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"Azipod" Azimuth Thruster for large capacity arctic transport ship with high ice category Arc7. Ensuring of operability and operating strength under severe ice conditions

A.V. Andryushin[1], S. Hänninen[2], T. Heideman[2]
[1]CNIIMF, St. Petersburg, Russia; [2]ABB Marine & Cranes, Helsinki, Finland

ABSTRACT

Intensive development of the Arctic shelf and icebreaker fleet are in the progress now. Nowadays large capacity arctic ships are being designed to provide effective transportation of hydrocarbons from the Arctic shelf. These ships will operate without icebreaker assistance under severe ice conditions. The type of this ships is pushing-pulling i.e. both ahead and astern modes can be used in ice covered waters. However, astern mode is used for navigating under severe ice conditions. It is planned to fit these ships with high power AZIPOD Azimuth thrusters to achieve the highest operating efficiency. Assurance of Azimuth thruster reliability is one of the most important problems within the framework of designing of modern large capacity arctic ships.

This paper describes modern methods and results concerning the assurance of operating strength of 15MW AZIPOD for large capacity pushing-pulling tanker with category Arc7. Pushing-pulling ice ship has moderate ice bow and can move both ahead and astern under ice conditions. The calls at Siberian river mouths with fresh ice of a higher strength are the typical operational conditions for this ship. The main principles of the assigning of ice strengthening on main elements in line of force as well as ice loads acting on the propeller and AZIPOD elements are considered in this paper. The main results concerning the assurance of operability of main electrical engine are presented as well.

INTRODUCTION: Trends of modern arctic shipping and shipbuilding.

Nowadays the Extreme North is being intensively explored. First of all it is caused by the development of oil and gas deposits and etc. Volume of cargo traffic on the NSR is permanently increasing.

Increasing of the effectiveness of transport systems in the Arctic regions is associated with the increasing of capacity of ice ships, improvement of their operational characteristics such as ice propulsion and maneuverability. These tendencies call forth the general increase of displacement and propulsion power of ice ships. In perspective the south-eastern part of the Kara Sea including mouths of Yenisei and Ob rivers will be actively used for transportation of general cargo, oil and carbon dioxides to the Western Europe all year round. The most effective transportation in these water areas is carried out by large-capacity Arc7 ships without icebreaking assistance in the Kara Sea. To a considerable extent this is defined by the restricted number of powerful icebreakers for escorting of these ships. In order to provide independent operation during severe navigations in the south-western part of the Kara Sea icebreaking capability should be about 2.4 m [1]. The mentioned above is the reason for the increase of icebreaking capability and propulsion power of the perspective ice ships. Double-acting (DAS) and "Pushing-pulling" ships [2] moving astern in heavy ice conditions are the most effective solution for the increase of ice propulsion. Installation of azimuth thrusters (AT) improves operational characteristics of icebreaking ships and is one of the main conditions of practical realization of DAS and "Pushing-pulling" ships. The stated above calls for the necessity to develop new azimuth thrusters of a higher power with additional strengthening to ensure strength while operating under heavy ice conditions including astern movement mode. Propulsion power of 15 MW is the basic one for the formation of propulsion units consisting from one, two and three azimuth thrusters for the perspective ships with icebreaking capability up to 2.4 m in astern movement mode. Conceptual design of 15MW “Azipod” with additional strengthening was made to ensure year-round independent navigation in the south-western part of the Kara sea taking into account calls at Yenisei and Ob river ports.

1. MAIN APPROACSHES TO ENSURE RELIABILITY and OPERABILITY OF ICEBREAKING AZIMUTH THRUSTERS.

Movement of ships is provided by propulsion complex (PC) and strength of the elements which should withstand strong ice loads. Load carrying capacity of AT under ice conditions is determined by fatigue and pyramidal strength of the main elements in lines of force. Fatigue strength is determined by ice loads acting on propeller and hull of AT.

Propeller is the main element of AT. The fatigue caused by ice loads under ice milling regimes is the determining factor to assign its strength sizes (blade scantlings) for steel propellers.

Principle of a pyramidal strength is the main one for designing of icebreaking propulsion systems. This principle may be used as a main criterion to estimate strength sizes of AT at the initial stages of design. It doesn’t exclude verification and correction of azimuth thruster strengthening proceeding from the condition of strength caused by action of ice load on propeller and hull of AT.

