2.6 History and Development of Arctic Marine Technology

Growth of Arctic Marine Technology

During the latter part of the 19th century, oars and sails gradually became obsolete and were replaced by engines as a means of propulsion. This innovation facilitated the building of ships capable of operating in ice conditions. At that time, navigation in the northern hemisphere was restricted to ice-free periods of the year. The countries affected most by this limiting factor were the United States, Canada, Russia and the countries around the Baltic.

The first ship intended for icebreaking purposes was the *City Ice Boat No. 1*. This 51-meter paddle boat was built for the City of Philadelphia in 1837 by Vandusen and Birelyn. She was a wooden structure and was provided with paddle wheels, reinforced with iron coverings. She was kept in operation on the Delaware River for 80 years until eventually scrapped in 1917. The small steamer *Pilot* is often considered as being the first icebreaker in Europe. She was built in 1864 for the Russian merchant Britnev, who tried to secure connections from Kronstadt during the ice-freezing and melting periods. Another pioneer in Europe was the German-built *Eisbrecher I*, later known as the *Eisfuchs*, which was designed by Ferdinand Steinhaus and built in Hamburg in 1871. In the years to follow, the number of icebreakers increased and their sphere of operation extended. By the end of the 19th century most of the major ports in northern Europe were provided with icebreakers of their own. The first purpose-built icebreakers incorporated many design features still in use today. Efficient modern icebreakers break the ice by pressing it down and they are pushed forward through the ice by the thrust of propellers. Nevertheless, considerable changes have occurred in hull form, propulsion machinery and general design.

New solutions have been achieved partly by taking the latest technology into operational use and partly by developing totally new solutions. Until the late 1960s icebreaker development was mainly based on trial and error, and new solutions were tested on real full-scale icebreakers. Today, new solutions are largely developed by testing in model basins or, on a somewhat larger scale, under real ice conditions. The solutions applied in each new icebreaker design should provide the operator with more capabilities for lower cost, the capabilities being defined and evaluated by the end user of the vessel. Thus, when applying new technical solutions, the ship designer has to understand fully the operational needs and priorities, while taking account of the existing ice conditions and all aspects of icebreaker technology.

Operating Conditions and Icebreaker Duties

The traditional and most usual icebreaker duty is to lead convoys of one or more merchant vessels through ice-infested waters. These vessels are usually ice-strengthened, but are not able to manage by themselves. When they are icebound, the icebreaker must be able to free them by breaking the surrounding ice. The assisting icebreakers built in Europe differ from their North American counterparts in being fitted with a towing notch, which allows close towing of the merchant vessels.

In subarctic regions, such as the Baltic, the Great Lakes and the St Lawrence Seaway, the thickness attained by the annually accumulating ice is usually less than one meter. The movement of the ice cover causes rafting, ridging and hummocking. Thus, the normal ice conditions in which the vessels have to operate consist of a combination of rafted ice and level ice, often under pressure, ice floes, leads and broken channels. The ice ridges may reach a thickness of more than 30 meters and are penetrated by ramming; that is, the ship is driven forward until it stops, backed off and driven forward again. In recent years, after introduction of azimuthing thrusters for icebreaking vessels, a stern-first technology has been introduced, representing a more energy efficient penetration into heavy ice conditions.

In the Arctic, the first-year level ice may reach a thickness in excess of two meters, due to the much lower air temperatures. In addition to ice ridges and frequent pressure ice, hard multiyear ice several meters thick is also found in these areas. Today, the only regular trade in Arctic waters is in the Russian Arctic, north of Siberia. Here, two main types of icebreakers have evolved: extremely powerful nuclear and diesel-electric lane-icebreakers and somewhat smaller shallow-draught icebreakers, mainly intended for assistance duties in the Yenisei River and its estuaries.
Assisting icebreakers, for both subarctic and Arctic waters, should generally have the following main features:

- They should be able to maintain a continuous speed of advance, without the need of ramming, in most of the prevailing ice conditions;
- They should be able to penetrate ridges of the size usually encountered;
- They should be wider than the majority of the cargo vessels to be assisted;
- They should be able to maintain the propeller thrust in all normal assisting conditions;
- Their propulsion machinery should be able to keep the propeller rotating in all ice conditions; and
- They should have extremely good maneuverability in all ice conditions, both ahead and astern, in order to be able to operate close to the merchant ships.

