Proceedings of the 25th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2019, Delft, The Netherlands

Development of propulsion technology of Arctic ships operating in ice, from MV Arctic to Norilskiy Nickel

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ABSTRACT

Ships transporting different goods have been around for as long as there has been the need to trade between countries and nations. Arctic shipping was until 1970ies restricted into summer season, especially in the Soviet Union where the supply of goods for the Arctic settlements took place during the easy ice condition time. Ice strengthened ships were assisted by icebreakers.

Lengthened season and year-round trade in the Arctic started for real during the second half of the 1970ies. Mining products were transported out from the Canadian Arctic by powerful and effective MV Arctic. In the Soviet Union new icebreakers and a fleet of bulk carriers and multipurpose cargo ships were built. Even the vessels were better in icebreaking than their predecessors, they still needed icebreaker assistance during the midwinter months. Not until 2006 when the first Arctic container vessel MV Norilskiy Nickel was commenced, it was possible to operate a cargo vessel without icebreaker assistance, even in worst ice conditions.

The development in utilizing new arrangements in cargo ship propulsion started for real in the late 1960ies. when the winter traffic in Finland exploded as the Finnish government decided to keep all the major ports open year-round. This started serious development of ships capable of more independent ice operation. The first propulsion solutions were modifications of well proven technology. We had fixed pitch and controllable pitch propellers connected directly or through a gearbox to low/medium speed diesel engines. Also, in some applications the propeller was equipped with a nozzle. However, it was needed two decades more and the development of the propulsion devices from direct shaft lines to azimuth devices to get the propulsion revolution going at full speed. This development through the development of icebreakers and tankers resulted to azimuth thrusters, which could be used in vessels operating in high Arctic year-round. The first such vessel was MV Norilskiy Nickel, which started in 2006 traffic carrying mining products out from Dudinka, Yenisey river, to Murmansk and beyond. The paper describes the development of the propulsion of dry cargo vessels in the shadow of the development of icebreaker propulsion to more independent vessel operation.

KEY WORDS

Propulsion; Cargo ship; Icebreaking; Development; Arctic shipping.

INTRODUCTION

People have been always interested in the unknown. The Arctic sea routes have been long out of reach. In late 19th century, when propellers and steel hulls became technically possible, it was possible to think about ice navigation in the Arctic. However, most of the 20th century only summer operations were possible as there was not enough technical knowledge on how to break ice efficiently and how to avoid damages. To be honest, the development had to proceed step by step.

Most of the development took place among icebreakers and cargo ships were not considered so important. this activity was blooming in Finland and Soviet Union.

Summer season in the Northern Sea Route, NSR, was very important and new ships were developed and built to carry goods to the Arctic and export forest and mining product. One of the early series of ships was the Amguema-class general cargo vessels, Length 139.1 m Breadth 18.9 m, Draught 8.94 m, Power 5500 kW. These diesel-electric vessels in series of 15 ships, were built between 1962 and 1975, were actually pioneers in the Arctic trade. One of the vessels, Mikhail Somov, is still in operation as a research ship off Archangelsk, Figure 1.

Figure 1, RV Mikhail Somov

TOWARDS THE ARCTIC

In late 1960ies as more minerals and hydrocarbons had been discovered in the North, ships grew bigger and there was more knowledge on technical solutions we started to be interested in really build ships that could survive in the harsh Arctic conditions. The development started not in the Arctic but in the Baltic, where winter traffic increased rapidly. There were new ice rules in place and technical solutions were just around the corner. Summer traffic all over in the North was normal practice. Winter traffic was still waiting to be started.

MV ARCTIC

MV (Motor Vessel) Arctic is an icebreaking cargo ship built in 1978 at the Port Weller Dry Docs in St. Catharines, Ontario, Canada. The main dimensions are: Length 220.82 m, Breadth 22.92 m, Draught 11.52 m (summer), 10.67 (winter), Power 10.9 MW. The propulsion machinery of the vessel comprises of a slow speed, two stroke diesel-engine connected to a controllable pitch propeller with the diameter of 5.23 m in a nozzle. The vessel has an ice class of CAC4. The cargo volume in 7 holds is 34500 m^3 grain and 24300 oil. MV Arctic is of ship type OBO, Ore-Bulk-Oil. The displacement of the vessel today is 39400 tons. She was modified to present appearance during 1985-86, when she received a new bow, which allowed to break 1.5 m thick level ice with a speed of 2 knots. The new bow before building was tested quite extensively at the Wärtsilä Arctic Research Centre in Helsinki, Finland. At the same time her ice strengthening was increased from CAC2 to CAC4. MV Arctic has been serving earlier carrying mining products from the Canadian Arctic Islands from Polaris and Nanisivik mine. Today she serves mainly mines more in the South, Raglan and Voisey`s Bay.