Providing for the operability of main electric engine (MEE) under ice conditions is one of most important task. Under operability of MEE one understands its ability to maintain the required power and speed of rotation to ensure thrust and prevent propeller stoppage and damage of its blades. This issue is very important for DAS and icebreakers’ propellers which permanently operate under heavy ice conditions and interact with ice. Maximum torque of MEE is one of the main parameters defining its operability, rotor diameter and overall dimensions of Azimuth thruster. Therefore the solution of this task should be of first-priority in design of icebreaking Azimuth thruster.

In addition it is necessary to determine required values of power and torque of Azimuth thruster steering system to provide its effective operation as well as operation of whole ship.

The problems listed are interrelated and, solving one problem it is necessary to take into account the others. Nowadays the solution of the mentioned problems is within the bounds of a special consideration.

2. TYPICAL OPERATING CONDITIONS FOR Arc7 ICE CATEGORY SHIPS OPERATING IN THE KARA SEA AND CALLING AT MOUTHS OF SIBERIAN RIVES

Characteristics of ice conditions of the Kara Sea are presented in publications [3, 4]. Thickness of the first-year thermal ice in the south-western part of the Kara Sea may reach 1.5-1.8m [4]. The fast ice thickness is about 2m. For the Kara Sea strong ice sheet compression and ridges are typical. Ridges present the heaviest conditions for the propulsion system of DAS in the movement astern mode. Average and maximum depth of the ridge keel is 8 m and 15 m calling forth the interaction of ridge with azimuth thrusters. The consolidated layer of ridge may reach 2m.

Main operating and planned ports are located in the Yenisei Gulf and in the Ob Bay. Thickness of the thermal ice in the mouths of Yenisei and Ob rivers reaches 2 m. The indicated water areas are characterized by the fresh ice with a strength larger than sea ice. Crushing strength of the fresh ice and ice loads on the propeller and on other AT elements for the Yenisei Gulf and Ob Bay exceed on the average by 25% those for the Kara Sea (under other similar conditions) [2].

Relatively low depth of the Yenisei Gulf and the Ob Bay is a serious restriction influencing the design of propeller and other azimuth thruster elements. Without dredging works the maximum passage draft of ship in the Ob Bay is about 9.5 m. In this case, the delivery of high propulsive power leads to the increase of the expanded area ratio for propeller (AER) and its strength sizes. The last factor results in the increase of ultimate blade damage load and in the supplementary strengthening of other azimuth thruster elements.

3. PROPELLER DESIGN AND ASSIGNING OF PROPELLER BLADE SCANTLINGS

Limited depths of the Yenisei Gulf and of the Ob Bay regulate the draft of ship and to a considerable degree define principal propeller characteristics – diameter D, expanded area ratio AER. Evaluation of D and AER (blade width) was made proceeding from the condition of ensuring acceptable overtorque safety factor of the MEE, preventing the second stage of cavitation under the bollard condition. Distribution of the blade width was determined on the assumption of the optimum distribution of circulation along the propeller radius. Fig. 3.1 shows the relative blade width $\bar{c}(\bar{r}=0.8)$ depending on ship's draft for diameter $D = 6$ m at a relative radius of 0.8. Fig. 3.2 presents the respective cavitation diagram obtained as a result of the analysis of full-scale tests of icebreaking ships under bollard conditions. Value $\bar{c}(\bar{r}=0.8)$ is determined the following way:

$$\bar{c}(\bar{r}=0.8) \geq \left[k_C \cdot F(K_1)\right] / \omega_{design} \tag{3.1}$$

where $F(K_1) \overset{def}{=} \left[\bar{c}(\bar{r}=0.8) \cdot \omega\right]$; ω - cavitation number determined by the submergence depth of upper blade tip; ω_{design} - design cavitation number; k_C - coefficient of correlation; K_1 - thrust coefficient.

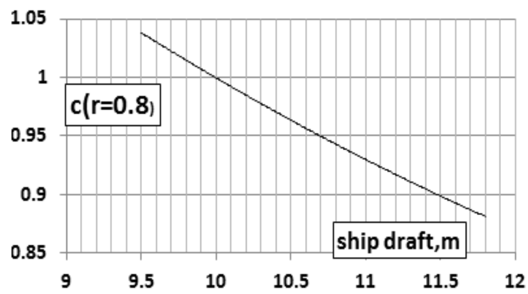


Fig. 3.1 Relative propeller blade width c(r=0.8) for D=6м at 15MW depending on ship draft

