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Developments of new patented ice breaking devices for ice going Vessels.

Gianpiero LAVINI [a,1], Gennaro AVELLINO [a,2]
[a] *Fincantieri S.P.A. - Direzione Navi Mercantili, Trieste, Italia*

Abstract. Arctic and Antarctic areas are getting more and more attractive for cruises. The vessel designed for the operations in these and other ice areas like Canada and Baltic Sea must sail in ice in a safe and efficient way, as far as possible, without support of icebreakers. At the same time they should be quite efficient also in open waters. However the hull hydrodynamic shape of an efficient vessel designed for the open sea operation is normally not suitable to operate in ice, while a vessel optimized for proper sailing in ice normally suffers from strong penalties when sailing in free waters. This paper deals with the development of new patented devices applied to the bulb and to the stern of the ship which can provide at the same time excellent performances in ice breaking without any detriment when the ship is operated outside ice seas. The new devices are called ICE SABRE, applied to the bulb and ICE MIRROR installed on the stern transom. A comprehensive ice model testing description of two devices shall be given including tests in pack ice, brash ice and manoeuvre against ice ridges.

Keywords. ice, ice sabre, mirror wedge , ice bulb, ice classification, ice testing.

1. Introduction

This presentation deals with two new Fincantieri patents developed to improve hydrodynamic design of twin screw merchant ships used for navigation in ice. Lot of ferries are operated in ice areas like the Baltic sea or close to North American costs and at the same time many new cruise vessels must be designed to operate in Antarctica, Alaska, Greenland, which are getting more and more popular and attractive for passengers. These vessels are operated both in ice and free waters and there is therefore a new challenge in the hydrodynamic design of ship suitable for this dual operational sailing profile. The requirements imposed by navigation in ice and open waters are very different and consequently the ship must be designed by finding the appropriate compromise solution to be efficient both in ice breaking and in free water navigation.

Merchant ships dedicated to navigation in ice are usually provided with bulbs with a shape that has been properly studied to crush the icy surface. These are the so-called ice bulbs which have very sharp sections on the leading edge which allow an easier crushing of the ice. These bulbs, however, when the ship sails in free water, have a very bad hydrodynamic behavior and are significantly penalized in terms of efficiency compared

[1] gianpiero.lavini@fincantieri.it
[2] gennaro.avellino@fincantieri.it

to conventional delta and elliptical bulbs commonly used on ships that do not sail in ice. On the other hand, these types of bulbs cannot be used for navigating in the ice, since they are not suitable to yield concentrations of stress on the frozen surface such as to crush it. Conventional ships are also equipped with a device fixed on the transom called trim wedge that allows the generation of high lifting forces which can significantly reduce the resistance of the ship. If the wedge is used in an icy area, being completely flat on the aft side, in backing condition it would completely block the motion of the ship making any ice maneuver impossible. Given these premises, it can be understood that a ship suitable for navigating through ice, with a very sharp bulb and without a trim wedge, is not efficient in free water, while a ship with an efficient trim wedge and bulb is not absolutely suitable for navigating through ice. Fincantieri has developed and patented two systems called Ice Sabre and Mirror Wedges that, without any penalties in open water, allow a ship to proceed in icy waters with extreme efficiency and safety. See Figure 1 and 2. These devices have a particular shape to perform a cutting action of the icy crust both in forward and backward motion. The Ice Sabre has the European patent EP3107801B1, while the mirror wedge EP3086998A1. It should be noted, however, that for any type of ship operating in the ice the best possible solution is to fit as propelling device an electric or mechanical pod. The pod allows avoiding to get stuck in the ice in any situation since they can deliver the maximum thrust through 360 degrees thus getting the ship free from ice capture with alternating maneuvers of lateral, forward and backward motions.

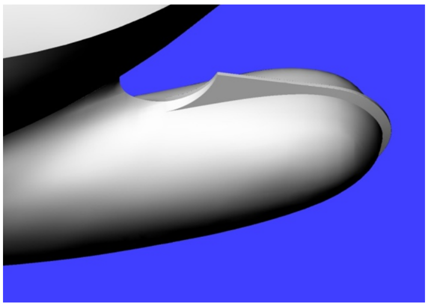

Figure 1. The Ice Sabre

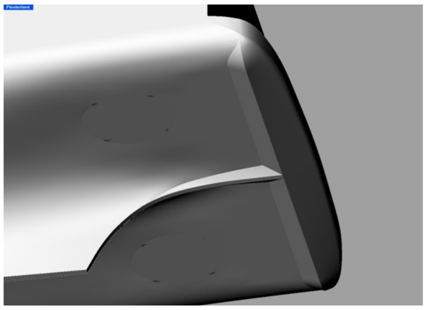

Figure 2. The Mirror Wedge.