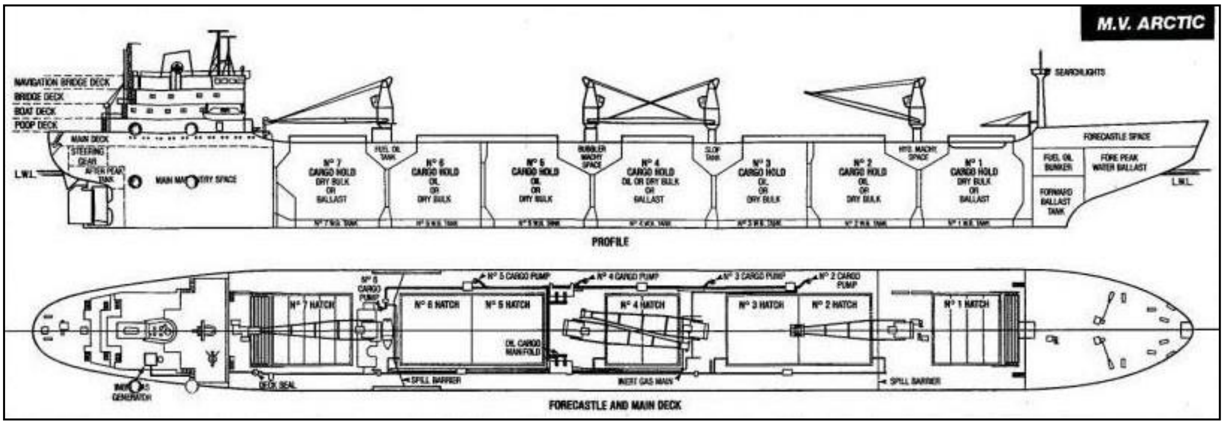

Figure 2, MV Arctic, Fednav Group

MV DIMITRI DONSKOI

In the middle of 1970ies the Soviet Duma decided that year-round Arctic shipping should start soon. For this there was under construction new nuclear icebreakers (Arktika-class) and shallow draft diesel-electric icebreakers (Sorokin-class) to allow navigation through Gulf of Yenisei to Dudinka, the source of nickel mining products. Bigger ice strengthened cargo vessels were needed, and a number of dry cargo ships of Russian Maritime Register of Shipping UL-class (today LU4) was ordered from East-Germany, Warnowwerft. The vessels had as built the following main dimensions: Length 162 m, Breadth 22.9 m, Draught 9.88 m. The maximum cargo capacity was 20000 tons. The propulsion plant consisted of one slow-speed diesel engine connected direct to a fixed pitch propeller. The machinery had no modern electronic control and thus at low speed the maximum power of the engine (8200 kW) could not be utilized. The maximum output at low speed was around 60% of the maximum an icebreaking capability was some 0.5 m. The traffic from Murmansk to Dudinka was handled by the icebreakers, which towed the cargo ships most of the voyage, Figures 2 and 3. During some of the trips the vessels also got hull damages.

Figure 2, MV Stepan Razing in the Kara Sea

Figure 3, MV Ivan Bogun towed by ice-breaker

SA 15, (ARCTIC SHIP 15) NORILSK-CLASS

Following the start-up of year-round Yenisei traffic Soviet Union ordered 19 multi-purpose cargo ships from Finnish yards Wärtsilä and Valmet, Figure 4. After extensive studies, it was decided that the vessel will be built with two medium medium speed diesel engines followed by clutches, hydrodynamic couplings, reduction gear, elastic couplings, single controllable pitch propeller, Figures 5.and 6 (Kanerva, et al., 1984).

