CRAFTS TO MAKE NAVIGABLE ICE LANES

Sazonov, Cyril E. *– D. Sc. (Tech), head of the laboratory of ice technology of Federal state unitary enterprise «Krylovsky state research center», St.Petersburg, Russia.*
Dobrodeev, Alexey A. *– acting head of division of ice technology studies of Federal state unitary enterprise «Krylovsky state research center», St.Petersburg, Russia.*

ABSTRACT
One of the main tasks for ice-breaking crafts is pilotage of freight ships under ice-bound conditions. The use of icebreakers which are complex engineering structures with high operative costs is not always reasonable, especially for inland waterways and for coastwise navigation. The effective solution of the problem of extension of navigation period could be found through designing of specialized ice-breaking devices which can make ice-lanes at less cost. The article is devoted to evaluation of different ice-breaking devices for icebreakers and towboats. The authors describe push-train and fish mounted crafts designed in Krylovsky research center to create wide ice-lane.

ENGLISH SUMMARY
Background. *Ice navigation is usually provided for by an ice-lane which is made by ice-breaking craft, normally by icebreaker. But the use of icebreakers is too expensive to be economically reasonable, especially for inland waterways and coasting. There is a rather frequent need for single transportation operation or for a short range delivery of a limited cargo. Besides we come across a limiting factor of shallow water. Therefore ordinary towboats with ice strengthening are used for those operations.*
But there is another possible solution: that is to use ice-breaking attachment. This is a dumb ice-breaking craft, located at the bow of a pushing vessel, which does not possess necessary ice-breaking features. First ice-breaking attachments appeared in the latter part of 19th century (E. Wedermann's «ice boot» patented by a German engineer from Flensburg). Such attachments were used in Baltic Sea area. The growth of number of icebreakers and of ice-going vessels at the end of 19th century and at the beginning of the 20th century stopped further development of ice-breaking attachments for a long period (See, e.g.: Veselov Pavel. …Forgotten old [facts]. Technica molodezhi, 1993, № 8, pp.37-39. – Ed.note.). The interest towards ice-breaking attachments was reborn in ex-Soviet Union in 1970 when engineer G. Serbul of Moscow ship line suggested the design of ice-breaking attachments of his own. The pontoon with a tapered prow was equipped with a cutter. Bottom of the attachment had special parts which were designed so that they were able to move the ice, submerged by attachment, aside, putting it under the edges of ice-free canal [1]. The design of attachment of that type was further enhanced by engineers of Gorky institute of water transport engineers. Pictures 1 and 2 show different types of attachments pushed by tug boat. The idea of pushed ice-breaking attachments was continued by Gorky polytechnic institute (now called Nizhni Novgorod polytechnic university named after R. Alexeev). They used non-self-propelled air-cushioned platform. Prototype (pic.3) was tested at Gorkovsky artificial lake and proved to be efficient for ice-breaking [1].
Objectives. *The need to prolong navigation period for inland water ways and for coastal navigation requires a search for ice-breaking devices with reduced operation costs. The additional condition for their design requires optimal use of tow-boat, tugboat and other special boats. New device should be capable to make broader ice-free canal than previously designed models.*
Methods. *The authors used mathematical modeling to create model of ice-breaking attachment. On that very basis the authors created and used models of 1:30 scale which were tested in experimental tank of ship-research station of Krylov research center. The tests in model basin permitted to measure force of ice resistance. The researches included comparative studies of ice resistance of towed device and of ice resistance of arctic diesel ice-breaker.*
Results. *Federal state unitary enterprise «Krylov state research center» has developed within the framework of federal program «Development of civil sea vessels for the years 2009–2016» a concept of new multi-hull ice-breaker capable to pilot safely huge-tonnage vessels [2, 3]. The center has also developed proposals concerning towed and pushed devices capable to make broader ice-free canal.*
New pushed attachment consists of three hulls, which have raked stem and irregular sides (pic.4). There are a head hull and two side hulls, rigidly attached by frame, which is also equipped with a device for tight contact with push tug. Each hull at the water-line level is nearly triangle-shaped and has plain truncated stem. The outline of such type simplifies manufacturing technology and reduces specific quantity of metal.
Side hulls are located with displacement not less than 0,1 of main hull width, counted at midship, down the flow. It helps to improve passing of fragments of broken ice amidst ice-breaker's hulls, reducing thus ice resistance of the towed train in broken ice and reducing consequently power consumption of the tugboat. Lateral hulls have the same width and their similar positioning at two sides of main hull allows achieving more course stability and consequently positively influences ice resistance of towing ship.
The most width of created ice-free canal is ensured if lateral hulls are positioned so that centerline plains are located at a l distance from centerline plain of ice-breaker, the l distance being not less than the value determined from relation:

$$l \geq \frac{B_г + B_в}{2} + 5\ , м,$$

where $B_г$ and $B_в$ – is the width of, respectively, main and lateral hull measured at a midship, and the device, that couples attachment with tugboat and which is placed on the frame, runs out from line passing by sternposts of lateral hulls not more than for 3 meters.
The positive effect of described positioning of the hulls of ice-breaking attachment and of tugboat is achieved through different character of ice breaking by side hulls. They will destroy the ice by chopping and directing its small fragments into the canal created by head hull. It results in reducing integral ice resistance of the train «attachment-tugboat» [4].
Besides the pushed attachment Krylov research center has developed a concept of towed ice-breaking device (patent application registered under № 2012120875). The towed device is deemed to be used along with traditional-type ice-breaker (pic.5). The hull of ice-breaking device consists also of three

hulls, providing thus for increasing width of ice-free canal up to 10 meters more as compared to single-hull ice breaker. The efficiency of such an attachment is ensured by reduced ice resistance.