2. Conventional Bulbs and ice Bulbs

In the hydrodynamic design in ice-free waters the following bulbs are normally selected: *delta bulbs* and *elliptical bulbs*, characterized by a large volume and a blunt shape.

The selection of the bulb shape is normally done considering the sailing profile of the vessel. If the vessel is specified to sail most of time at full speed the bulb shall have a form called delta type. The bulb shall be very large with most of the volume concentrated in the upper part close to the water line and its water lines shall be very blunt at the leading edge. This shape produces the strongest bow wave which will interfere with the ship wave in order to have the maxim wave smoothing when the two waves are in opposite phase. On the contrary this type of bulb does not behave quite well at lower speed. This bulb therefore creates a greater wave but has a higher form resistance as the waterlines have larger entrance angles. Most of the time the bulb is inclined towards the stern and its head can be above the water level. The shaping of these types of bulbs is made like a fist. The front surface is very flat and the angle of entrance is very close to 90 deg.

So the steel surface that is expected to cut the ice is almost straight, wide and this is the most ineffective way to cut the ice surface. The pressure exerted on the ice is quite low, there are no concentration points and the delivered breaking force is normal to the ice surface. It is easy to understand that this bulb is one of the worst solutions to cut an ice crust. When the ship is expected to have a wider operational speed range the delta bulb are not suitable and another type of bulb must be selected. This bulb has transversal elliptical sections, the upper part is almost horizontal, the shape is less blunt and the entrance waterlines are sharper.

These types of bulbs produce a lower wave but at the same time they have a lower form resistance and the effect on the reduction of hull resistance is beneficial on a wider speed range without producing deep hollow behind the bulb at lower speeds. This bulb is not the very best at full high speed but it works quite well also at lower speeds.

This type of bulb has a sharper leading edge, which is more suitable to cut the ice surface than the previous delta geometry. The trouble is that the angle of entrance is close to 45 degree, so also in this case the pressure concentration is not that high and not enough to break in an efficient way the ice. These bulbs have the largest section at frame 20.25 and it is normally too wide and thick to penetrate in an efficient way in the ice.

Then a vessel is classified with an ice class and is expected to sail in ice areas no one of the listed bulbs is suitable to break the ice and have a low resistance in ice breaking. In ice sailing the vessel must be fitted with a type of bulb called *knife bulb*, their shape is quite long and very slim with quite sharp edges at the water line entrance, all the bulb is below the water line and its longitudinal profile is inclined to the bow. The sharp leading edge helps in breaking the ice surface creating a high stress concentration on the ice structure while the inclined shape penetrates below the ice surface, lifts it and bends it leading to an easy ice surface fracture. On the other side when a ship equipped with such type of bulb is operated in open water its performances are quite poor. Due to its reduced volume and its deep position, this type of bulb is not able to create a sufficient wave elevation to cancel the ship wave. As a rough estimation the power absorption is more than 10% higher than a vessel equipped with a good bulb designed for sailing in free waters. So when a ship is designed to operate in ice, it is strongly penalized in efficiency in open water, while if it is well designed for free waters it is very likely that it is not suitable to break the ice. When a ship has a dual sailing profile it is mandatory to find a suitable compromise solution to sail safely and efficiently in both conditions. The ice sabre and the mirror wedge are an answer to this request.

3. Ice classification

In order to see which are the ice condition which can met by a ship and what characteristics must be known for a correct development of its hydrodynamic ice design it can be useful to give a very short description of the sea ice types and their classifications. Ice classification and nomenclature is a complicate matter and the aim of this paper is not to

Cover	Type	Development	Thickness	Form of floating ice	Flat extension	Ice surface features	Separate ice features
10/10	Consolidated Pack ice	New Ice	1-5 cm	Ice fragment		Level ice. Undeformed	Hummocks
9/10	Very close pack ice	Nilas	5-10 cm	Giant Floes	over 10 km	Deformed rafted ice	Ridge
7-8/10	Close pack ice	Grey Young Ice	10-30 cm	Vast Floes	2-10 km	Deformed rough ice	Ridge belt
5-6/10	Open pack ice	White first year ice 1 White first year ice 2	30-50 cm 50-70 cm	Big Floes	500-2000 m	Hummok ice	Line of ridges
4/10	Very open pack ice	Medium first year ice	70-120 cm	Medium Floes	100-500 m	Hillocky ice	Floeberg
3/10	Very open pack ice	Thick first year ice	120-200 cm	Small Floes	20-100 m		Schamukha
2/10	Open water	Residual first year ice	30-180 cm	Ice cake	2-20 m		Windroe
1/10	Open water	Second year ice	Up to 250 cm	Brash ice	2 m		Ram
0/10	Ice free	Multi year ice	Up to 3 m or more	Pancake ice	0.3-3 m		

