Figure 5 Brash ice thickness in three transverse sections of the Channel 1 and in one section of the Channel 2. The sections in Channel 1 were about 2 km apart from each other.

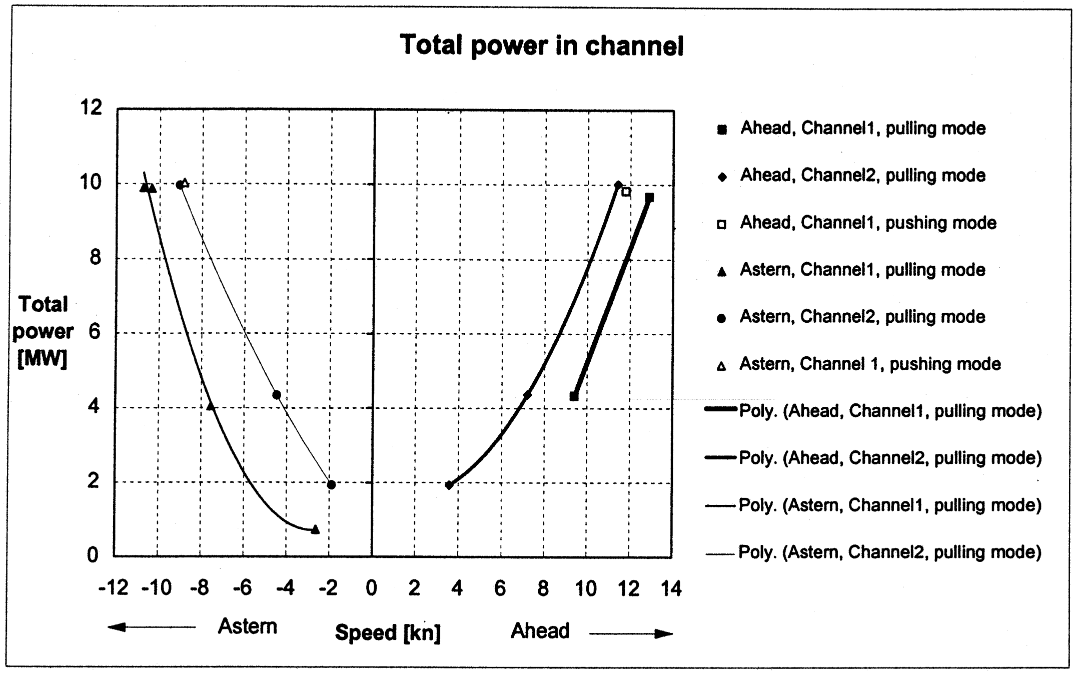


Figure 6 *Total propulsion power in old channel as a function of the speed. The speeds astern are denoted with negative values. Polynomial trendline curves were fitted to the datapoints from the tests in pulling mode.*