The basic design parameters for assisting Arctic and subarctic icebreakers are an efficient hull form, sufficient width, propeller thrust and power, and sufficient displacement to achieve the mass-force required when penetrating rafted ice and ridges. Many icebreakers must also be designed with reasonably good open water characteristics. The U.S. Coast Guard's icebreakers, for example, make annual journeys to the Antarctic in addition to their assistance duties and scientific duties in the North. Another type of icebreaker is that intended for assisting duties in harbors. Since the early 1990s a new vessel type has become dominant, a multipurpose icebreaker that fulfills both of these requirements and is designed to work in an efficient way both in winter and summer conditions.

The special type vessels which operate almost solely in the Antarctic often combine icebreaking capability with cargo capacity space and equipment for scientific research and accommodation for the vessel's and the base's scientific personnel. The main design parameters of Antarctic vessels include deadweight capacity, good behavior in open seas and good fuel economy.

River icebreakers represent a totally different type of vessel. Operating in the Siberian and other rivers, they must combine good icebreaking capability with extremely shallow draft. They are regularly required to operate in conditions in which the pack ice reaches down to the river bottom. The same demands have also emerged for vessels operating in the shallow northern part of the Caspian Sea.

The Arctic offshore operations in North America have created a need for icebreaking offshore supply vessels, which supply cargo to the drilling sites and perform ice management duties by breaking approaching ice in front of drilling vessels and sites into smaller pieces. These vessels do not have to be as maneuverable in ice as assisting icebreakers and their width may be less. Recently also anchor handling and oil spill combating functions have been added to these tasks.

The hull form represents a compromise between minimum ice resistance, maximum maneuverability, low water resistance, maximum displacement and acceptable behavior in the open sea. As these requirements are usually contradictory, the importance of each has to be weighed against the others for all new icebreaker projects, and the final selection is based on the specific mission profile of the vessel.

Over the years, ship designers have paid much attention to the icebreaker bow form. As a general rule, a bow with a small angle between the stem and the ice sheet and with pronounced flare of the bow sections is advantageous in reducing the resistance of level ice, as the forces acting on the ice more vertical. However, this type of bow causes slamming and is not suitable for vessels spending much of their time in open seas. A round or flat stem area in the bow also reduces the ice resistance, as crushing of the ice is avoided. A sharp-edged stem, as opposed to a round flat stem, and a steeper bow angle may be advantageous when operating in ice floes and among ice growlers and bergy bits. Because of these considerations, an Antarctic vessel, for example, will receive a totally different bow form from that of an icebreaker that operates only in ice-covered waters.

In Europe the first real icebreakers - the *Eisbrecher I* (Hamburg 1871), the Swedish *Isbrytaren* 1881, Danish *Starkodder* and *Bryderen* 1883-84, the Finnish *Murtaja* and the Norwegian *Mjölner* 1890 - each had full lines and a spoon-shaped bow, which resulted in good icebreaking characteristics in clean ice.
However, snow-covered ice piling in front of the bow together with ice and snow sludge virtually brought these vessels to a standstill.

The favorable abaft capabilities in ice of the steam ferries of the Great Lakes of the United States led to the construction of two double-ended ferries, the Saint Ignace and the Saint Marie, built in 1888 and 1893 respectively. The bow propeller arrangement was so advantageous that it was adopted in the designs of major icebreakers built in England: the Sampo (1898) for Finland and the Ermak (1899) for Russia. These vessels had bows of the modern wedge type and a side flare of 20 to 22 degrees, compared to the former 10-11 degrees. Both ships operated successfully in the Baltic. However, the Ermak broke her bow propeller while operating in multiyear ice in the Arctic and the whole bow propeller arrangement was removed. Since that time, most Baltic icebreakers have been provided with one or two bow propellers; however, this arrangement has not been adopted on Arctic icebreakers.