Table 1. Summary of the ice classification.

give a detailed and exhaustive description of all types of ice that a vessel can meet during navigation. For a detailed description of all floating ice at sea reference should be made to the international standards of World Meteorological Organization (WMO) where very detailed description can be found. The Table 1 presents a summary of the ice classification. Just for a brief note it can be said that the sea ice can be classified according to the following parameters: concentration, stage of development, ice form, ice surface features, separate ice features, ice fracture and openings, ice thickness, stage of melting.

The ice concentration is measured in a scale from 0, which means free from ice, till 10/10 when we talk about pack ice where the whole surface is covered by ice. The ice development is relevant to the age and the thickness of the ice. The form of the ice is dealing with the surface extension of the floating ice. The ice surface features are relevant to the fractures of the ice surface. The scale starts from the level ice which is the sea ice which has not affected by deformation and considering other types of shapes of the ice breaks. The separate ice features describe the ice conglomerates that can be created underwater or close to the cost by mean of the action of wind and currents.

Under the engineering point of view the most import ice types to be considered is the level pack ice, the brash ice and the ice ridges. The level pack ice is a surface completely covered by ice of a certain thickness, without fractures, and it is that commonly used during tank testing to evaluate the ice breaking capability of a vessel as it is the hardest to be broken. The brash ice is an accumulation of floating ice made up of fragments not more than 2 m across, the wreckage of other forms of ice as a result of melting or breaking. This type of ice is considered in classification society rules to calculate the minimum installed power and whose thickness is depending on the ship required ice class.

The ice ridge is a conglomerate of ice pieces with a linear shape and it is formed by pressure at the contact line of ice floes. Usually the ridge is formed in way of boundaries between different age ice floes. The underwater part of the ridge is a deep keel which can extend below the water ice surface for tens of meters (see Figure 3 and 4).

The ice ridge has an outstanding importance in ship design as when a vessel is designed to enters some harbors where wind and current are accumulating ice ridges the detailed characteristic of the ridges must be know in detail in order to reproduce them exactly in the towing tank to verify if the ship is able to pass them or not. Climbing over the ridge ice is usually one of the most challenging tests that a ship has to sustain during the ice sailing.

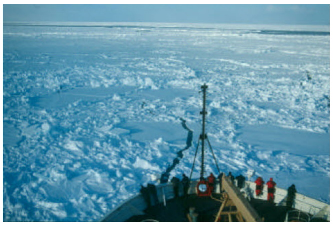

Figure 3. Level pack ice.

Figure 4. Brash ice.

Figure 5. Ice Ridge.

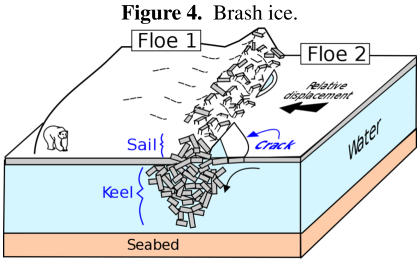

Figure 6. Section of ice Ridge.

4. Ice Sabre and Mirror Wedge

The patented ice devices which allow a vessel to sail with the best performances both in ice and in free waters are hereafter described. The ice saber (see Figure 7) is a casted steel structure with a curved shape placed on the front and top of the bulb. It allows to create a very high stress concentration; it bends the ice crust from the bottom to the top, creating on the ice surface a fracture line such as to allow an easy advancement of the ship even with large thicknesses of ice. The device can be fitted to delta and elliptic bulbs and allows excellent performance both in presence and absence of ice. The ice sabre is placed on the leading edge of the bulb till a depth of about 2 meters below the waterline. The rostrum must not in fact clash perpendicular to the ice, but it must exert a collision from the bottom upwards in order to crush the frozen surfaces by bending it. It is in fact well known that the ice is very resistant to compression but very fragile to bending so that the ice saber system is shaped to hit the frozen surface from below, crush it by bending with the ram and lift it once broken by means of the forward motion of the bulb. In section the ice saber has a trapezoidal shape with one base of about 200 mm thick and the other of about 300 mm. The piece is a single casting element that has to be welded to the internal structures of the bulb. Also the height of the trapezium is not too high as with the impacts with the ice it could create high bending moments that in time could lead to bending deformations of the structure. The ice sabre avoids completely the accumulation of ice in front part of the ship. In fact the broken ice pieces are immediately moved downstream to the bottom of the ship. At the same time the ice sabre tested in open water showed no penalization in power absorption.

