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Multi-pod icebreakers. Influence of bow thruster units on icebreaker performance in open water and ice conditions.*

Leonid G. Shchemelinin[1], Aleksander I. Malikov[1], Ilkka Saisto[2], Artur Nerman[2]

[1]Krylov State Research Center (KSRC), St. Petersburg, Russia
[2]Aker Arctic Technology Inc., Helsinki, Finland

ABSTRACT

The development of infrastructure for transportation of crude hydrocarbons from continental shelf of the Arctic seas required the designing of special-purpose icebreakers that can be operated in restricted shallow water areas with specific ice conditions.

For these purposes, Aker Arctic Technology Inc. proposed the designs of icebreakers equipped with several azimuthing thruster units. These designs are featured by installation of one or two thruster units at the bow in addition to two stern units.

Aker Arctic Technology Inc. ordered and KSRC performed in its towing tank the model investigations of propulsion and pulling performance of such kind of vessels in open water conditions. Within the scope of these investigations, KSRC analyzed the effect of one or two thruster units on propulsion and pulling performance of vessels at various power distribution between bow and stern units.

In particular, these investigations showed:

- significant difference in operation conditions of PS and SB stern thruster units for the vessel with one thruster unit at the bow;
- influence of bow thruster units' toe-out angle on vessel's propulsion performance at various speeds;
- significant difference in the efficiency of power consumption by bow thruster units between bollard pull and full speed modes.

Moreover, the paper presents separate results of ice model tests of such icebreakers performed in Aker Arctic ice basin.

Keywords

Icebreakers, bow thruster units, propulsors' interaction.

1 INTRODUCTION

Aker Arctic Technology Inc. proposed the designs of icebreakers that can be operated in restricted shallow water areas with specific ice conditions in order to support the operation of Novoportovskiy terminal and provide year-round export of Liquefied Nature Gas (LNG) from port Sabetta. The distinctive feature of these icebreakers is that they have one or two thruster units at the bow in addition to two stern units.

Previously, the installation of additional propellers at the bow of icebreakers was practiced many times, in particular, on icebreakers of "Kapitan Belousov" type and some others. The installation of these propellers resulted in the reduction of ice resistance due to washing of the hull by propellers' slipstream. Moreover, they were used for washing of broken ice features.

The installation of azimuth thruster unit at the bow of icebreaker suggests a high maneuverability in open water and ice conditions, which is very important in restricted water areas. Also propeller flushing effect reduces ice resistance and improves ridge penetration capability

On the other hand, it is evident that the installation of the additional thruster unit at the bow of a vessel can affect the operation of the main stern thruster units and reduce the efficiency of propulsion plant.

Open water model tests were performed in KSRC towing tank in order to determine the propulsion and pulling performance of such vessels. Moreover, it was investigated how bow thruster units effect the interaction between stern units and vessel's hull.

Self-propelled models were used in the tests performed in bollard-pull and similar modes as well as in full speed modes at various power ratio of bow and stern thruster units. The tests were performed according the procedure of self-propulsion tests for multi-shaft vessels referred to in the paper (Kanevsky et al 2011a).

Ice model tests were performed in ice basin of Aker Arctic Technology Inc.

Some results of mentioned investigations are included in this paper.

2 CONFIGURATION WITH ONE THRUSTER UNIT AT THE BOW AND TWO THRUSTER UNITS AT THE STERN

The model of icebreaker (project Aker ARC 130A) was used in the investigation of interaction between stern thruster units and the hull of icebreaker equipped with one additional bow thruster unit.

The photos given in figure 1 show the layout of bow and stern thruster units installed in "ahead running" position.

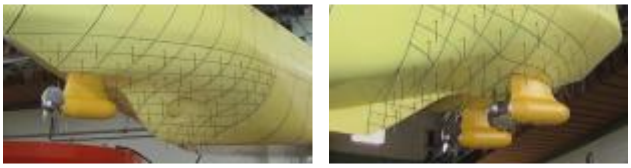

Figure 1. Thruster units installed on the model of Aker ARC 130A icebreaker.

Basic parameters of Aker ARC 130A icebreaker thruster units are given in Table 1.