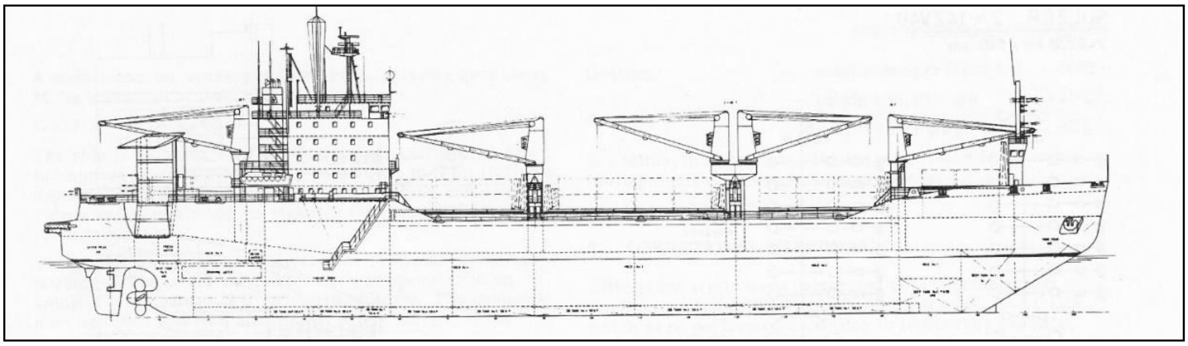

Figure 4, Side view of SA 15-class cargo ship

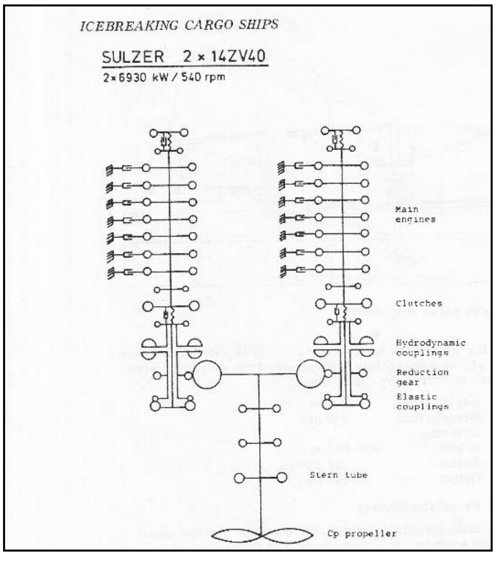

Figure 5, Propulsion system of SA 15

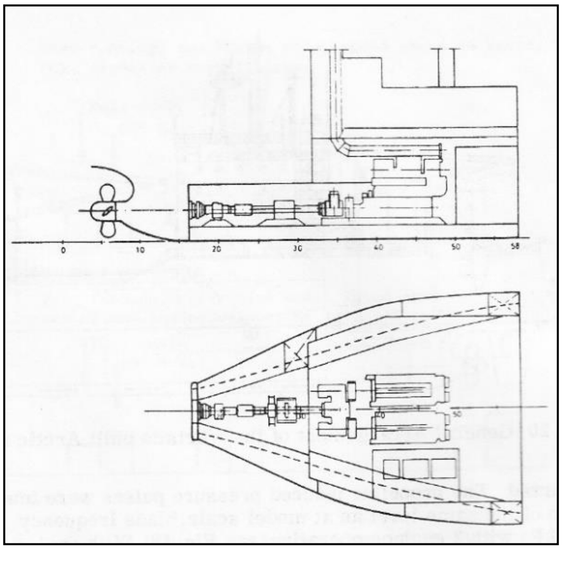

Figure 6, Machinery arrangement of SA 15

The icebreaking capability requirement for SA 15 project was 1.2m thick level ice with a continuous speed of 2 knots. This required extensive model test in ice at the Wärtsilä Ice Model Basin (WIMB). The final design had the following main dimensions: Length 164 m, Breadth 24 m, Draught 9.0 m (ice), 10.5 m (open water). These vessels have been still operating with icebreakers assisting them. However, they showed that independent operation is not too far away.

Figure 7, MV Igarka in ice

NS SEVMORPUT

In the 1980ies the boom to build nuclear ships in Soviet Union was blooming and during the time SA 15 ships were already in operation it was decided to develop a huge barge/container carrier vessel for the Northern Sea Route, NSR. The main dimensions of NS (Nuclear Ship) Sevmorput were: Length 260 m, Breadth 32.2 m, Draught 10.65 m (ice), 11.8 m (open water). She has one nuclear reactor, a steam turbine connected to one controllable pitch propeller in a nozzle. The total power is 29400 kW. Side view of the vessel is in Figure 8. The icebreaking capability in level ice of the vessel was 1.2m.

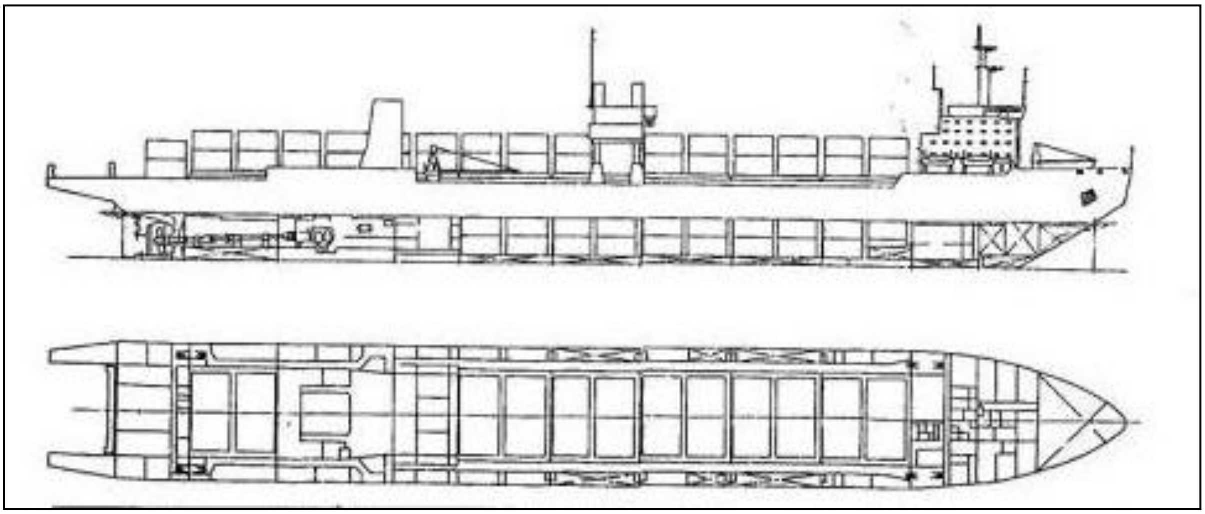

Figure 8, NS Sevmorput

DE/V NORILSKIY NICKEL

The development of propulsion took giant leaps towards azimuth drives in the 1990ies. Icebreaker and tankers in the Baltic Sea trade were installed with both mechanical Z-drives and electric podded drives, Azipods. The biggest units were installed onboard two 106000 dwt tankers Tempera and Mastera of Neste shipping, 2002, Wilkman, et al., 2004. These tankers showed the icebreaking possibilities that had not ever seen before. They were so called double acting designs developed by Kvaerner Masa-Yards Arctic Technology, where the vessel is running astern in most difficult ice conditions.