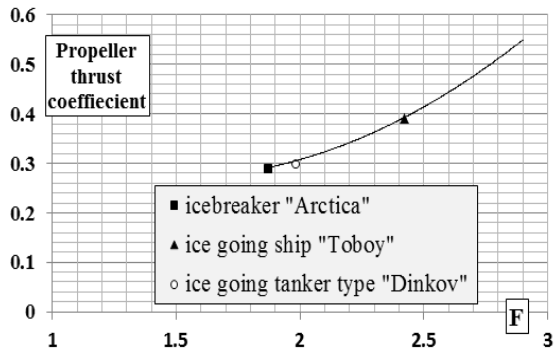


Fig. 3.2 Cavitation diagramm for icebreaking propellers under bollard conditions

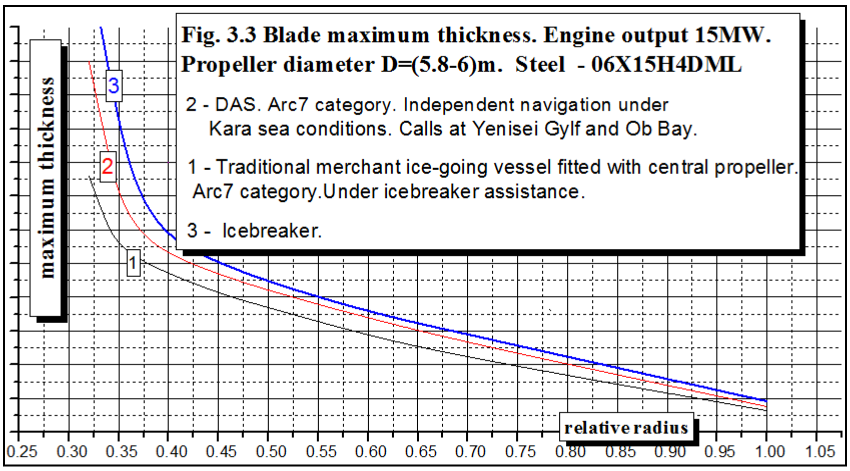


Fig. 3.3 Blade maximum thickness. Engine output 15MW. Propeller diameter D=(5.8-6)m. Steel - 06X15H4DML

k_C value depends on blade thickness, blade outline, type of profile. For icebreaking propellers with traditional profiling $k_C \cong 0.95$. Ship's draft was taken equal to 9.5m disregards of dredging. The latter assumption determines the largest values of AER and azimuth thruster strength sizes this permits evaluation of the possibility of azimuth thruster delivery for the most unfavorable conditions. Table 3.1 shows preliminary values of principal parameters of the propeller.

Table 3.1 Principal characteristics of the azimuth thruster propeller with a power of 15 MW

Propeller diameter, m	AER	$\bar{c}\,(\bar{r}=0.8)$	Pitch ratio at $\bar{r}=0.8$	blade material	The blade surface	Bollard thrust at 15MW,t
$D \cong (5.8-6)m$	0.74	1.05	$(P/D)=0.8$	Steel type 06X15H4DML	shot peening	490

Blade scantlings were assigned at the request of the draft of RS rules [5] as applied to DAS considering the independent operation in the Kara Sea and regular calling at mouths of Ob and Yenisei rivers. To reduce blade thickness it is recommended to use shot peening of the blade surface [2,5]. Fig. 3.3 presents the results of assignment of maximum blade thicknesses along the radius. The analysis shows that the required propeller strength sizes are between those of the icebreaker and the traditional Arc 7 category icebreaking ship with a central propeller.

Determination of principal propeller parameters and the assignment of his strength sizes provides the possibility to assign its strength sizes and provide operability of MEE.

4. OPERABILITY ASSURANCE OF MAIN ELECTRICAL ENGINE UNDER SEVERE ICE CONDITIONS. ASSIGNING OF OVERTORGUE SAFETY FACTOR

4.1 Principal criterion to ensure operability of the main electrical engine.

Assurance of operability of the MEE comes to the assignment of its limit torque $(Q_{engine})_{\lim}$ and the range of rotor rotation speed, where the constant power mode is maintained, see fig.4.1. Limit engine torque $(Q_{engine})_{\lim}$ should not be less than the maximum propeller shaft total moment $(Q_{total})_{\max}$ (without torsional vibration).