Table 1. Basic parameters of Aker ARC 130A icebreaker thruster units

Stern units	Type		Pulling AZIPOD
	Number		2
	Power at unit's propeller	MW	7.5
	Propeller diameter	m	4.2
Bow unit	Type		Pulling AZIPOD
	Number		1
	Power at unit's propeller	MW	6.5
	Propeller diameter	m	4.0
Design speed of the vessel		kn.	16

The investigations were performed at right-handed rotation of bow unit's propeller and at various power distribution ratio of bow and stern units in bollard pull mode as well as in running modes.

Test results are given as relationships between wake coefficient w (Figure 2) and thrust deduction factor t (Figure 3) and effective thrust load coefficient K_{DE} (Voytkunsky 1985) at various ratios of units' power.

K_{DE} coefficient is determined as for the vessel with 3 propellers:

$$K_{DE} = V \cdot \sqrt{2 \cdot D_{PA}^2 + D_{PF}^2} : \sqrt{\frac{T_E}{\rho}} \qquad (1)$$

where: D_{PA} and D_{PF} = diameters of propellers of stern and bow thruster units respectively; V = model speed; T_E = total effective thrust of the thruster units; ρ – water density.

The following meanings of subscripts are assumed hereinafter:

$_A$ – values related to stern thruster units;
$_F$ – values related to bow thruster units;
$_{SB}$ – values related to SB thruster units;
$_{PS}$ – values related to PS thruster units.

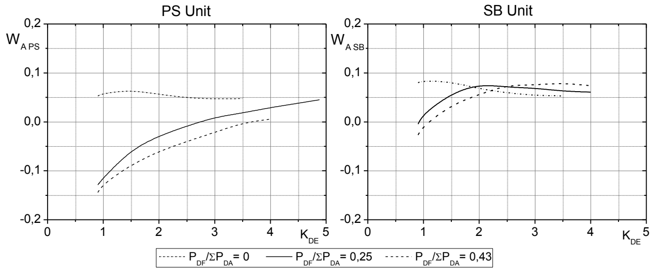

Figure 2. The relationships of wake coefficients w for SB and PS stern thruster units at various power ratios of bow (P_{DF}) and stern (P_{DA}) thruster units.

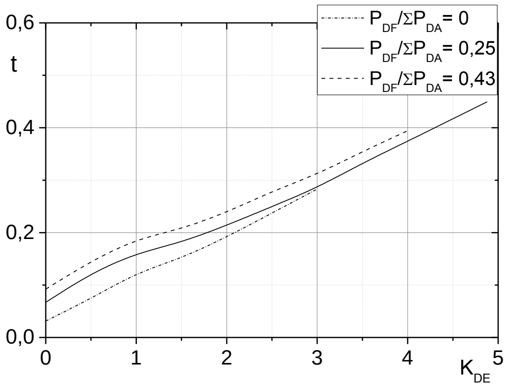

Figure 3. The relationships of thrust deduction factor t at various power ratios of bow (P_{DF}) and stern (P_{DA}) thruster units.

Such configuration of thruster units features a significant difference in operation conditions of PS and SB stern units due to the influence of bow unit slipstream. It can be illustrated by the relationships for wake coefficient in Figure 2 as well as by performance curves of PS and SB models of unit behind hull given in Figure 4.

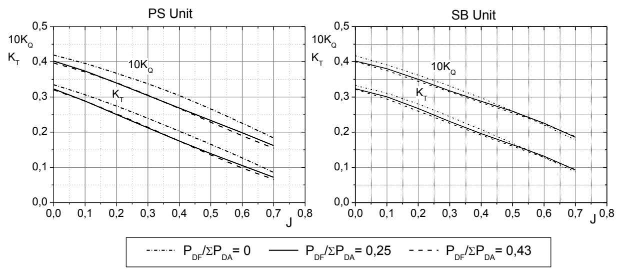

Figure 4. Thrust coefficient K_T and torque coefficient K_Q for SB and PS stern units versus advance J_V at various power ratios of bow and stern units.

3 CONFIGURATION WITH TWO THRUSTER UNITS AT THE BOW AND TWO THRUSTER UNITS AT THE STERN

The model of port icebreaker (project Aker ARC 124) was used in the investigation of interaction between stern thruster units and the hull of icebreaker equipped with two additional bow thruster units.

