CHALLENGES OF AN ICE-PROOF TRANSDUCER DESIGN

Multibeam Systems for Extreme Environments

The search for resources and energy reserves for the future is continuously increasing in the polar region. More and more states are trying to stake their claims and to register their rights. For the same reasons, the clarification of the exact borders of the continental loop is becoming important and is thus a subject of exact examination. The exploration of the existence of methane, in particular in polar waters, is a challenging task for the future and requires robust and reliable equipment.

Survey of polar waters with the assistance of modern multibeam systems on icebreakers is a challenge to the acoustic and mechanical design. Current designs, proven on traditional research vessels, fail under the extreme conditions in the eternal ice. Therefore, the ability to safely endure the considerable mechanical load from the ice is the main consideration in the design of a multibeam system for an icebreaker. Ultimately, not only the integrity of the multibeam system but also the security of the whole vessel is at risk.

Hence, just as in the nearly 150 years of development history for the icebreakers themselves, these requirements will lead to individual and characteristic features in design, defined by the medium of ice.

The development process of icebreakers was continuously attended by the responsible national classification companies, who helped to define the special requirements for such vessels and to summarise their experience in construction regulations. Over time, diverse construction regulations were issued by the nations such as Finland, Russia and Canada who build and operate icebreakers. Unfortunately, this resulted in manifold definitions of ice classes, since some companies also considered the age of the ice and the snow lying on it in addition to the strength of the ice. However, the various national construction regulations became increasingly similar as identical ice strengths produce similar technical requirements, which in turn lead to comparable solutions. Today, these are summarised in the IACS Unified Requirements.

Since comparison of the national ice classes can be very confusing, one should rather concentrate on the common design features of most of the actual and planned research icebreakers:

- Conventional propulsion (no nuclear propulsion)
- Net weight approximately 12,000t
- Gross weight approximately 17,000t
- Length approximately 130m
- Draft approximately 9m
- Width approximately 25m
- Research and survey operations in Arctic regions during summer
- Continuous icebreaking of ice with 1.1 to 1.5m strength
- Ramming of ice with approx. 3m strength

Most of these icebreakers are also used to supply the Antarctic/Arctic research institutions. Therefore they correspond to the Russian ice class Arct. 7 and to the IACS polar class PC5-PC6.

Extreme Environments Require Special Know-how

In 2006, the Japan Maritime Self-Defense Force (JMSDF) placed an order for the construction of a SeaBeam multibeam system for the type of vessel defined above with no compromises whatsoever in regard to ice resistance and acoustic performance. To secure the latter, the installation area was set as far as possible in the bow; the accepted limit was only the directly necessary geometric space requirement as defined by L-3 ELAC Nautik. Auxiliary constructions such as ice deflectors or special keel forms were prohibited in order not to interfere with the ideal form of the icebreaker design. Furthermore, the latest state-of-the-art transducer and system technologies for multibeam systems were to be installed.

The installation in the bow created design-related ice loads of 30MPa on the complete surface of the location of the multibeam system. Determination of these design loads is generally achieved by tests and empiric formulas. During the quasi-static continuous icebreaking procedure, the direction of the ice flows is in most cases still predictable since the form of the bow is constructed to press the broken ice under the unbroken ice, thus producing an ice-free fairway. In case of ramming, however, this prediction becomes significantly less predictable and 'rebound' effects may occur, including in the bow area. This also applies to the contact in the ice edge area with floating ice in heavy sea.

It was also mandatory to ensure that broken ice, which within this area could come into contact with the outer hull of the vessel and therefore also with the outer surface of the multibeam system, would not cause any damages or scratches which could subsequently negatively influence the acoustic system performance by flow noise.