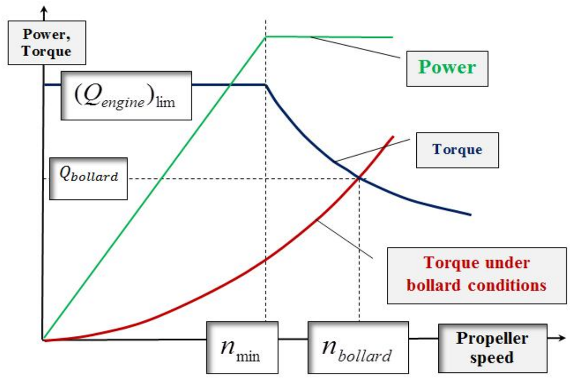


Fig. 4.1 Principal scheme of engine power and torque for main electrical engine vs propeller speed.

$$(Q_{engine})_{\lim} \geq (Q_{total})_{\max} \overset{def}{=} \max(Q_{total}) \qquad (4.1)$$

Where - Q_{total} -– total propeller shaft torque; $(Q_{total})_{\max}$ - maximum value of Q_{total}

Total shaft torque Q_{total}

$$Q_{total} = Q_{hydr} + Q_{ice} - \theta\frac{\partial n}{\partial t} \qquad (4.2)$$

where Q_{hydr} - hydrodynamic propeller shaft torque; Q_{ice} - average ice propeller shaft torque (disregarding torsional vibration); n – propeller speed, $\theta(\partial n/\partial t)$ - inertial torque component; θ - inertia moment of the system “rotor of the MEE – propeller shaft – propeller”; t – running time

If the total shaft torque $(Q_{total})_{\max}$ exceeds $(Q_{engine})_{\lim it}$, MEE does not maintain constant power and results in the strong drop of the propeller speed and can cause its stoppage while interacting with ice. These situations are extremely undesirable because of the strong limitation of operating speeds of ship and can result in the blade damage. For the prevention of such situations it is necessary to fulfill condition 4.1 It comes to determination of $(Q_{total})_{\max}$ and Q_{ice}.

4.2 Propeller ice torques

Ice torques Q_{ice} were determined by the results of full-scale trials of large capacity tanker of the "Dinkov" type with two "Azipod" azimuth thrusters and icebreaker "Arktika" moving astern under ridge conditions. Q_{ice} values are determined by propeller parameters, ice thickness H_{ice} and ice crushing strength $(\sigma_{ice})_{crush}$. It is necessary to take into account the dependence of Q_{ice} on the propeller advance coefficient J (attack angle of the blade profile) and accordingly on the ship speed V. Fig. 4.2 presents coefficients q_{ice} of maximum Q_{ice} depending on J. Values of coefficients were determined by formula developed taking into account the results of paper [2]:

$$q_{ice} = \frac{Q_{ice}}{(\sigma_{ice})_{crush}^{design} \cdot D^{2.6} \cdot k_{Hice}} \tag{4.3}$$

where $(\sigma_{ice})_{crush}^{design}$ - design ice crushing strength; k_{Hice} - coefficient taking into account the effect of ice thickness H_{ice}, [2].

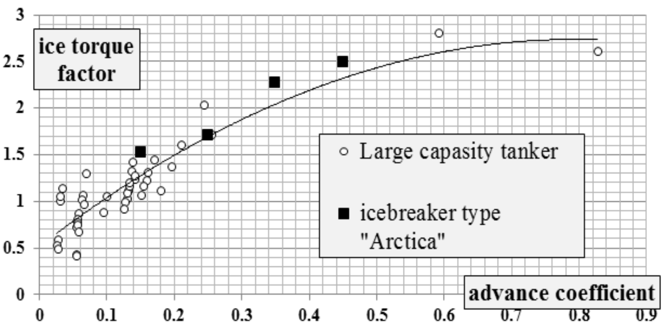


Fig. 4.2 Ice torque factor vs advance coefficient
for astern modes under ridge conditions

The design strength of ice for crushing was determined by the methodology [2] depending on ice unconfined strength at vertically loaded ice sheet. Design values Q_{ice} were recalculated by formula 4.3 for values $(\sigma_{ice})_{crush}^{design}$ and H_{ice}, corresponding to winter-spring operation in the Kara Sea and river mouth sections.

4.3 Results of the modeling of the total torque of electrical main engine for the designed azimuth thruster. Assignment of the design overtorque safety factor.