The photos given in figure 5 show the layout of bow and stern thruster units installed in "ahead running" position.

Figure 5. Thruster units installed on the model of icebreaker Aker ARC 124.

Basic parameters of Aker ARC 124 icebreaker's thruster units are given in Table 2.

Table 2. Thruster units of icebreaker Aker ARC 124

Stern units	Type		AZIPOD ICE1400
	Number		2
	Power at unit's propeller	MW	3.0
	Propeller diameter	m	3.0
Bow units	Type		AZIPOD ICE1400
	Number		2
	Power at unit's propeller	MW	3.0
	Propeller diameter	m	3.0
Design speed of the vessel		kn.	15

The tests of this model included the studies of the effect of the toe-out angle of propeller shafts' axes of the bow units on the effective thrust of icebreaker in bollard pull mode. During these tests, performed at the load corresponding to three variants of power distribution between bow and stern units, steering angles of bow units were changed in the horizontal plane

The results of these investigations are given in Figure 6 as total effective thrust coefficient K_E versus toe-out angle of bow units φ.

$$K_E = \frac{T_E}{\rho n^2 D_P^4} \quad (2)$$

where: D_P = diameters of units' propellers; n = rotational speed of stern units' propellers; T_E = total effective thrust of the thruster units; ρ = water density.

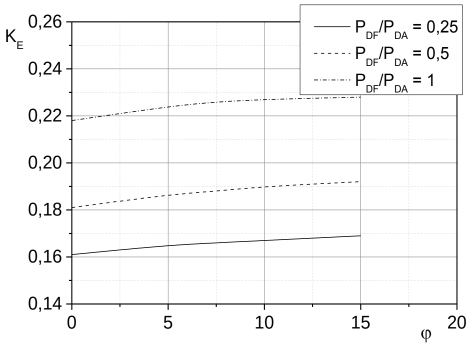

Figure 6. Total effective thrust coefficient K_E versus toe-out angle of bow units φ for various power distributions between bow and stern units in bollard pull mode.

Based on results of these investigations it was decided to proceed self-propulsion model tests with bow units turned at toe-out angle of φ=10º. As it was expected, the greatest effect of toe-out angle is observed at the equal power at the bow and stern thruster units.

Subsequent model tests in running modes were also performed at various ratios of power delivered to bow and stern thruster units. The results of these tests are given as relationships between wake coefficient of stern units w_A (Figure 7) and thrust deduction factor t (Figure 8) and load coefficient K_{DE}.

K_{DE} coefficient is determined as for the vessel with 4 propellers of the same diameter:

$$K_{DE} = V \cdot D_P : \sqrt{\frac{T_E}{4\rho}} \quad (3)$$

and thrust deduction factor t is determined as:

$$t = 1 - \frac{T_E}{\sum T_i} \quad (4)$$

where: D_P = diameter of units' propellers; V = model speed; T_E = total effective thrust of the units; T_i - thrust of each unit; ρ = water density

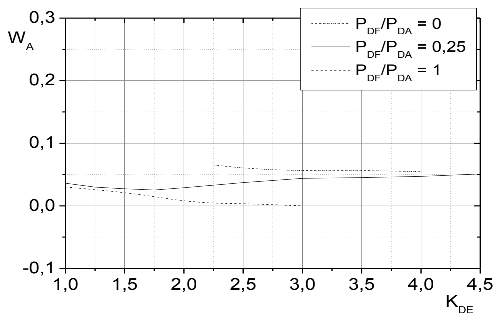

Figure 7. The relationships for wake coefficient of stern thruster units w_A at various ratios of power delivered to bow and stern units.

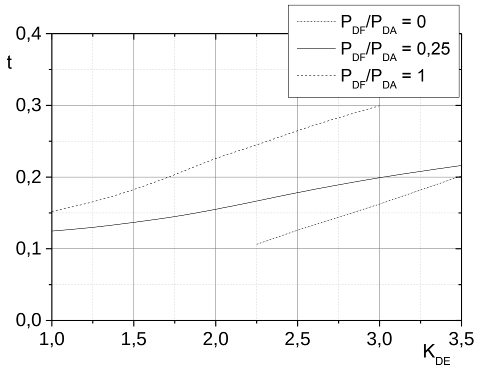

Figure 8. The relationships for thrust deduction factor at various ratios of power delivered to bow and stern thruster units.