These typical early icebreakers had a spoon-shaped bow and well-rounded sections and waterlines in order to improve maneuverability and to minimize the risk of getting stuck in ridges and in ice fields under pressure. The first Finnish icebreaker, Murtaja, built in Stockholm in 1890, had a displacement of 825 tonnes, a 10.77 meter waterline beam and a 1200 ihp steam engine. These early icebreakers operated well in relatively thick solid ice without a snow cover, but performed rather poorly in slushy ice and snow-covered ice. A bow propeller was introduced at the end of last century, as it was found to improve the vessel’s progress in ice ridges by milling the ice and by creating a lubricating water flow in the bow area.

Between 1900-1932 development continued along the lines of the Yermak with steam reciprocating machinery with two or three screws aft and one forward. The three large icebreakers Leonide Krasin, Stephan Makarov and Lenin represented the peak of development in the United Kingdom, which then, with the exception of two ships, ceased to build for many years. Generally speaking, the vessels with bow propellers were in the majority and intended for service in the Baltic and those without bow propellers for Arctic service in the White Sea and at Archangel.

This period saw the entry of Canada as an icebreaker building country, the first vessel noted being Mikula Selianinovitch, built for the Archangel/White Sea service in Montreal in 1916. This considerable icebreaker of 8,000 horsepower was the start of the tradition of icebreaker building in Canada and was followed in 1929 by the Saurel of approximately half the power (3,600 hp) and intended for St. Lawrence service and Arctic escort. The N.B. McLean followed in 1930 for the same service and was approximately half as powerful again (6,500 hp).

It is to be noted that during this period, Canadian icebreakers adhered in type very closely to the European with flare in the region of 20 degrees and strong or moderate tumble home below the upper deck, this feature having been introduced in Sampo.

In Europe in 1932, a notable ship Ymer was constructed at Malmö for service at Stockholm. What was unusual was the installation of diesel-electric propulsion making it the forerunner of the majority of modern icebreakers whether fitted with bow propellers or not. Towards the end of the 1930s, the Russian ice breaking fleet was augmented by seven large icebreakers of the Stalin and Kirov classes, designed for work in Arctic waters with three stern propellers, as it would have been useless to try and break the hard polar ice with fore propellers.

The Stalin class was fitted with steam reciprocating machinery and the Kirov was dieselelectric. In basic type, therefore, the Stalins followed closely the tradition set by the modified Yermak and were a continuation of what was fundamentally an out-dated type of ship as dieselelectric machinery made possible a higher output per unit weight and volume; and also gave superior maneuverability, in comparison to steam engine machinery, allowing direct control from the bridge which was exploited in the Kirov class.

The Finnish Sisu built in 1939 followed closely the design principles of the Ymer. The Ymer era was continued right through the Second World War, in particular in the United States, where eight dieselelectric icebreakers were built, each with 10,000 propeller hp closely following Ymer as a pattern and
with lines almost identical to Sampo. Seven of these vessels were sister-ships and formed the well-known Wind class; the eighth vessel Mackinaw was designed for the Great Lakes with a smaller draft, but larger length and breadth.

The first icebreaker with two bow propellers was Voima, built in 1954 for Baltic assistance duties. From then on, bow propellers were a standard arrangement for many sub-Arctic icebreakers for almost 30 years. Icebreakers intended for operation in the high Arctic are not fitted with bow propellers; experience showed that the ice loads imposed on the bow propellers in the Arctic would be too high to make them technically justified.

The hull form of the Canadian icebreaker Louis S. St Laurent, built in 1969, represents the traditional rounded type with relatively vertical hull lines in the waterline area. The utilization of ice-model tests dramatically increased the understanding of the icebreaking process. These tests made it possible to study several alternatives for hull form, propeller arrangements and other requirements, thereby speeding up the whole development process.

The Urho-class Baltic icebreakers were the first that were developed using ice model tests (Wärtsilä Ice Model Basin, 1969). The model tests led to the introduction of many new features not only in hull form but also in the design of hull appendages, such as propeller bossings and rudder arrangements. Urho was the first icebreaker fitted with two rudders, one behind each of the stern propellers, for improved manoeuvrability. The shallow-draft Arctic icebreaker Kapitan Sorokin, built in Finland in 1977, had inclined but straight verticals and inclined frames in the waterline area. Compared with that of earlier vessels, the pure ice resistance was reduced by the more downward breaking bow form, which still retained a reasonably ship-like and seaworthy shape.