Modeling of torque Q_{total} was made on the basis of equation 4.1 with necessary correction for a design power of 15 MW. Figures 4.3 and 4.4 present the results of calculation $q_{overtorque} = (Q_{total} / Q_{bollard}) = f(V)$ and $q_{overtorque} = f(n / n_0)$ for astern mode under heavy ridge ice conditions of the Kara Sea. For the assignment of the design torque of MEE it is important to determine maximum service speed of ship in ice $V_{\max}$. During the movement in real ice conditions there are always sections with easy ice conditions where ship can speed up. Fig. 4.5 shows a bar graph of operating speeds of a large capacity tanker of the "Dinkov" type for astern movement in ridges. Average speed of movement is about 2 knots. Maximum speed is about 9 knots and corresponds to the running out to light ice conditions between ridges. Assessment of the maximum speed of ship may be carried out by formula $V_{\max} \cong 0.6 \cdot V_0$, where V_0 - ship speed under open water conditions at full power [2]. Taking into account the above stated for large capacity DAS ship the design overtorque safety factor of MEE should be taken equal at least to $q_{overtorque} \cong (1.7 - 1.8)$.

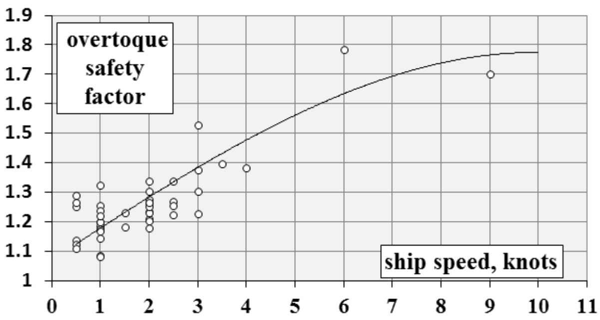


Fig. 4.3 Overtorque safety factor vs ship speed. Kara Sea, ridges. Astern

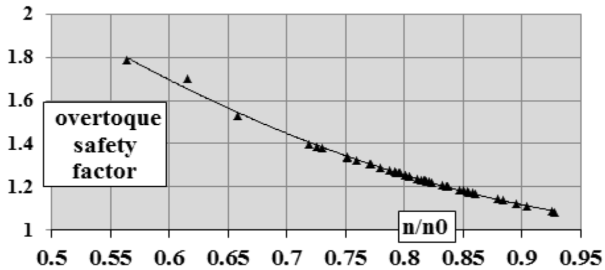
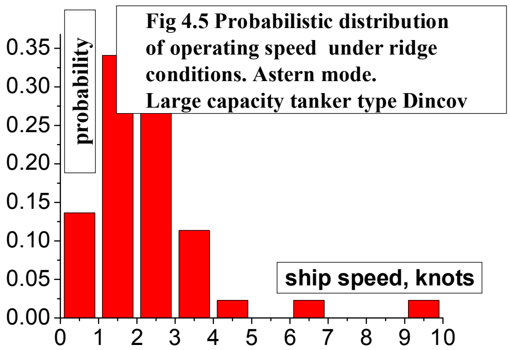


Fig. 4.4 Overtorque safety factor vs propeller speed n, n0-propeller speed under bollard conditions. Kara Sea, ridges. Astern



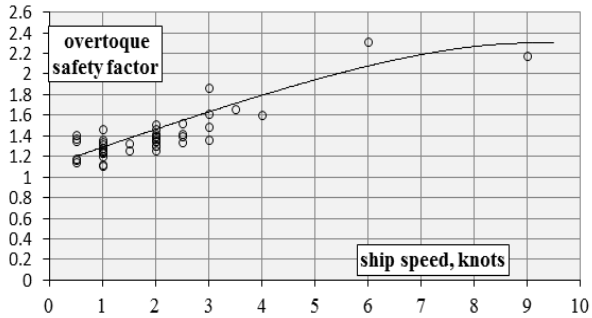


Fig. 4.6 Overtorque safety factor under ice conditions. Enisey Gulf, Ob bay. Astern

During the operation in river mouths with fresh ice, ice loads on propeller increase. As a result it is necessary to reduce ship' speed in order to ensure safe operation. Fig. 4.6 presents the results of modeling of $q_{overtorque}$ for the independent operation in the Ob Bay (Enisei Gulf) moving astern in ice of about 2m thick. At $q_{overtorque} \cong (1.7 - 1.8)$ permissible speed should be reduced down to 4 knots in order to ensure MEE operability and strength of AZ. The analysis shows that the assurance of strength of the propulsion system is the determining factor for the assignment of safe speeds of DAS in astern movement mode. The last circumstance should be born in mind while developing ice certificate

5. ASSIGNING OF MAIN DIMENSIONS AND STRENGTHENING

Overtorque safety factor of MEE determines rotor and pod dimensions. Length of the pod is to be specified more accurately proceeding from the arrangement of propeller, intermediate and thrust shafts as well as of main-thrust bearing (MTB). At the first stage, propeller shaft diameter and type of MTB are determined from the condition of pyramidal strength. Assignment of the ultimate blade damage load was made according to the RS draft requirements [3,4]. Determination of main propeller and azimuth thruster dimensions permits to assess relevant ice loads at later stages of design in order to specify the strengthening more accurately proceeding from fatigue and pyramidal strength.