At the same time the Russians were looking to develop the next generation cargo vessel to replace SA 15 ships. After numerous simulations and model tests the new arctic cargo vessel concept was approved and the firs vessel was to be built at the Helsinki shipyard. The vessel named Norilskiy Nickel was delivered in April 2006 after successful ice trials in the Gulf of Yenisei, Wilkman et al, 2007

DE/V (Diesel-electric Vessel) Norilskiy Nickel is a Container/General Cargo Ship designed for year-round operation in Arctic regions, including calls at Siberian river estuaries. The vessel can navigate independently without icebreaker assistance on the planned route. The hull form is adapted to the DAS (Double Acting Ship) operating concept, i.e. the stern lines are optimized for effective ice operation, while the bow form is designed for good ice performance in light and medium ice conditions.

The diesel electric power plant enables the ship to operate with full shaft power in severe ice conditions, as well as in open water with reduced economical shaft power. The ship is designed to operate in heavy ice conditions with all three main engines running, while sailing in open water only two engines are in use and still reaching the service speed of 16 knots. Propulsion and steering are provided with a single ABB Azipod rudder propeller unit giving the ship an excellent maneuvering capability.

Hull and machinery are dimensioned to obtain the Russian Maritime Register of Shipping (RMRS) ice class notation LU7. The ship has double hull in the cargo hold area, as well as in the main engine room. Norilskiy Nickel operates with different draught in open water conditions and when icebreaking. The reason for this is due to reduce the extent of hull strengthening area, the hull form encounters better the ice sails and more demanding damage stability criterions from ice damages. The RMRS, good, but demanding damage stability regulations require deterministic and probabilistic calculations, both for normal damages and ice damages. This produced a relatively large number of side ballast tanks in cargo hold area.

The main dimensions of the vessel are: Length 169.5 m, Breadth 23.1 m, Draught 9.0 m (ice), 10.0 m (open water). Cargo capacity is 14918 tons (ice), 18486 tons (open water). Propulsion power is 13 MW.

The ice trials showed the capability of the vessel in most harsh conditions in the Gulf of Yenisei in March 2006, Figures 9 and 10.