In the 1980s some quite different hull forms have been introduced. The Canadian icebreaking supply vessels Canmar Kigoriak and Robert Lemeur also played the role of small scale test vessels, incorporating possible design features for future Arctic tankers. Both have a spoon-shaped bow, sharp shoulders, a parallel midbodies and straight vertical sides. Vertical sides are advantageous for a large tanker with regard to displacement, but result in a less maneuverable vessel. To allow turning in ice, these vessels were fitted with reamers, which made the forebody wider than the rest of the hull and thus increased the width of the broken channel.

This modern period has seen the development of new icebreaking forms, and a more scientific approach to the modeling of ships in ice with extensive model testing and, most recently, numerical methods.

Canadian Arctic oil exploration and development led to new designs such as the Kigoriak, and Terry Fox, while European development activities led to the Oden, double acting tankers (DAT) with Azipods, FPSOs in ice, and research ships such as the Nathaniel B. Palmer, USCGC Healy, and the converted CCG Franklin now called CCG Amundsen. A cylindrical bow, which lowered ice resistance and provided the vessels with extra displacement, was fitted to eight extremely shallow draft river icebreakers, the first of which was the Kapitan Evdokimov, built in Finland in 1983. The Waas bow, introduced in West Germany, is another interesting concept. This basically square shaped bow cuts the edges of the channel by shearing, instead of breaking. Similarly shaped icebreaking clearing devices have been in use in Soviet rivers since the early 1970s; these barges have a landing craft bow and a plough under the bottom intended to create a clean channel for the following cargo vessels.

The latest Baltic icebreakers of the Otso type, built in 1986, have a rise of floor, which promotes sideways clearance of ice by buoyancy forces, its effect being reinforced by the Wärtsilä Air Bubbling System (WABS).

An experimental Finnish bow, tested in the Gulf of Finland in 1985, has rounded waterlines in the stem area, rounded shoulders and an ice-clearing plough. These tests, and several additional model tests with bow forms of similar type, have shown better turning ability than with the landing craft bow type, low ice resistance and smaller slamming forces in seas.

Depending on the operational needs, these new icebreaker hull concepts may be added for channel-clearing capability. It is not self-evident, however, that the channel behind an icebreaker should, ideally,
be free of ice. New ice forms rapidly in cold air temperatures, and a frequently utilized channel in a narrow river will soon become unnavigable due to renewed accumulation of ice.

Starting in 1990 with a 1.3 megawatt buoy tender, M/V Seili, podded propellers have been used in conjunction with designs which allow the ship to go astern in heavy ice and forward in open water and light ice. Full power can be applied in either direction by rotating the Azipod.

The development has now progressed to a 16 MW tanker with one Azipod unit, two of which were in 2003 delivered to Neste Shipping by Sumitomo Heavy Industries for use in the Baltic. The idea was to design an efficient icebreaking stern for the vessel, while keeping an efficient open water bow. This idea originating from Aker Arctic has since then been picked by many other operators, like LUKoil/ConocoPhillips for three 70.000 tdw; Sevmorneftegaz/Sovkomflot for two 70.000 tdw shuttle tankers from Busan, Korea and St. Petersburg respectively; and Norilsk Nickel for a series of five Arctic independently operating 14.500 tdw containerships.

The steel materials utilized for icebreaker plating have a high yield point, are ductile even at low temperatures and they should be resistant against wear and corrosion even when unprotected, as the protective coating often wears off very quickly during operation in ice. In addition, the steel should be easy to work and weld and should not lose its favourable characteristics while being welded.

Due to these numerous requirements, special steels are employed in the construction of icebreakers, (e.g., steels with yield points up to 31 and even 56 kp/mm2). The welding of these HT steels is a difficult task as the material easily corrodes and cracks near the welds. Therefore, until the mid 70s normal shipbuilding steel was employed in the construction of icebreakers, then a transition to 32 and 36 kp/mm² and more recently to 50 kp/mm² steels took place.