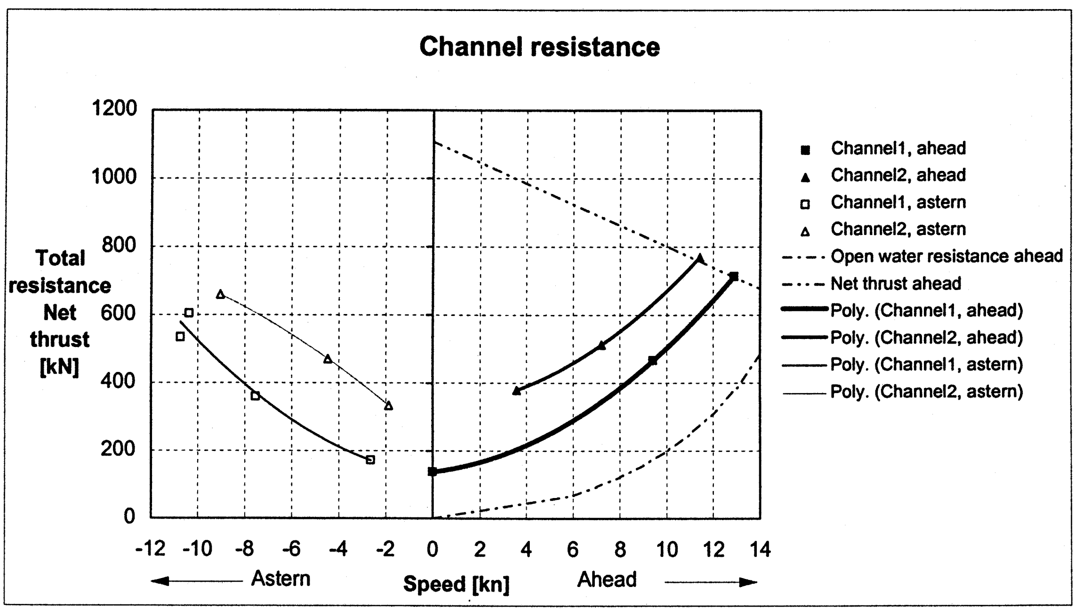


Figure 7 *Total resistance in old channel as a function of speed. The speeds astern are denoted with negative values. In the figure also the curves of net thrust and open water resistance are included. "Net thrust" is the total thrust of the Azipod units multiplied with the thrust deduction factor (1-t).*

3.4 Turning ability

The bow reamers and Azipod thrusters give MSV Botnica good turning ability in ice (Figure 1). Turning is difficult if the stern cannot move in lateral direction towards the outer edge of the channel. The channel broken by the reamers is broader than the aftership allowing the stern move outwards without breaking more ice. The turning force, given by the azimuth thrusters, reaches maximum at zero speed, contrary to conventional rudders. This enables the ship to turn around on the spot without initial forward speed up to a limiting ice thickness. In order to study these characteristics a series of turning tests both without initial speed, and with maximum forward speed were performed.

3.4.1 Zero speed tests

Two turning tests were performed with constant power, the first having the azimuth thrusters in pulling mode, the second in pushing mode. The azimuth angles were 60° in the outermost unit and 90° in the inner unit. Table 2 includes the results measured for MSV Botnica and also for comparison corresponding results for MSV Fennica. From the table it can be seen that MSV Botnica performs the full turn in pulling mode in 138 seconds in effective ice thickness of about 70 cm. This is only 9 seconds slower than the time measured for MSV Fennica although MSV Botnica performed the turn with reduced output.

Table 2 Turning times of MSV Botnica and MSV Fennica [1] for turning 90° and 180° without initial forward speed in level ice.

Propulsion mode	Time to 90° [s]	Time to 180° [s]	Total power [MW]	H_{eff} [cm]	L/B	Reamer width on waterl. [m]
pulling	106	138	8,33	70	4,0	1,13
pushing	124	172	8,39	76	4,0	1,13
Fennica	98	129	15	72	4,5	1,8

3.4.2 Turning tests with forward speed

Four turning tests with full initial forward speed were performed, two of them with moderate azimuth angles of 50°/50° and 30°/30° and remaining two with the same azimuth angles as in the zero speed tests 60°/90°, the first to starboard and the second to port. The shapes of the turning circles can be seen in Figure 8 and numeric data in Table 3.

Several turning tests were carried out during the model test series. An example of these results, comparable to the first test mentioned in Table 3, is presented in Fig. 8. This test was carried out in level ice of thickness 60 cm. The tactical diameter of the turning circle is seen to be about 95 m. The model test series was carried out with several ice thicknesses and from the corresponding turning circle tests it can be deduced that the tactical diameter is, at least, piecewise linear in the ice thickness range from 55 cm to 83 cm. The model test series was carried out with several ice thicknesses. In order to make the comparison of the different turning circles in Fig. 8, we may assume that the tactical turning circle diameter is piecewise linear in the thickness range of the model tests i.e. between 55 cm and 83 cm. Based on the tests a correction factor for the tactical diameter versus ice thickness may be derived. It is

$\frac{\Delta D}{\Delta h} = 420$. With this correction, the model test results are almost identical with the full scale results.