Figure 9, Tests running astern in 1.5 m thick ice

Figure 10, Air temperature -32 C, wind speed 12 m/s

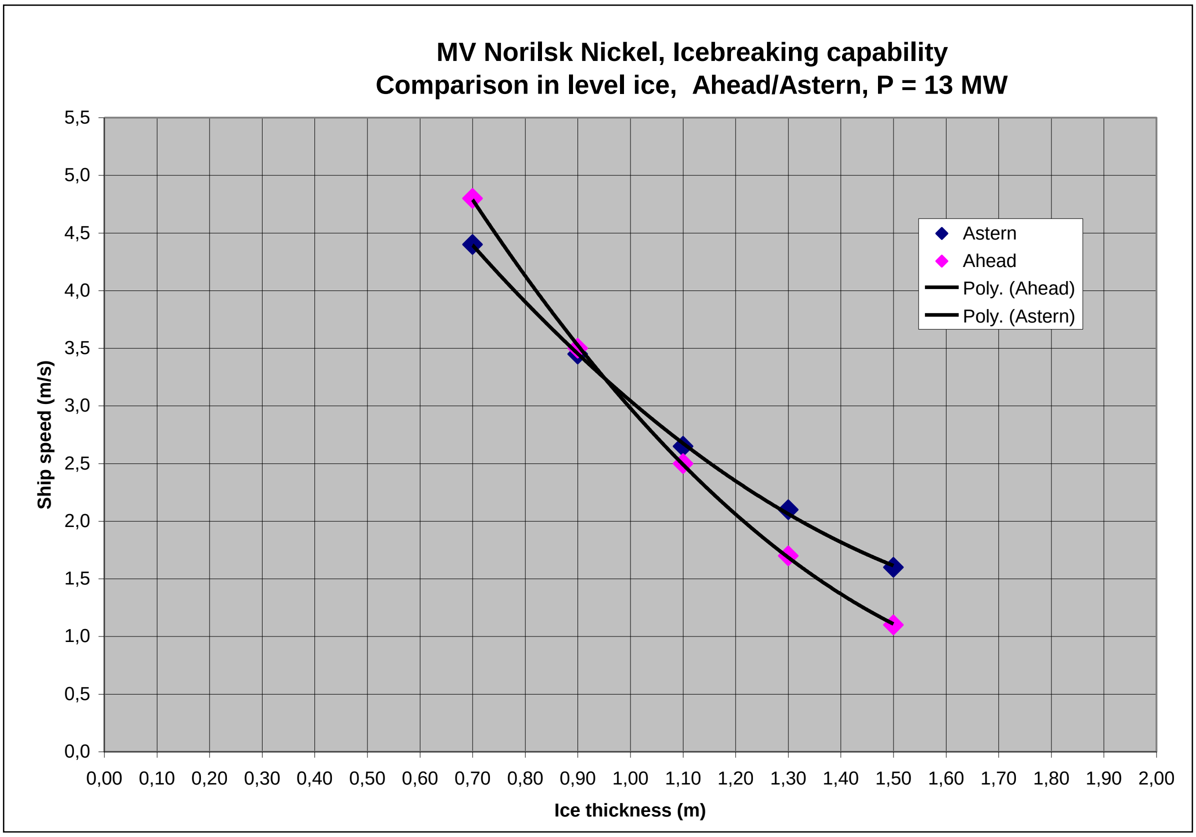

Figure 11, Icebreaking capability of DE/V Norilskiy Nickel, Wilkman, et al., 2007.

The ice trial results showed clearly that the breakeven point running ahead versus running astern in level ice was around one meter, Figure 11. In level ice thicker than one meter it is more beneficial to run astern (Wilkman, et al., 2007). In ridges the benefit is even larger. The vessel could go through a 10 m thick ridge running slowly astern without ramming by eating its way through. This was done by using actively the Azipod unit turning it from side to side and around 360 degrees.

Variable speed, electric drive is the key component in Norilsk Nickel electric propulsion. Today a range of frequency converter concepts are available, but the special requirements for ice going vessels led to the use of frequency converters that have high torque capability with high control precision in the whole speed range. Hence, AC cyclo-converters with good controllability at low RPM were used.

Norilsk Nickel power plant and electric distribution system was similarly designed as for other vessels with electric propulsion. However, the dimensioning is differing, since Norilsk Nickel have higher propulsion power demand of 13 MW, and some over torque requirements. In Norilsk Nickel 130% transient over torque capability was selected. Also, since the load variations of the propeller are high during heavy icebreaking, the power plant must be capable of handling the corresponding load variations. Running the propulsion in power control mode during operations in ice reduces the load variations significantly compared to traditional speed (RPM) control mode. The principles of different control modes are presented in Figure 12.

In the same graph it is also illustrated the load torque characteristics in the torque diagram for the variable speed propulsion motor. This has a maximum continuous rating given by the rated torque of the motor, and normally an intermittent over torque, in the range of 130 % of rated torque.

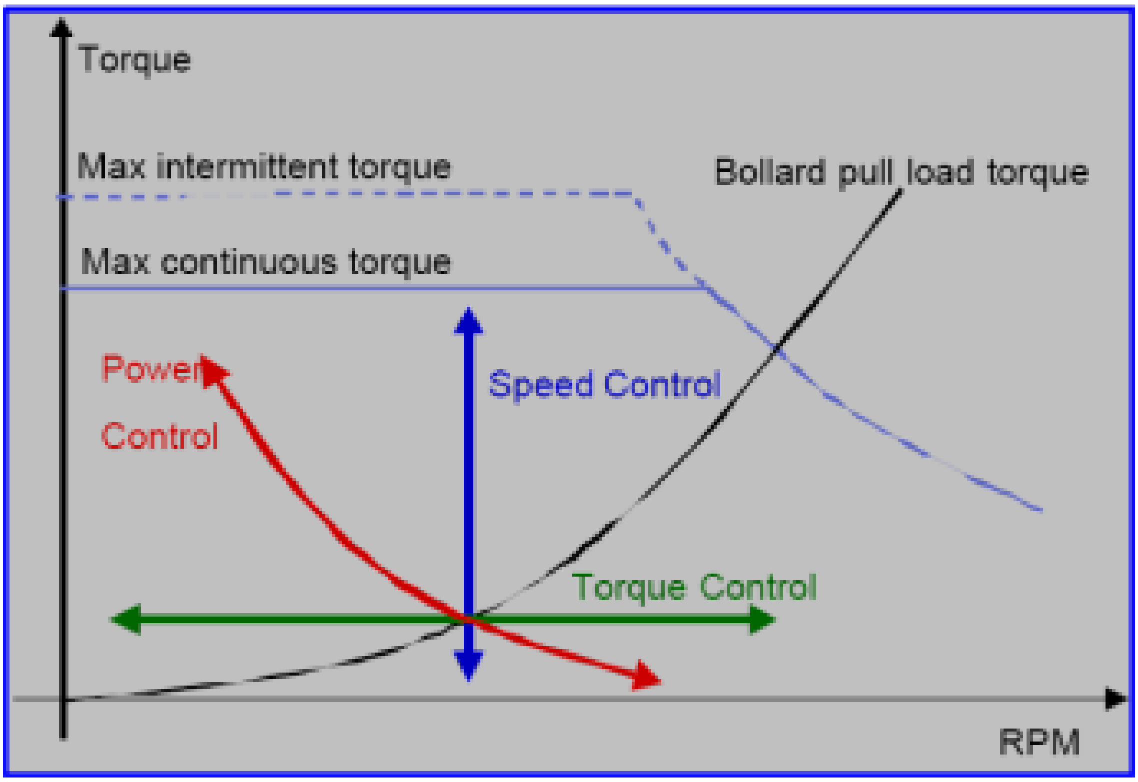

Figure 12, Torque, power and speed (RPM) control characteristics.