Development of Auxiliary Systems

The resistance due to breaking of the ice sheet often represents only a fraction of the total ice resistance. One early innovation, which today is a standard installation on most icebreakers, is heeling tanks. Pumping water from one side to the other and then back again results in continuous rolling of the vessel, which reduces friction between the ice and the hull and makes steady progress easier in difficult ice conditions. If a vessel becomes beset in an ice ridge, the heeling system creates an extra force which helps the vessel to break loose. Trimming tanks have also been installed on icebreakers for the same purpose.

The Inerta 160 epoxy hull coating is another innovative solution which today is applied on most ice-going vessels. The coating, developed in Finland in the 1975, can withstand the abrasive action of the ice and prevents corrosion of the hull. The friction between the hull and ice is kept low.

Another friction-reducing innovation is the WABS system, first applied in 1969. Compressed air is forced through a series of nozzles located along the lower part of the hull. As the air rises along the hull, it creates a strong current of water and air, which forms a lubricating layer between the hull and the ice, reducing friction from the ice and snow. This system is today installed on more than 55 icebreakers and on cargo vessels all over the world.

The propulsion machinery of an icebreaker faces severe demands arising from extreme variations in the load on the engines. These are due to propeller-ice interaction and to the frequent necessity of changing the mode from full power ahead to full power astern within a few seconds. The various parts of the propulsion system must be strong enough to withstand frequent shock loads.

What is needed is a high propeller thrust both forward and astern at low vessel speed, combined with acceptable propulsive efficiency at higher speeds. The propulsion machinery should ideally provide great power with small fuel consumption. The torque should be high at all possible propeller revolutions.

A system working on a similar principle is the Jastram system, in which a combination of air and water is blown out through nozzles. Applied in the early 1980s, the Jastram system also incorporates the waterfall principle, water being blown out in front of the bow and thus reducing friction from the snow. The waterfall was first applied on the Canmar Kigoriak.
A promising innovation is the use of a stainless steel-compound belt in the waterline area. Introduced on the icebreaker *Otso*, this eliminates the need for hull treatment in the area of the hull usually subject to most wear, where no hull coatings can last for long. Thus, the stainless steel belt extends the intervals between dry dockings.

**Powering Options**

The reciprocating steam engine was the only possibility for icebreaker propulsion until 1932, when the first diesel electric icebreaker named the *Ymer* was delivered in Sweden. Steam driven icebreakers were built in Canada up to 1957 (the *Montcalm*) and 1960 (the *Wolfe*). The torque of the steam engine is suitable for icebreakers and additional torque could be developed by using high-pressure steam in low-pressure cylinders, if the propeller was jammed by ice. The steam engine is silent and easy to control, but has many disadvantages: immense size and weight of machinery and, primarily, low efficiency.

A steam turbine is utilized on icebreakers mainly as a part of the turbo-electric machinery in conjunction with a nuclear power reactor so that the icebreaker becomes practically independent of fuel capacity, thus the low efficiency of the turbine becomes insignificant. Only three nuclear powered icebreakers have been built so far; one is presently commissioned, one is under construction and one is still in the design stage.

For decades diesel electric machinery has dominated the icebreaker machinery market. The conventional method is to use direct current, as the speed of a direct-current propeller motor is easy to control. Moreover, full power is available over a wide engine speed range with an advantageous torque curve. The number of main diesel engines can be increased for improved reliability, and the power can easily be distributed economically between the main engines.

However, even diesel electric machinery is complicated, heavy and expensive and energy losses due to the electric transmission are significant. For improved efficiency and economy, the development has been towards the utilization of alternating current motors as achievements in controlling techniques have made it practical and possible.

One attempt to simplify the arrangement is the power-plant system, whereby all main generators are connected to a common bus bar from which all electrical consumers are fed, including the auxiliary network, thereby facilitating the removal of auxiliary diesel generators.

The distribution of power demand between main diesels is easily accomplished by means of this system, so that the engines run continuously on adequate load for improved economy. Moreover, higher voltages are used to make the electrical components more compact and to avoid high currents that are difficult to handle and necessitate heavy cabling.