4 INFLUENCE OF POWER DISTRIBUTION BETWEEN THRUSTER UNITS ON PROPULSION AND TOWING PERFORMANCE

The calculations of propulsion and towing performance of both icebreakers were performed for various variants of power distribution between bow and stern thruster units based on model test results.

These calculations showed that due to bow thruster units, the maximum speed of icebreaker in open water can be increased but the consumption of power delivered to these units is low.

The result of the use of bow thruster units in open water can be illustrated by means of K_P factor. This factor is equal to the relationship between total power consumed by propulsion system with operating bow thruster units and the power consumed during the operation of only stern thruster units at trailing of bow units' propellers. Corresponding relationships are given in Figure 9 for Aker ARC 130A icebreaker with one bow thruster unit and in Figure 10 – for Aker ARC 124 icebreaker with two bow thruster units.

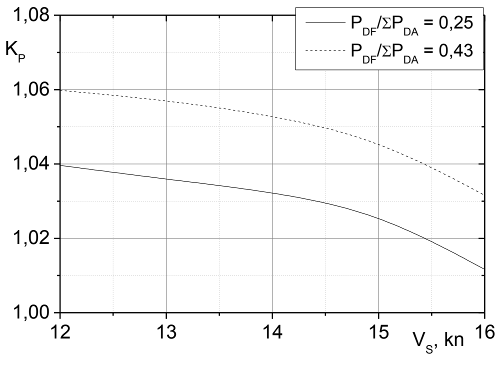

Figure 9. K_P factor versus speed of Aker ARC 130A icebreaker with one bow thruster unit.

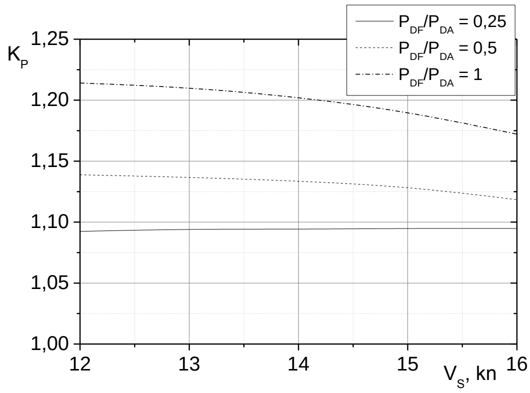

Figure 10. K_P factor versus speed of Aker ARC 124 icebreaker with two bow thruster units.

It should be noted that during the operation of bow thruster unit of icebreaker ARC 130A, the propellers of its stern units should be rotated with different speed. Figure 11 shows the relationships between rotational frequencies of PS and SB stern thruster units at various power ratio of stern and bow thruster units.

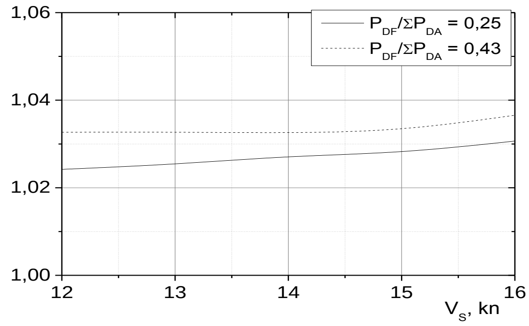

Figure 11. The relationships of rotational frequencies of PS and SB stern units' propellers of Aker ARC 130A icebreaker during the operation of bow thruster unit.

Model test results made it possible to calculate the effective thrust of the vessel in bollard pull and similar modes. These calculations were performed by means of a special "bollard pull" system of thruster unit/hull interaction coefficients (Kanevsky et al 2011b) because the application of conventional calculation procedure is not correct for these modes.

The analysis of effective thrust calculation results made it possible to determine the relationships between bollard towpull of icebreaker during joint operation of stern and bow units $T_{Z(A+F)}$ and bollard towpull during the operation of only stern units in bollard pull mode and at speed of 3 knots. Such comparison seems to be even more important for this kind of vessels. Table 3 gives such relationships along with corresponding relationships between total power consumed by all thruster units and power at stern thruster units.

Table 3. The relationships of bollard towpull and power consumed in bollard pull and similar modes.