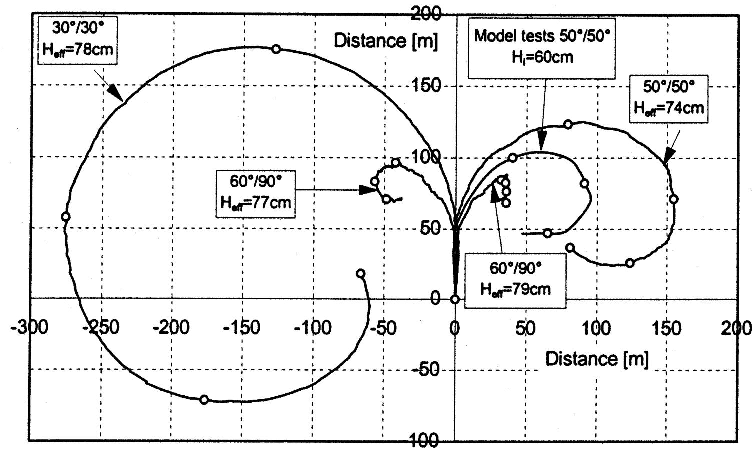


Figure 8 *Tracks of the ship mid-point in turning circle tests. The thrusters were deflected in origo, and the dots on the track denote positions, where the ship had turned 90°, 180°, 270° and 360° respectively. The 60°/90°-test to port as well as the model test were stopped after the ship had turned 270°.*

Table 3 *The dimensions of the turning circles were determined from the track of the ship mid-point.*

Init. speed [kn]	Azimuth angles	Time to 90° [min:sec]	Time to 180° [min:sec]	Time to 270° [min:sec]	Time to 360° [min:sec]	Advance at 90° [m]	Transfer at 90° [m]	Tactical diameter [m]	Eff. ice thickness [cm]
8,5	50°/50°	1:05	2:09	2:46	3:14	123	79	155	74
7,9	30°/30°	1:10	2:17	3:11	4:15	176	127	276	78
7,6	60°/90°prt	1:23	2:15	2:45	-	95	44	59	77
7,9	60°/90°stb	1:01	1:52	2:20	2:44	84	32	35	79

3.5 Ridge tests

During the trials four ridge penetration tests in all were performed. As an example of the ridge penetration capability of MSV Botnica are the two tests performed in the same ridge section, the thickness profile of which was measured by coring holes through the ridge and the shape of the top surface was measured by levelling. The length of the measured section was 250 m, maximum thickness 17 m and maximum height 2,7 m above water level. The whole ridge profile is given in Figure 11. About a half (116 m) of the section length was penetrated the bow first by ramming, the rest (134 m) by backing. The ridge top profiles rammed going forward were measured with the onboard laser. A result from these measurements is given in Fig. 9.

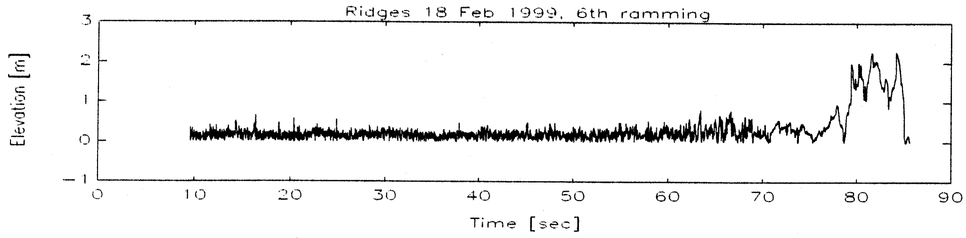


Figure 9 An example of the ridge profiles measured with the onboard laser.

Eight rams in all were performed, the ramming distance was about 450 m. Each ram was divided into phases as can be seen in Table 4. The rams are visualized in Figure 10.