Norilsk Nickel was the prototype of independently operating double acting cargo vessel for year-round Arctic operation. Therefore, ABB together with Aker Helsinki shipyard and VTT, Technical Research Centre of Finland, decided to install extensive measurement system to collect information of propulsion system performance and ice loading.

The objective was to measure ice loads on the body of the Azipod propulsion unit when the vessel is operating in Arctic waters as well as to gather information on the loads on the shaft bearings and relative movements between the shaft and shaft bearings, and on the overall system performance in ice.

Measurements were carried out from 2006 until 2009 and collected data verified the chosen dimensioning principles. Based on the measurements the most important Azipod ice loading scenarios were identified and optimum design criteria for ice classed Azipod units was further developed, like definition of Azipod turning torque.

It was also noted that ship operation mode and operation manner have great effect on Azipod ice loading as well as ice loading on ship hull. The measurements further proved that the ship crew has well utilized benefits of DA vessel operation principle. The excellent operational experience and measurement results from Norilsk Nickel have given the needed proof and knowledge to develop double acting ship concept and its propulsion solutions further for larger and higher power applications.

MV UMIAK I

Mining activity in northern Canada increased and Fednav Group ordered the next vessel to run side by side with MV Arctic from Japan, delivered in 2006. MV Umiak I is a bit shorter than MV Arctic, but has roughly the same loading capacity. The main dimensions are: Length 188.8 m, Breadth 26.6 m, Draught 11.7 m. Ice class is DNV ICE 15 and power 21770 kW. The vessel has similar propulsion arrangement than MV Arctic, slow speed two stroke diesel, single shaft, controllable-pitch propeller in a nozzle. The icebreaking capability of Umiak I is 1.5m.

The third vessel for Fednav was delivered under the name of Nunavik in 2014, a sistership to Umiak I, but has ice class is PC4.

MODULE CARRIERS AUDAX AND PUGNAX

The huge Yamal-LNG project in Sabetta in the Ob Bay (Russian Federation) led to the construction of a whole fleet of dedicated vessels. The module carriers Audax and Pugnax are parts of that fleet. They were delivered in 2016 and started right away to deliver modules for the construction of the site. ZPMC-Red Box Energy Services owns and operates the China built vessels.

The vessels have the following main characteristics: Length 206.3 m, Breadth 43 m and Draught 7.5 m. Propulsion machinery is diesel-electric with two shaft lines and fixed pitch propellers. Power is two times 12 MW. Ice class is PC3.

CONCEPTS FOR THE FUTURE

In the Arctic there are several new possibilities for mining, but in most cases the winter conditions have been restricting the operation. For instance, the iron ore deposits on Baffin Island have been in the developing stage for the last 12 years. This remote located site has huge potential but with a cost. One of the challenges is to be able to ship the ore material to the market. For this there was established a study, where different alternatives were designed and studied making ice model tests, Wilkman et al., 2008. The main varaints studied were:

- Conventional Arctic Ore Carrier (based on Fednav's experience)
- A Double Acting Diesel Electric Arctic Ore Carrier (Aker Arctic’s experience).

The side views of the vessel variants are in Figure 13. Table 1 shows the capacity and capability of the vessel alternatives.

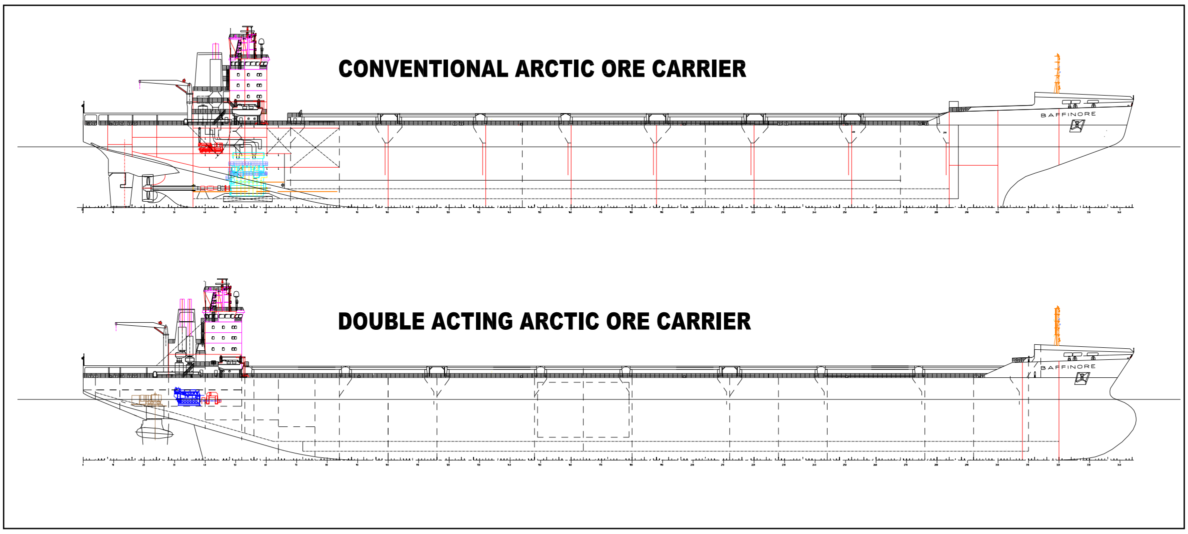

Figure 13, Baffinland ore carrier alternatives

The icebreaking capability of the tested concepts (conventional and DAS) were good when operating in ice condition around the Baffin Island. Both versions were able to proceed with constant speed in 1.7 m thick level ice, even capable to break thicker ice than that.