The disadvantages of the diesel electric system have fed the dream of a geared diesel propulsion plant with controllable pitch propellers adapted for icebreaker use. This arrangement has proven itself to be advantageous as some machineries of this type have been successfully employed on icebreaking ferries and cargo ships. In the past few years, some icebreakers have been built with geared diesel machinery; e.g. the *Mudyug* and *Stroptivyj* classes.

The gas turbine has also been employed on icebreakers as a booster power source despite its poor efficiency, as full power is seldom required. The excellent maneuverability required for the propulsion machinery of an icebreaker is achieved by using a diesel electric system. For this reason the propeller itself has been of a fixed pitch type, with either fixed or detachable blades. The fixed pitch propeller is a simple and reliable construction offering high efficiency. An icebreaker propeller is normally a compromise between different requirements: primarily, a good bollard pull-force is required in addition to reasonable efficiency at full speed, plus good reversing characteristics. Moreover, heavy ice loads are taken into consideration while dimensioning.

Controllable pitch propellers have been employed on many ice going vessels for a long time and, if properly dimensioned, they are suitable for icebreakers and independently operating cargo vessels. Provision is made to prevent ice from working its way into the sea intakes and blocking the pipes of the
machinery cooling systems. The ice wells are designed to separate pieces of ice from the inlet water and are heated by warm return water. Some icebreakers are also equipped with reserve cooling systems, which circulate the cooling water through the ballast water tanks if the primary system should fail. An air cooling system has also been used for electrical components. The weak links in this system are the air intake grills and filters, which easily freeze over and may be filled with snow under unfavorable weather conditions.

The diesel-electric system today predominates on icebreaking vessels. The electric motors have a rising torque curve with decreasing propeller revolutions, which is most suitable for icebreakers. The early diesel-electric icebreakers were of the Ward-Leonard type, having DC generators and DC propeller motors. Over the years, the power of these DC-DC systems has increased. The most powerful diesel-electric icebreaker in the world, *Jermak*, has a shaft power of 26500 kW (36 000 shp). Three vessels of this type were built in Finland in 1974-1976 for operation in the Arctic.

The development of semiconductor technology made it possible to shift from directcurrent to alternating-current generators. At the initial phase, the propulsion machinery was regulated with the aid of diode rectifiers but separate auxiliary machinery was still needed for the electrical network of the vessel. The introduction of thyristor rectifier control made it possible to supply both the propulsion power and the auxiliary power from the main generators. The powerplant machinery was first installed in 1976 on the subarctic icebreaker *Kapitan M. Izmaylov*.

Since the birth of *Otso* and her sister ship *Kontio* (1986, 1987), the propeller motors are typically of the alternating current type. The propeller motors are regulated through static frequency converters. The shaft power of these vessels is 15000 kW. The modern AC-AC system has several advantages: the efficiency is higher and the propeller motors are smaller and lighter and need less maintenance. It is also possible to construct larger AC propeller motors than DC motors.

**Steam and Gas Turbines**

Steam and gas turbines have also been used in icebreaker propulsion machinery. The Canadian icebreaker *Louis S. St Laurent*, built in 1969, has a power-plant consisting of four water tube boilers providing steam for three steam turbo generating sets, which provide power for three propulsion electric motors. The total output is 17 600 kW. Later Canadian icebreakers, the Rclass vessels *Pierre Radisson*, *Franklin* and *Des Groselliers* (1978-1982), have been fitted with diesel-electric propulsion, which provides better fuel economy than the steam or gas turbines (10000 kW and 11 030 kW).

The U.S. Coast Guard's Polar-class vessels *Polar Star* (1976) and *Polar Sea* (1978) achieve a total output of 44100 kW by using both the three gas turbines coupled to the propeller shafts and the diesel-electric AC-DC system. The diesel-electric system alone gives an output of 13 200 kW. The vessels have three controllable-pitch propellers.