6. DETERMINATION OF ICE LOADS ACTING ON THE AZIMUTH THRUSTERS

Determination of ice loads on propeller and hull of Azimuth thruster is the obligatory condition to provide ice strength.

6.1. Ice loads on propeller

Axial design ice loads on propeller for assigning thicknesses of its blades and providing load carrying capacity of main thrust bearing and other elements were determined on the basis of design project (draft) of new RS requirements[2,3].

6.2 Ice loads on Azimuth thruster hull

6.2.1 Scenarios and regimes for determination of ice loads on Azimuth thruster hull

Ice loads on Azimuth thruster elements may be determined by the following scenarios:

1. Impact with ice fragment
2. Cutting of ice by the elements of Azimuth thruster (by struds) at the astern mode.

Process of the permanent ice cutting by struds of Azimuth thruster leads to the dramatic increase of ice resistance, decrease of ice propulsion and makes the turning of Azimuth thruster impossible. Therefore one should avoid this scenario in designing. For the ships considered in this work the heaviest ice conditions are realized in the mounts of Ob and Yenisei rivers. In order to provide safe navigation in these areas transition of ships is fulfilled, as a rule, in a channel made by an icebreaker. Ship's speed in channel reaches 8-9 kn [6]. Formation of the submerged ice fragments occurs under channel edges. Analysis of the operational experience of DAS Norilsky Nickel (NN) type showed that maximum ice loads were stipulated by impacts of the submerged ice block from the edge of channel. Taking into account the above mentioned scenario and regime are taken as the basic design characteristics. In addition it is necessary to take into account loads from Azimuth thruster/keel ridge interaction under operation in the Kara Sea astern.

Axial and transversal ice forces acting on cup of propeller and Azimuth thruster pod are the main in providing of the strength of fastening of AT to hull. Axial force on the cup of propeller should be taken into account for the estimation of load carrying capacity of main thrust bearing.

6.2.2 Main approaches for the estimation of ice loads on the elements of Azimuth thruster

Fig. 6.1 and 6.2 present schemes of longitudinal and transversal ice forces acting on propeller cup and thruster pod. Propeller cup/ice interaction occurs in conditions close to plane deformation. In this case (fig. 6.1) contact ice compression p_{ice} is determined on the basis of hydrodynamic ice/indenter interaction theory [2]

$$\bar{p}_{ice} = 0.66854 \cdot e^{\left(-\frac{x}{0.027}\right)} + 0.33147 \cdot e^{\left(-\frac{x}{0.497}\right)} \qquad (6.1)$$

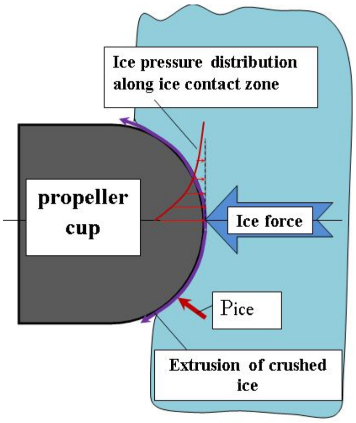
where $\bar{p}_{ice} = p_{ice} / (p_{ice})_{\max}$ - dimensionless contact ice compression; $(p_{ice})_{\max}$ - maximum contact ice compression, p_{ice} - contact ice compression; x - dimensionless ice contact zone; $x \in [0,1]$, 0 – beginning of contact zone; 1 – end of contact zone, $(p_{ice})_{\max} = 15 \cdot \sigma_{compr}^{0.6}$ [7], σ_{compr} - uniaxial compression of ice.

Ice force F_{ice} under given contact area s is determined as:

$$F_{ice} = \int p_{ice} \cdot \cos(n,z) ds \qquad (6.2)$$

where p_{ice} – ice contact compression; (n,z) – angle between surface normal vector and direction of force.

It is assumed that the main impact of the propeller cup is directed vertically to the ice sheet this calling forth the largest values of strength characteristics of ice and ice longitudinal force. It is necessary to consider the ice splitting along ice contact zone during transversal interaction between pod and ice block, see fig.6.2. The latter factor results in the scale effect of the ice strength for crushing $\sigma_{crush}(S)$ on contact area S.