Table 1, Ore Carrier main operation parameters

	Deadweight (tonnes)	Power (MW)	Ice breaking capability
Conventional	130000	43.5	2.0 m/ 3 knots
Double Acting	150000	26	1.8 m/ 2 knots

At the time of the study the iron ore price was not in favor for such multibillion investment. To transport 18Mtpa of iron ore from Steensby Inlet to Rotterdam a total fleet of 10 - 11 ships were required, and from Milne Inlet a fleet of 15 - 16 ships would be required.

The capital cost of each vessel alternative is estimated to be between USD 200 - 265 Million. and the fleet of several ore carriers and railroad from the mining site to coast became too expensive and the planned solutions had to be left for future consideration.

Today the iron ore production and seasonal sea transport is ongoing with conventional tonnage.

PROPULSION TECHNOLOGY FOR FUTURE ARCTIC BULK CARRIERS

Today 77 Azipod VI2300 units have been delivered or ordered to various icebreaking cargo vessels in power ranging from 10 MW to 17 MW. The first vessel equipped with a 13 MW Azipod VI2300 propulsor, Norilsk Nickel, was highly successful project and it has broken the way to other Arctic projects such as fleet of the 172k YAMAL Arctic LNG carriers, each vessel equipped with 3 x 15 MW Azipod propulsors, see Figure 14.

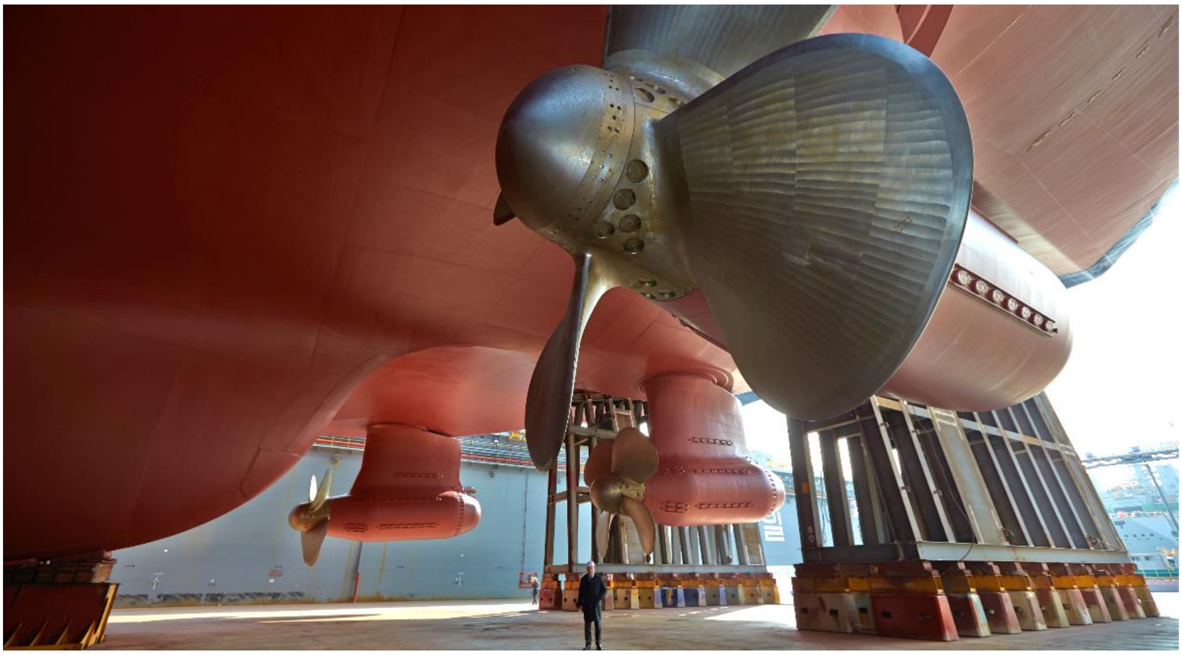

Figure 14. Three gigantic 15 MW Azipod units installed on LNGC Christophe De Margerie. The vessel dimensions are: Length 299 m and Breadth 50 m.

The good operational experience and onboard measurements have formed a valuable database for the design of Azipod with higher ice class and even more power. The development so far carried out gives full confidence to believe that it is feasible, both technically and economically, to build an Azipod with power in the range of 17 MW and beyond to the highest Arctic ice classes. Component manufacturers can deliver components that can withstand the loads and the mechanical solutions do not become unmanageable. In the latest design, new solutions to reduce the need for maintenance and improve maintainability have been introduced. The updated features are in the steering module, the hydraulic steering system and the thrust bearing.