Figure 7. Ice sabre rostrum.

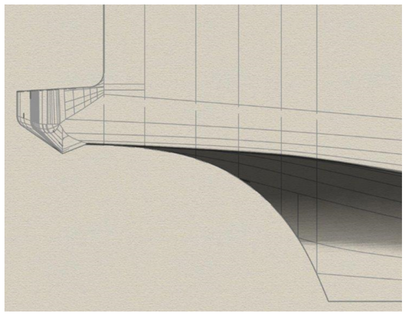

Figure 8. Mirror wedge lower knuckle.

The mirror wedge (see Figure 8) is a wedge positioned on the *transom* of the ship. As discussed a conventional trim wedge is used in order to improve the propulsive performance in open water. The trouble is that it cannot be absolutely used in ice as it has on the rear part a very large flat surface that does not allow the backing motion. The mirror wedge instead, when sailing astern allows the ship to climb the frozen surface and fracture it with its weight. The mirror wedge extends in the extreme part of the stern along the whole width of the transom (aft mirror) from side to side. In this case the crushing of the ice does not occur by bending upwards, as for the ice saber, but by means of a downward bending crush. Its cross section has a triangular wedge shape placed in the most aft ward part of the stern with its knuckle oriented downwards. The wedge is raised above the ice by sliding the aft side of the triangle above the iced surface and then the wedge is working like an ax cutting the ice surface with the downward weight force of the ship as in the case of icebreakers. The mirror wedge is made of thick steel plates and casted parts appropriately sized for impacts with ice with internal longitudinal reinforcement structures.

5. Ice testing

In order to see the performances of the two devices they were fitted to an Ice Ferry suitably designed to be operated in the ice waters of Canada and they were extensively tested at HSVA ice towing tank. The adopted testing method is usually the one called towed propulsion test. The model is driven against the ice by means of a towing force of variable intensity. For each value of the towing force the thrust generated by the propellers is measured. In this way, a diagram of Towing Force-Propeller Thrust is drawn (see Figure 9). This diagram is subsequently corrected by difference in ice thickness, by difference in mechanical strength and difference in hull-ice friction coefficient. Entering the diagram with the value of zero towing force you get the correct propeller thrust value. Having measured for each point both the thrust and the power we enter the Thrust-Power diagram with the correct thrust value and the required power value is obtained. This value

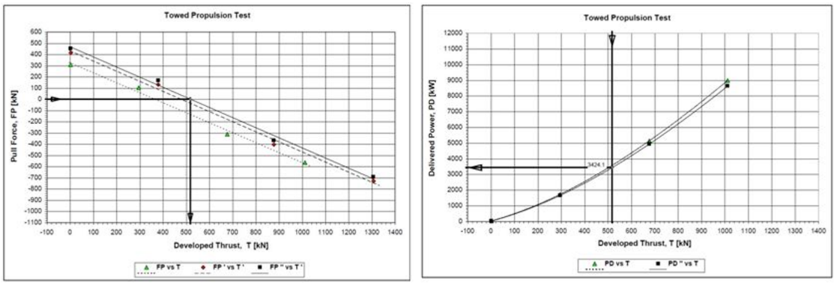

Figure 9. Towing propulsion test in pack ice.

must then be corrected for a statistical seawater coefficient, based on the type of ice considered.

Both devices were tested in the ice tank in ahead and astern condition and they proved experimentally excellent ice breaking performances. The following ice tests were carried out to verify the ice breaking capability of the vessel:

1. Propulsion tests in pack level ice conducted to verify the maximum crushable thickness.
2. Brash ice propulsion tests to see if the ship can navigate in a channel crushed by an icebreaker and if it meets the 5 knot speed required by ice class standards.
3. Tests on the ridge ice to verify if the ship is able to pass these submerged obstacles very commonly met in frozen seas.