Mode	Power ratio	Ratio of bollard towpull values	
		$V_S = 0$	$V_S = 3$ kn
	$(\sum P_F+\sum P_A)/\sum P_A$	$T_{Z\ (A+F)}/T_{Z\ A}$	$T_{Z\ (A+F)}/T_{Z\ A}$
2 stern units	100%	100%	100%
1 bow +2 stern	125%	125%	119%
	143%	136%	132%
2 bow +2 stern	150%	149%	-
	200%	179%	173%

Table 3 shows that in bollard pull and similar modes the increase of bollard towpull justifies the increase of consumed power due to bow thruster units.

5 OPERATION IN ICE CONDITIONS

Port Icebreaker (Aker ARC124) intended for supporting LNG carriers' operability in approach channel to harbor and in the terminal of Sabetta. The primary tasks of the icebreaker is escorting LNG carriers through approach channel into the port, the icebreaking in port and the assistance in harbor manoeuvres of the tankers. One task is also the ice management in the approach channel and harbor basin.

The port icebreaker (Aker ARC124) with four azimuthing propulsion units is designed with ice-going properties both ahead and astern. She is able to proceed at 2 knots speed in 1,5 m thick level ice and 4 knots speed at 5 m thick brash ice in limited conditions water depth which prevails in Sabetta harbor area.

The hull form and propulsion arrangement are designed to give maximized operability in level ice and especially in pre-broken very thick brash ice in limited water depth conditions which prevail in approach channel and in harbor basin.

Two of the thrusters are pushing type located to stern of the vessel maximizing ice management by ice flushing effect of propeller wake. This is especially important close to the mooring dolphins where otherwise the brash ice could block large LNG carriers to complete mooring. Two pulling type thrusters are located in bow of the vessel minimizing ice resistance by efficient flushing of hull and maximizing operability in brash ice and rubble fields. Hull form and thruster arrangement give excellent maneuverability in ice and enable managing ice by pushing it away by the vessel's vertical sides.

The propulsion system of icebreaker, Aker ARC130A, consists of three azimuth thrusters: two in the stern and one in the bow of the vessel. This propulsion layout is considered to be particularly suitable for difficult ice conditions such as thick brash ice and ice ridges which are expected to be very challenging in Ob bay winter season. The icebreaker is capable of breaking two meters thick level ice with 30 cm snow cover both ahead and astern. The tanker traffic will become intense once the oil terminal is completed, resulting in a large amount of brash ice. The consolidated brash ice cover is estimated to grow to a thickness of up to seven meters, in an area where the water depth can be as little as ten meters. The new icebreakers are designed to operate in these challenging conditions. Their maneuverability, which is considered an important safety factor when operating in close proximity to oil tankers, is also exceptionally good for such large vessels.

The performance in ice of both icebreaker concepts were tested in ice at Aker Arctic's ice model basin.

6 CONCLUSION

Based on performed investigations it is evident that additional bow azimuth thruster units used on icebreakers with stern azimuth thruster units and limited draft can significantly increase their pulling performance in bollard pull and similar modes. In this case, the vessels acquire excellent maneuverability. But during the operation in open water, it is reasonable to provide only trailing of bow propellers in order to reduce their resistance. The use of bow units' power to increase the maximum speed of the vessel is inexpedient.

Installation of one bow thruster unit at the centerline of the vessel results in significant difference of stern units operating conditions, so their propellers are required to be rotated with different speed.

When two additional thruster units are installed at the bow, it is reasonable to provide divergence angle of their propeller shafts of about 10° in order to direct their slipstreams towards the respective sides.

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DISCUSSION

Question from Hannu Jukola

What are the rotation directions of the aft propellers in the bigger vessel and all of the propellers in the port icebreaker?

Author's closure

The rotation directions of the aft propellers in the model of ARC 130A vessel and all of the propellers in the model of port icebreaker were outward.

Question from Francesco Salvatore

Consider the single-pod at bow. Do you expect that efficiency in transit operation (free running) could be improved by an asymmetric hull bow design?

Author's closure

No, I don't expect that asymmetric hull bow design can impove efficiency in transit operation.

Question from Asif Amin

Ice management ?

Author's closure

Yes, of course. This type of icebreakers will be very effective for tasks of ice management.