CONCLUSION

Direct comparison of the propulsion systems is quite difficult as the vessels are of different size. The performance of the ships is not only dependent on propulsion, but also the hull form plays a big role. In the 1980ies the big plans for oil transport, tankers were designed for the

Arctic with power output over 100000 HP (75 MW), which is almost 70 % more than the 45 MW of the Yamal LNG carriers. This is a big saving and also shows that the emissions truly can be reduced with new technology.

One case, where a comparison can be made, is the fleet developed for the Dudinka trade in the Russian Arctic. Three vessel classes have been built with different propulsion systems. These 15-20000 ton vessels are of same size and have a single propeller:

- Dimitri Donskoi, FPP direct transmission, one diesel
- SA 15, CPP geared transmission, two diesels
- Norilskiy Nickel, electric podded azimuth drive, three diesels, double acting ship

Dimitri Donskoi-class vessels having a very small icebreaking capability needed icebreaker assistance in Kara Sea, Arktika-class (75000 HP), and in the Yenisey river (Sorokin class 22000).

HP and later Taymyr class 50000 HP. Also, SA 15 having more than double icebreaking capability to Dimitri Donskoi needed the same icebreakers to help. Norilskiy Nickel with the Azipod propulsion and superb icebreaking capability can travel from Murmansk to Dudinka without any icebreaker assistance. This means that the travel time is minimized, and power consumption is reduced remarkably. Today the assisting icebreakers are all with nuclear reactors and thus the emissions are low in normal use. The comparison of icebreaking capability of these three ships in same trade is in Figure 15.

In practice, Norilskiy Nickel vessels are using most of the journey only two diesels which reduces the power to 8.7 MW. The time from Murmansk to Dudinka has dropped from 14 days to 6, which is also reducing the emissions.

The possibility to use Z-drives, mechanical or podded electric, has changed the picture completely. Together with the double acting operation concept we can say that cargo ships are becoming more independent and the emissions are lower, which is of course due to the fuel selected.

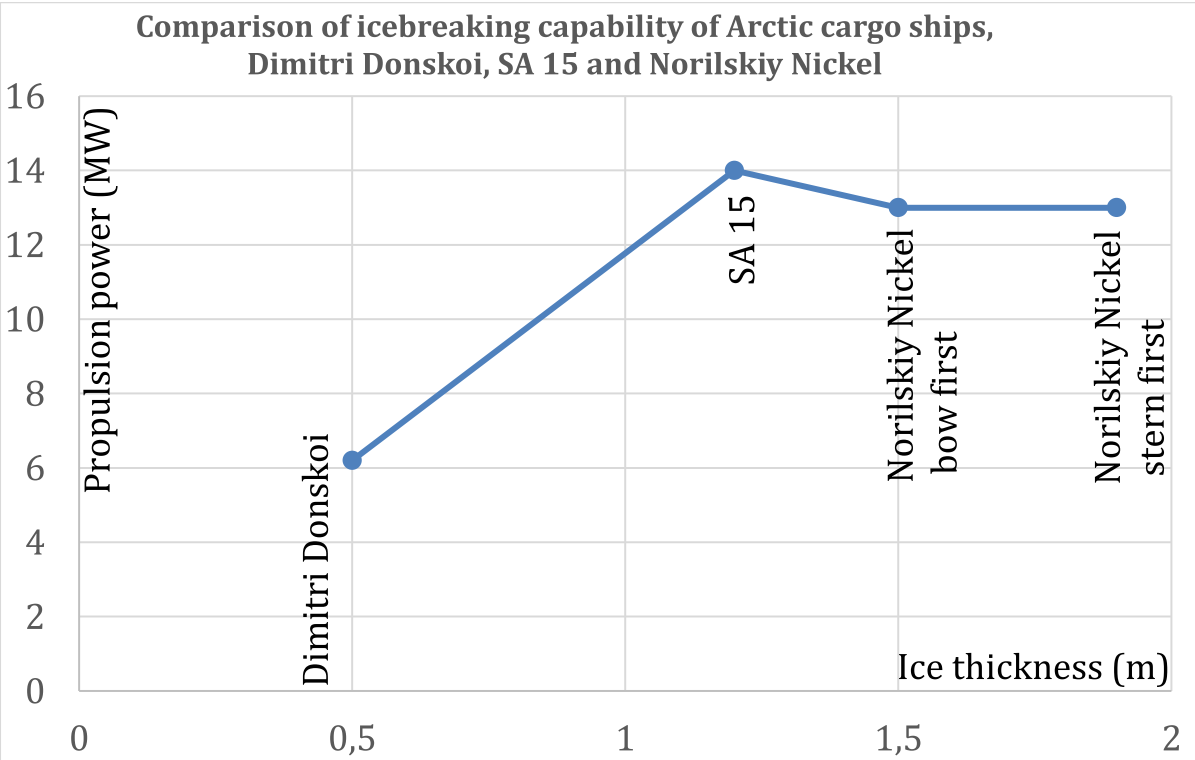

Figure 15, Comparison of icebreaking capability of vessels in Dudinka trade

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