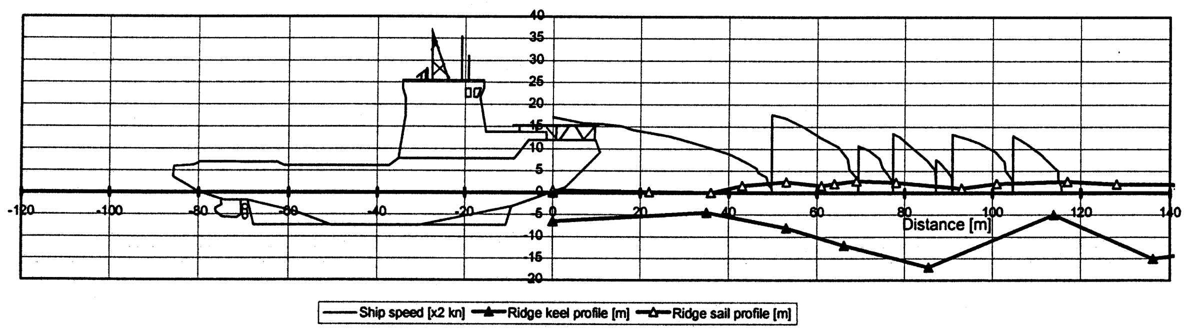


Figure 10 MSV Botnica's speed in each penetration phase as a function of the penetrated distance. In the picture also the ridge profile is presented. For clarification the measured speed values were doubled.

Table 4 Data from the ridge ramming test. Acceleraton phase ends when the bow hits unbroken ice and penetration starts. During penetration phase the speed decreases from the initial penetration speed to zero. In two last columns the length of each penetration and average ridge thickness on this distance were presented respectively. Penetrations in rams 3, 5 and 7 were short due to widening the bow imprint.

Ram	Acceler. phase [s]	Penetr. phase [s]	Stuck in ice [s]	Backing phase [s]	Max speed [kn]	Initial penetr. speed [kn]	Penetrat. length [m]	Aver. thickness [m]
1	110	21	0	239	11,6	8,6	50	9,7
2	103	8	14	134	12,2	8,9	20	12,4
3	111	4	61	54	12,0	5,3	8	16,2
4	61	5	24	95	12,3	6,7	10	17,9
5	105	3	56	68	12,1	3,8	4	16,2
6	106	7	127	149	12,2	6,7	14	12,4
7	117	0	103	97	12,2	2,2	0	10,6
8	121	6	483		12,3	6,5	12	8,8

The penetration by backing was performed using only the propeller thrust contrary to penetration by ramming, when the inertial force of the ship is used in addition to the propeller thrust. It can be seen from the speed time-history in Figure 12, that the penetration is not continuous, but happens periodically, positive speed values denoting moving by backing. First brash ice in the ridge was broken and removed aside with the propeller flow turning the Azipods ±90°. During this operation no penetration took place, but the stern moved laterally 2-3 m. Then the Azipods were turned to full astern and penetration continued several metres untill the ship stopped and the process described above was repeated. From comparison of these two penetration methods in Table 5 it can be seen, that MSV Botnica penetrates in ridges by backing much faster than bow first by ramming.

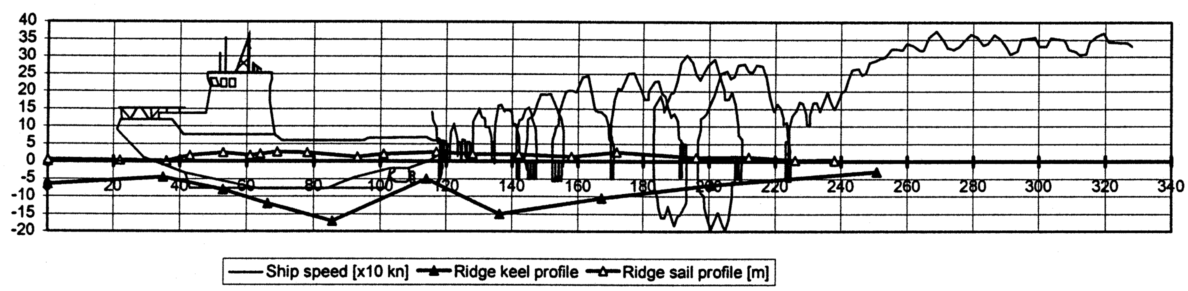


Figure 11 MSV Botnica's speed as a function of position in the ridge profile. The speed values were multiplied by ten for the picture.