Development of an Ice-proof Multibeam System

Various characteristic features of multibeam systems for installation on icebreakers resulted from the demanding environmental requirements for such special research vessels, while avoiding compromises and high risks. An acoustic window for protection of the Rx/Tx transducers at the acoustically best installation area in the bow is inevitable. It protects the transducers against shocks by rebounding ice floes which have been pressed under the vessel during the ice breaking process. The transducers must additionally be protected against abrasion by ice floes slipping along the hull – these can cause considerable notches, even in the steel of icebreakers. The windows must also be able to withstand the extremely high pressures during these processes and convey the resulting forces safely into the supporting ship structure. The extreme forces can be concluded from the bottom construction of the steel of an icebreaker in these areas: steel sheets of 30mm and more for the outer hull are the rule rather than the exception. Frame spacing of 600mm or less is also common in these areas, thus demonstrating the extreme loads.

These loads can only be withstood when the frames for fixing the transducers of the multibeam system are an integral structural part of the total vessel construction in the installation area. Even if they are possible, 'open', non-supporting constructions to redirect the flow of forces increase the expenditure for the vessel's construction to a disproportionately high extent and are therefore extremely unfavourable, both technically and financially.

This also means that within the arrays itself a universal support of the acoustic windows is required for the ship's structure. When even a 30mm outer steel hull must be supported at least every 600mm, an acoustic window cannot suffice with less if it is to guarantee a similar stability. These supports must also be integrated into the frames and the vessel in order to transfer the forces safely. A simple calculation shows that unsupported windows will not be able to carry these loads. It has to be considered that the window size is usually bigger than the normal 'footprint' of a multibeam system since the transducers unavoidably have to be shifted inwards, whereas the beam angle including the motion compensation should comply as far as possible with the coverage angle of a traditional system.

However, in contrast to the standard multibeam systems, steel braces are installed between the projector modules for reinforcement purposes. The braces increase the spacing of the transducer elements in the along-ship direction, resulting in modified transmission beam-forming algorithms and slightly increased side lobes on the transmission side. This effect must be minimised to an uncritical level for the overall system performance. For the hydrophone arrays of these multibeam systems, specific non-standard hydrophone modules are utilised which support mechanical reinforcement measures while keeping the spacing of the hydrophone elements the same as for the standard multibeam systems.

Due to the acoustic windows for ice protection, the depth performance decreases slightly (by approx.15%), and maximum coverage of the ice-proof multibeam systems is <130° compared to the 140° of standard multibeam systems.

What Protrudes Will Break Off

In order to make optimal use of the available space while also guaranteeing a high resolution, a multibeam system based on 20kHz is ideally suitable for two reasons: it covers the sea depths in the polar region securely and offers sufficient reserves for most of the sea areas worldwide. By choosing this frequency, the unavoidable acoustic windows and their necessary supports are restricted to a manageable size. Ice-proof solutions for 30 or 50kHz multibeam systems are also possible for installation on vessels that only need to detect in medium water depths.

Ice deflectors and special keel forms for integration of multibeam systems on icebreakers are not necessary. Usually they are merely a very expensive way of concealing the deficient design of such systems and do not eliminate their problems. In particular for icebreakers, the following rule applies: 'What protrudes will be broken off'. The protection of extensions and annexes as well as anything that does not correspond to the 'ideal' form of an icebreaker can become very expensive.

L-3 ELAC Nautik's many years of experience with installations on icebreakers have furthermore shown that it is of great benefit to construct the installation area of the transducer with the acoustic window as a closed system. The disadvantage of the slightly higher expenditure for such a system is quickly compensated by its advantages. It is very expensive to protect open systems with acoustic windows internally against biological growth, rust and sediments. It is mandatory to frequently dismantle the windows for cleaning purposes. However, the installation in a closed system is maintenance-free. The latest statistics provide evidence of the robustness: up until this day, all ice-proof SeaBeam systems are working properly and no damage has occurred. In addition to Japan, the ice-resistant SeaBeam multibeam systems are at present in successful operation on icebreakers in the Russian Federation and the Chilean Navy.