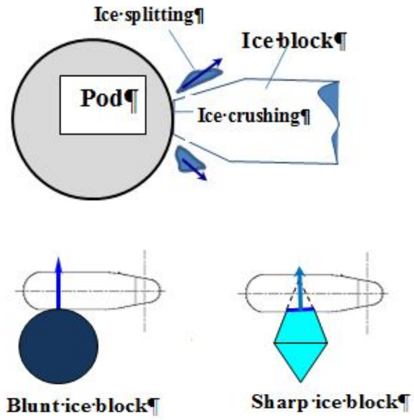


Fig. 6.1 Principal scheme of ice longitudinal force acting on the propeller cup
Fig. 6.2 Principal scheme of ice transverse force determination

Therefore for the estimation of ice force it is advisable to use the conventional approach $F_{ice}(S) = \sigma_{crush}(S) \cdot S$ using experimental data for the ice strength for crushing depending on contact area $\sigma_{crush}(S) = f(S)$, example see in paper [8]. In the transversal impact it is necessary to consider versions of the pod interaction with sharp and blunt edge of ice fragment, see fig.6.2.

Minimal ice force at collision between ice fragment of finite mass and AT element is determined from the general condition:

$$\frac{m_{ice}V_{ice}^{2}}{2} = \int F_{ice}(s) \cdot dl \tag{6.3}$$

m_{ice} – typical mass of ice fragment; V_{ice} – typical speed of interaction between ice fragment and Azimuth thruster l - typical distance of ice breakage.

Typical sizes of ice fragments and their mass were determined in accordance with the following method [9], based on the investigations of Dr. E. Enkvist [10].

6.2.3 The results of assigning of ice loads on the elements of Azimuth thruster

Figures 6.3 and 6.4 present the results of the assignment of extreme (maximum possible) ice loads on AT operating in ice channel of the Ob Bay or Yenisei Gulf. Thickness of fresh ice was taken about 2 m. Sizes of ice fragments were determined from the condition that a channel is made by a shallow draft icebreaker of Taimyr type. Analysis of the results of calculation of the longitudinal ice force shows that for service speeds (8-9 knots) the spherical propeller cup is fully plunged into ice. Calculated values confirm the results of full-scale measurements of loads acting on azimuth thruster of double acting ship of the NN type when operating in the Kara Sea moving astern in hummocks, see fig. 6.3.

Level of the transverse ice force effecting the azimuth thruster pod to a considerable extent is determined by shape of the ice fragment edge interacting with pod. Analysis of load data for the NN double acting ship recorded during the operation in channel of the Yenisei Gulf gives the possibility to take an average curve between sharp and blunt edges as the design curves, see fig.6.4. Estimation of the maximum possible load was made on the basis of the third asymptotic law using full-scale data.

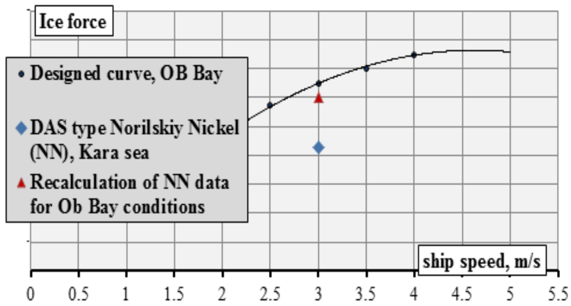


Fig. 6.3 Lognitudinal ice force acting on the propeller cup. Ob bay.
Ice thickness - about 2m.

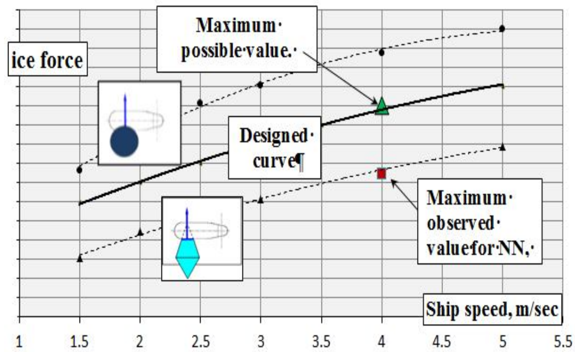


Fig. 6.4 Transverse ice loads acting on the Pod. OB Bay.
Fresh Ice. Ice thickness – about 2 m