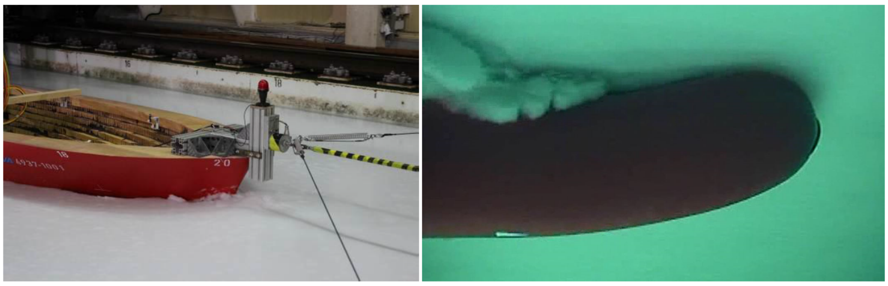

Figure 10. Towing propulsion test in level pack ice. Surface view and underwater.

Regarding the pack level ice performance in ahead sailing the vessel, classified with ice class 1AS, showed a clear breaking behavior with a center crack created by means of the ice sabre in the thick level ice. The crack was started on the lower surface of the ice extending suddenly on the upper part as result of the forward motion of the knuckle. Nevertheless the flat bottom of the vessel is covered by broken ice floes hardly any ice reached the pushing pods. Therefore the propellers do not meet any ice interaction and may operate undisturbed. The propulsion tests showed that the vessel was able to cut an ice a level pack ice thickness up to 0.7 meter. Regarding the backing performance the vessel was able to continuously operate astern in 0.5 m thick level ice. The mirror wedge proved to be a very effective device in climbing the ice surface and crack it with a continuous astern motion by means of its weight. To improve the vessel's ice breaking capability astern and thus to decrease the resistance it was helpful to induce an initial crack by means of added knives when pushing the level ice sheets downwards. The vessel also moved easily through a brash ice channel according to Ice Class 1AS at a speed of 5 knots fully fulfilling the regulations. During the test the flat bottom of the vessel was almost ice free so that no propeller ice interaction occurred. The vessel had also to overcome an ice ridge of about 6 m total depth. This test can be considered successful if the ship is able to pass the ice ridge at the first run without getting stuck in it. The vessel showed a good ability to break ice ridges up to 6 m in operation ahead at the first ram hit without any stop during the manoeuvre. In astern motion the vessel had to overcome a ridge of the same thickness as in operation ahead. Also in this case the vessel was able to break the ridge within the first attempt. In the end of the test the ice sabre and the mirror wedge proved that the ship was able to pass the entire test required in the ship specification showing an outstanding performance ice breaking.

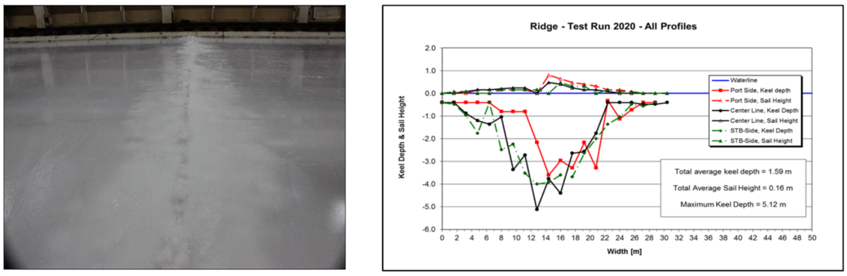

Figure 11. Ice ridge in the towing tank

6. Conclusions

After completing the ice testing session the following conclusions can be drawn concerning the installation of the patented ice sabre and mirror wedge on ferries and passenger vessel which are operated in ice areas. The two devices are providing an increased operational offer to navigation in ice as these systems allow the vessel to operate at medium levels of *pack ice* without icebreaker support. At the same time the vessel can operate in brash ice and ice floes in full safety. So also more challenging routes in ice area can be followed. At the same time the installation of such devices does not imply any penalization in navigation in free waters free: during summer sailing they do not have any propulsive penalties compared to ships built for normal sea going service as the bulb and the wedge can be designed for the best hydrodynamic open water performance. Compared to a ship specially designed for the ice service the two devices significantly reduce fuel consumption and emissions during the summer season. More generally speaking they represent optimal devices for all types of ships with dual operational profile, summer--winter in free waters and ice, such as passenger ships for Arctic and Antarctic cruises, Baltic and North America ferries and other vessels that runs through the Arctic routes to access gas and oil extraction sites or the new merchant ones which are expected to follow the north route to connect Europe to the far East. When the support of the ice breakers is needed to crash the ice in very severe condition the performances in the ice open channels are again better compared to vessels not provided with their own suitable devices for ice breaking.

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