It is known that ice resistance of an ice-breaker is in proportion to its width at a certain power B^k, where exponent $k > 1$ [4]. That's why growing width of a single-hull ice-breaker causes important growth of its ice resistance and consequently more power consumption N needed to move in the ice, because $N \sim R_I^{\frac{3}{2}}$. As far as a proposed design is concerned, ice breaking will be accomplished with the help of four hulls: that of tow-boat and those of three towed devices. Mathematical proportions lead to the conclusion that $B_t^k + 2(B_n)^k < (B_t^k + 2B_n)^k$, that's why the ice resistance of towed device will be less than the ice resistance of an ice-breaker of the same width.

Side hulls of the device are located symmetrically to its centerline plain. The central ice-breaking hull gives additional solidity to the towed device during moving in the ice. The effect of the designed tow set is explained by the fact that side hulls break the ice, chopping its important fragments into the canal, made by the towing vessel. Theoretical and experimental studies [3,4] show that in that very case the ice resistance of the hull represents about 0,6 of the value of full ice resistance of a single hull. Additionally, if a minimum distance between the sides of towing vessel and the sides of towed device is equal or more than 7 m, then the crushed ice can freely pass between the hulls and a probability that the towed device itself will tow ice bodies is avoided.

The device reduces therefore ice resistance of towed vessel and power consumption of ice-breaker while it makes a wide ice-free canal.

In order to experimentally test efficiency of a towed ice-breaking device a model of 1:30 scale was made and tested in ice experimental basin of Krylov research center. Experiments with the model (pic.6) were used to measure forces of ice resistance that affect both of side hulls.

The proposal to use central auxiliary hull was born as a result of analysis of testing. Therefore modelling of a central hull had not been held. But it can be assumed with certitude that the contribution of the central hull in integrated value of ice resistance is not so important, because it is located behind the ice-breaker and doesn't participate directly in ice breaking process, and its width is less if compared to the width of other hulls.

The tests were held in consolidated flat ice of different thickness, conform to ice depth of 0.9, 1.5 и 2.1 m in natural conditions, as well as in hummock conditions. The tests resulted in obtaining of consolidated data on dependency of ice resistance of towed device on velocity of movement through ice. The width of ice-free canal behind towed device, if recounted for natural conditions, was of 55 m. It is necessary to underline, that the width of ice-breaker of «Moskwa» type which was used for comparison, is of 28 m only. The wide canal is created thanks first to side hulls of towed device.

To analyze the results of data on ice resistance of towed device, the researchers compared them with the values of ice resistance of typical existing diesel-electric ice-breaker and with simulated values of hypothesized single-hull ice-breaker of 50m width (equal to the width of towed device) for consolidated flat ice of 1,5 m thickness (pic.7). It was supposed that the hypothesized ice-breaker is capable to make the canal of the same width as a towed device can do.

The study of experimental data has shown rather high efficiency of towed device. The picture 7 shows that the integral ice resistance of an ice-breaker coupled with towed device is two times lower than the resistance of hypothesized single-hull ice-breaker for the ice of the same thickness. Besides it is necessary to take into account the fact that an ice-breaker of «Moskwa» type during autumn and winter period is capable to use only 50% of its power capacity, so the rest of the capacity can be used for towing of designed device, and that will enhance performance factor rate of the ice-breaker and will permit to create a wider canal for heavy-tonnage vessels.

Conclusions. *The study can lead to a conclusion that the proposed means (pushed ice-breaking attachment, towed ice-breaking device) to break ice in order to create wide (more than 50 m) canal are new and promising.*

The mentioned means can enhance efficiency of transportation systems thanks to less power consumption as compared to traditional techniques of pilotage of heave-tonnage vessels. The researchers plan to hold additional studies in order to specify possibilities to use ice-breaking pushed attachment and towed device.

Key words: navigation, in-land water ways, coastwise traffic, ice, ice-breaking device, pushed device, towed device, ice-breaker, wide ice-free canal.

REFERENCES

1. Zuev V. A. Means of prolongation of navigation in inland water ways [*Sredstva prodleniya navigatsii na vnutrennih vodnyh putyah*]. Leningrad, Sudostroenie publ, 1986, 208 p.

2. Pashin V. M., Appolonov E. M., Sazonov K. E. New ice-breaker for pilotage of heavy-tonnage vessels. What are the advantages? [*Novyj ledokol dlya provodki krupnotonnazhnyh sudov. V chem preimuschestva?*]. *Morskoy flot*, 2012, № 1, pp. 50–53.

3. Appolonov E. M., Dobrodeev A. A., Klement'eva N. Yu., Sazonov K. E., Timofeev O. Ya. Some results of experimental study on new technical means intended to create a wide canal in ice to safely pilot heavy-tonnage vessels [*Nekotorye rezul'taty eksperimental'nyh issledovaniy novyh tehnicheskih sredstv dlya sozdaniya v ledyanom pokrove shirokogo kanala dlya bezopasnogo prohoda krupnotonnazhnyh sudov*]. *Vestnik NGU* (Serie «*Matematika, mehanika, informatika*»), 2012, Vol. 12, Iss. 4, pp.3–8.

4. Sazonov K. E. Theoretical fundamentals of navigation in ice conditions [*Teoreticheskie osnovy plavaniya sudov vo l'dah*]. St. Petersburg, TsNII imeni akademika A. N. Krylova, 2010, 274 p.

Координаты авторов (contact information): Сазонов К. Е. (Sazonov C. E.) – kirsaz@rambler.ru, Добродеев А. А. (Dobrodeev A. A.) – cnii_krylova@mail.ru.

Статья поступила в редакцию / article received 25.07.2013
Принята к публикации / article accepted 03.10.2013