7. ASSURANCE OF STEERING SYSTEM CAPACITY OF THE AZIMUTH THRUSTER

Experience of operation and designing of icebreaker azimuth thrusters show that torque of the steering system should ensure rotation of azimuth thrusters while propeller interacts with ice under ice milling mode. In this case, the design torque of steering system $Q_{steering}$ should be not less than

$$Q_{steering} = \max\left(\left(\frac{(Q_{ice})_{\max}}{0.8R}\right)\cdot l;\ (F_{ice})_{\max}\cdot 0.8R\right) \qquad (7.1)$$

where $(Q_{ice})_{\max}$ - maximum ice torque of the resistance to propeller rotation; $(F_{ice})_{\max}$ - maximum longitudinal force acting on propeller (blade); R – propeller radius, l – distance from the propeller disk to the rotation axis of AT.

Ice force $(F_{ice})_{\max}$ is determined in accordance with the draft new requirements of the RS [5]. Assessment of the value of $(Q_{ice})_{\max}$ may be made by the results of section 4 taking into account the component of blade frequency. Effect of operational loads which exceed the designed ones (force of blade breakage, ice loads on pod) should be limited by special protective devices (RS requirements, part VII, chapter 7, section 7.2). For "Azipod" thrusters this requirement is ensured by safety valves in hydraulic steering system.

8. AZIPOD DEVELOPMENT

As discussed in this paper there has been an evident need for azimuthing propulsion units with power in excess of 15 MW with highest ice classes, such as RMRS Arc7 and beyond. In response to the market demand ABB Marine has recently developed an Azipod propulsion concept with high power to meet the requirements of the high arctic ice classes.

The basis for the 15 MW pod design is the well proven Azipod type VI2300. To date 16 Azipod VI2300 units have been delivered to Russian owners and they have operated successfully for several years without any major problems. The first vessel of the "Norilskiy Nickel" was instrumented for four years and measured ice loads on the hull and propeller of the pod. These measurements form a valuable database for the design of a pod with higher ice class and more power.

The ice loads and ice loading scenarios presented in this paper have been applied to the hull of the pod and the structure of the pod can carry these loads. The structural response of the pod under action of ice loads was investigated both locally and globally, fig. 8.1 suppliers of critical components, such as bearings, were approached with the revised design loads and updated dimensions were obtained from them.

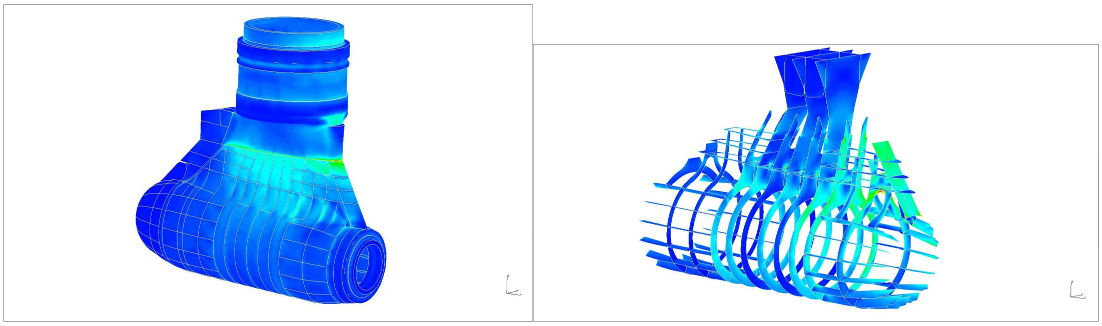


Figure 8.1. FEM model of Azipod hull was created to investigate structural responses under ice loading.

CONCLUSION

The paper presents principal results of the preliminary design of "Azipod" azimuth thruster with a power of 15 MW for modern large Arc 7 double acting ships intended to independently operate in the Kara Sea and regularly call at mouths of the Ob and Yenisei rivers. There were determined the parameters of ice loads effecting the azimuth thruster, its principal dimensions and strengthenings of principal elements in the lines of force. Strength sizes for ships moving astern in ice including fresh ice of months of Yenisey and Ob Bays exceed those for the traditional ships. The analysis shows that supplementary strengthening is not an obstacle for the delivery of "Azipod" with high propulsive characteristics. The performed investigations form the basis of the construction of azimuth thrusters for ships of higher arctic categories and powerful polar icebreakers.

The development carried out gives this paper authors full confidence to believe that it is feasible, both technically and economically, to build an Azipod with power of 15 MW for Arc7 class vessels. Component manufacturers can deliver components that can withstand the loads and the mechanical solutions do not become unmanageable.

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