**Mechanical Transmission and Controllable-pitch Propellers**

In the late 1970s and early 1980s, there was a period to use a reduction-gear-controllable pitch propeller application on ice-going vessels. This can be seen as a natural development of the increasing experience of the behavior of ice-going vessels and the improving methods of calculation and dimensioning. Ice-going vessels are frequently designed for both open-water and icebreaking service. Here, the mechanical transmission of diesel engines coupled to reduction gears and controllable-pitch propellers offer advantages as regards installation costs, weight and fuel efficiency. Three Finnish-built icebreakers and the Arctic supply vessels mentioned above have this type of propulsion system. As diesel engines do not allow large variation in their revolutions, vessels of this type are usually fitted with large flywheels in order to absorb the ice loads on the propeller.

In addition, sophisticated propeller pitch-control systems have been developed, which reduce the pitch when this is needed to maintain the correct main engine revolutions and to avoid overloading. The biggest installation of this type is the propulsion system used on the 19 Arctic multipurpose cargo vessels of the SA-I5 type. These vessels have one controllable pitch propeller with a diameter of 5.6 m and a main engine power of 15500 kW. In ice, a hydrodynamic coupling is used, by which the number of main
engine revolutions, and thus the motor torque on the medium-speed diesels is always maintained, regardless of the propeller revolutions.

**Nuclear Power**

Obvious advantages are attached to nuclear propulsion for Arctic icebreakers. Power consumption is high, and bunkering arrangements are difficult in these harsh and remote areas. By using a nuclear reactor as a source of heat for generating steam for the turbines, this problem is avoided and flexibility in Arctic operations is achieved. The first nuclear icebreaker, *Lenin*, was built in the Soviet Union in 1959. The power of this vessel is 32,300 kW (44000 hp). The steam turbines drive the generators which power the three propeller motors of the vessel. *Arktika*, with an output of 55,200 kW (75,000 hp), was built in 1975. This icebreaker was the first to reach the North Pole, and, together with the four other vessels of the same series (*Sibir*, 1977; *Rossija*, 1985; *Sovetskiy Soyuz*, 1989; *Yamal*, 1992; and *50 Years of Victory*, 2007) is the most powerful icebreaker existing today.

The two 36,800-kW (50,000-hp) *Taymyr*-class icebreakers built in Finland are the first created outside Russia. These vessels were equipped with a pressurized water reactor in St. Petersburg after delivery from Finland. The vessels have two main turbines and three propeller motors. The electric transmission is an AC-AC system with cyclo converters, the same as that applied on the *Otso*-type Baltic icebreakers. Compared with the larger nuclear icebreakers, with a draft of about 11 meters, the new icebreakers are very shallow-draft vessels, with a draft of only 8.1 meters, making them suited also for the northern rivers.

**Propellers**

Icebreakers of the *Kapitan Evdokimov* series require four stern propellers to absorb the power needed. The number of propellers installed on icebreakers depends on the draft of the vessel and on the power installed. The largest Arctic icebreakers are fitted with three stern propellers. The shallow draft river icebreakers of the *Kapitan Evdokimov* series require four stern propellers to absorb the power needed. These icebreakers, with a draft of only 2.5 meters, can penetrate level ice nearly one meter thick.

Ducted propellers, common on open-water tugs and Arctic supply vessels, give 20% to 30% higher thrust at low ship speeds than open propellers, but may become clogged by ice blocks, which will necessitate frequent reversals of the propeller. This is impractical and may be dangerous for an icebreaker leading a convoy. Thus, the application of a ducted propeller in an icebreaker project has to be studied carefully, the benefits being weighed against the drawbacks. The decision will be based on the operations, the conditions and the ice thickness in relation to the diameter of the propeller.

**General Design**

Since the early 1970s it has been a standard practice on Finnish-built icebreakers to decrease the level of noise and vibration experienced by the crew by placing all the crew accommodations above the main deck.

The general arrangement of a modern icebreaker is clear and straightforward. On *Otso*, the large deep fuel tanks have a central location amidships and the diesel-generator sets are situated on the main deck, which simplifies the arrangement of other ship systems and reduces maintenance cost. A high degree of automation has been adopted in this vessel, which has microprocessor-based alarm and monitoring systems and automatic control of the machinery. The control center is located on the bridge.

The view from the bridge wings is almost 360 degrees, which is useful on icebreakers when maneuvering near merchant vessels. Compared with the costs of Baltic icebreakers of the *Urho* type built 10 years earlier, the total annual operating costs have been reduced by 40%.