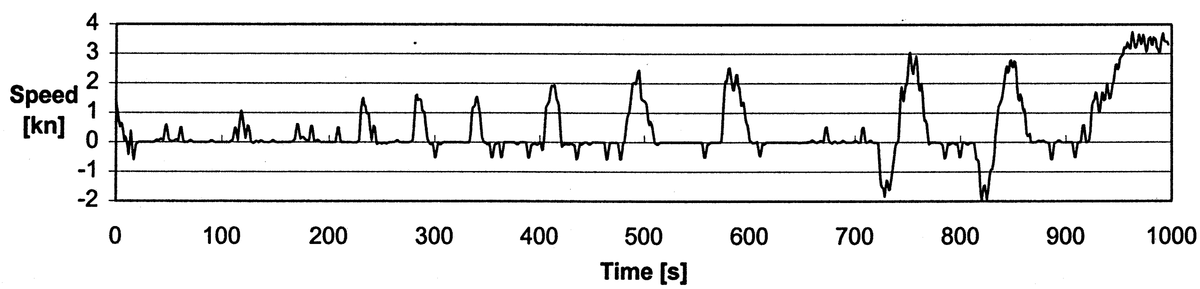


Figure 12 MSV Botnica's speed as a function of time elapsed from the start of the test.

Table 5 Comparison of the two ridge penetration methods.

	Ramming ahead	Backing
Penetrated distance	116 m	134 m
Time used	2592 s	952 s
Average ridge thickness	8,8 m	8,1 m
Average speed	0,09 kn	0,27 kn

3.6 Operative tests

3.6.1 Breaking out of channel

Special tests for breaking out of an old channel from full speed were performed both ahead and astern in both the measured channel sections in Figure 5. No difficulties were observed. Observations were similar also, when this operation was performed with lower speed during other channel operations on the area.

3.6.2 Clearance and widening of channel

The effect of the propeller flow in channel widening and clearance was tested both in level ice and in old channel. Level ice thickness was 65 cm with 18 cm snow, and the old channel profile Channel 1 in Figure 4. Thruster angles of 30°-60° were used in level ice and 15°-45° in old channel, thruster angle meaning here angle outwards on both sides. The channel width and clearance was recorded by video from helicopter.

However, in the test with thruster angles of 60°, disturbing vibrations were aroused due to too short distance between the pulling propellers. As a practical maximum of 45° for the thruster angles was concluded. In level ice the channel width increased about 20% when the thrusters were deflected from the center position to the angle of 45°, the ship speed decreasing from 9,2 kn to 4,0 kn. In old channel the increase in channel width was 50% compared with the initial state and the speed decreased to 6 kn from the initial speed of 12,5 kn. The results from the channel widening and clearance tests are in Figure 13 in which also corresponding results of the multipurpose icebreaker Fennica in 55 cm thick level ice are as a comparison [2]. It can be noticed that the channel widths in level ice are almost equal for these two ships with thruster angles of 45°, but with thruster angles of 60° the channel width of MSV Botnica was 1,5 times the initial width whereas that of MSV Fennica was 2,4 times the initial width. However the different ice thicknesses complicate the comparison as well as the observation that the power of MSV Botnica decreased from 10 MW to 7,5 MW due to the vibration.

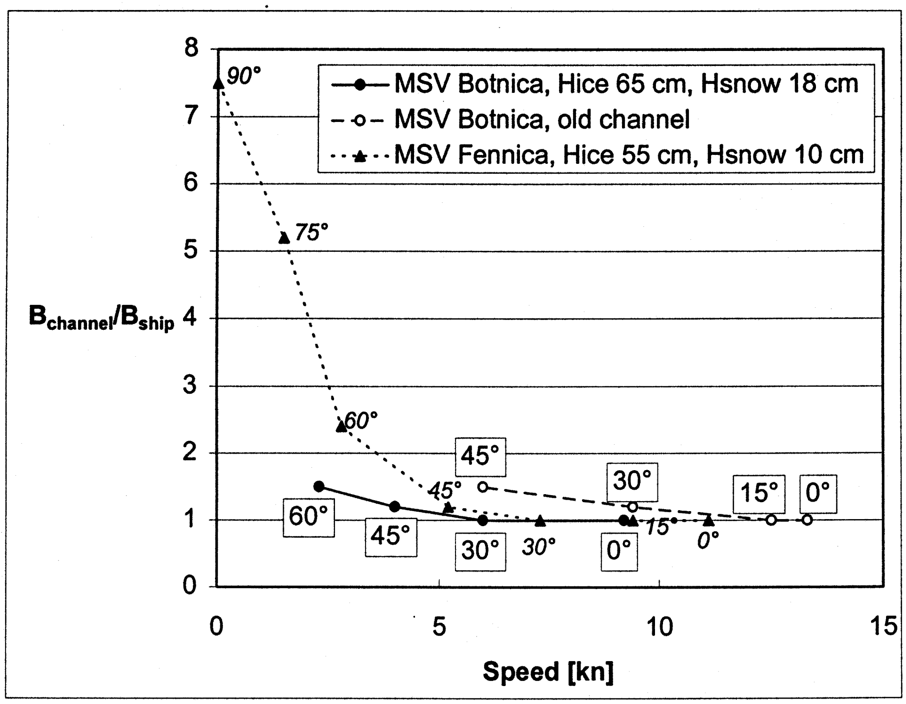


Figure 13 Results of the channel widening tests in level ice and in old channel. As a comparison also corresponding results from the tests in level ice of MSV Fennica were presented [2].

4. CONCLUSIONS

The full scale trials were conducted succesfully and the results confirmed the expectations of the designers. The vessel was able to exceed the speed of 8 knots in 60 cm level ice thickness. The manoevring performance is also good with the tactical turning circle diameter about 1.6 L_{oa} in 74 cm thick ice and the Azipod angles 50°/50°. Further, MSV Botnica is only slightly less capable of breaking level ice compared with the previous multi-purpose icebreakers Fennica and Nordica. This is shown in Fig. 14 where the performance of MSV Botnica is compared with other Finnish icebreakers. In ridges MSV Botnica penetrated faster by backing than the bow first by ramming.

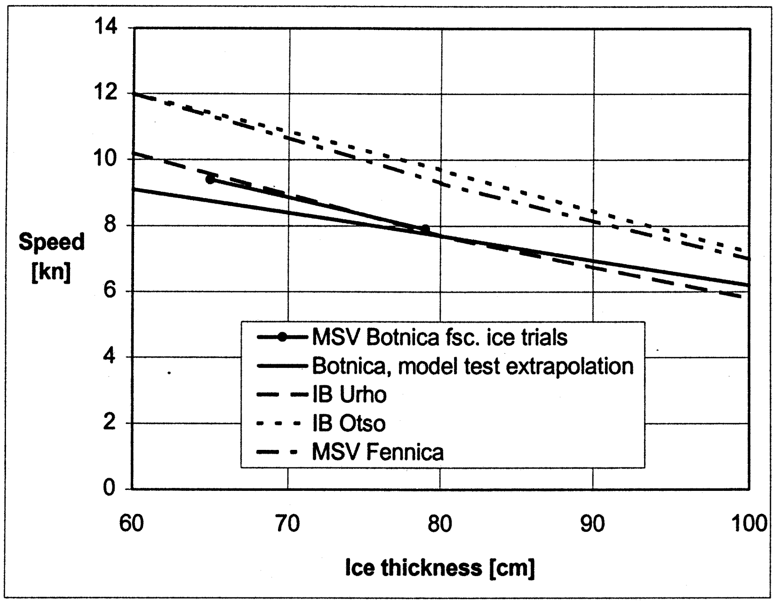


Figure 14 Level ice performance of MSV Botnica compared with other Finnish icebreakers and model tests extrapolation. The propulsion power of the icebreakers is URHO P=16.2 MW, OTSO P=15.0 MW and FENNICA P=15.0 MW.

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