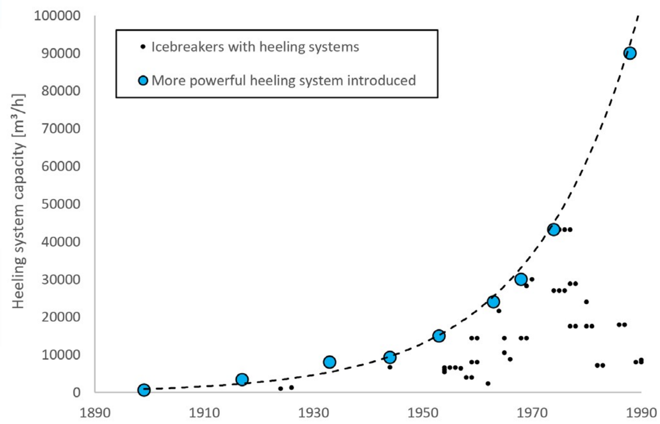
Understanding the physics behind active heeling

In addition to unbroken level ice, the effectiveness of the active heeling system was also evaluated in thick brash ice representing a large pressure ridge field.



Through the 20th century, the capacity of active heeling systems increased rapidly with each new icebreaker generation and can be said to having reached its ultimate development with the 1988-built Swedish icebreaker *Oden*.

In the previous issue of Arctic Passion News, we described the initial findings of a recent research project where Johanna Marie Daniel from Hamburg University of Technology (TUHH) studied the effectiveness of active heeling systems in vessels with modern icebreaking hull forms. A more detailed analysis has now been completed, and the encouraging results were presented at the 39th International Conference on Ocean, Offshore and Arctic Engineering (OMAE).

In the late 19th century, Admiral Stepan Osipovich Makarov devised a number of icebreaking auxiliary systems to improve the ice-going capability of the world's first polar icebreaker, Ermak, without increasing its propulsion power. One of these novel technical solutions was a pair of interconnected ballast water tanks used to induce a rolling motion by pumping water back and forth.

Standard feature in the past

This so-called active heeling system quickly became a standard feature fitted to most icebreakers through the 20th century, until the development of abrasion-resistant low-friction hull coatings and the adoption of azimuthing propulsion for icebreaking applications.

Despite the long history and extensive use of active heeling systems in a large number of icebreaking vessels, perception of the systems' overall effectiveness has been based largely on anecdotal operational experience rather than systematic research and quantifiable data.

"One of the reasons why we initiated this research project was to find out how the active heeling system affects the ice-going capability of modern icebreaking bow geometries," explains Naval Architect Tuomas Romu, who supervised the project at Aker Arctic.

In addition to ice model tests at Aker Arctic's in-house icebreaking laboratory in Helsinki, the research project included developing a semi-empirical calculation method to predict the ice resistance of an icebreaker using an active heeling system.

Simulation in model scale

In this project, a mechanical reciprocating weight was used to induce a forced rolling motion on the model. The system parameters were carefully selected to maximize the data obtainable for further analysis: two different weights (heeling tank sizes), two different rolling periods, and two different mass transfer rates (heeling pump capacities). The model used in this research project was one of the latest heavy polar icebreaker designs developed by Aker Arctic.

The two-day test program included performance tests both with and without the heeling system in heavy multi-year ice conditions corresponding to the maximum continuous icebreaking capability of the vessel. Additional tests were carried out to investigate how much energy brought into the heeling system dissipated into the surrounding water and ice.

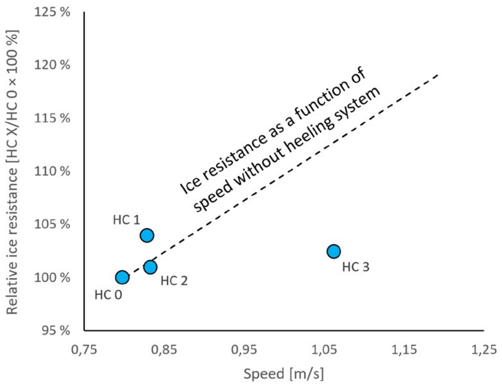
Interesting findings

Analysis of the ice model test results yielded a number of interesting findings.

Firstly, it is possible to improve the ice-going capability of a modern icebreaker operating in extreme ice conditions with an active heeling system.

Secondly, the highest performance gain (+30 % in speed; −10 % in level ice resistance) was observed with smaller heeling angles, indicating high optimization potential for heeling tank size and pump capacity.

Thirdly, to achieve ice-going capability, a correctly designed active heeling system uses less energy than what would be required by simply increasing a vessel's propulsion power. In addition to level ice, positive results were also obtained in thick brash ice used to simulate a ridge field.



Results from ice model tests with heeling system (HC 0 without forced rolling; HC 1-3 with different system parameters).

"Another interesting observation was a significant reduction in zero-speed starting resistance, in line with observations in past full-scale ice trials," says Daniel.

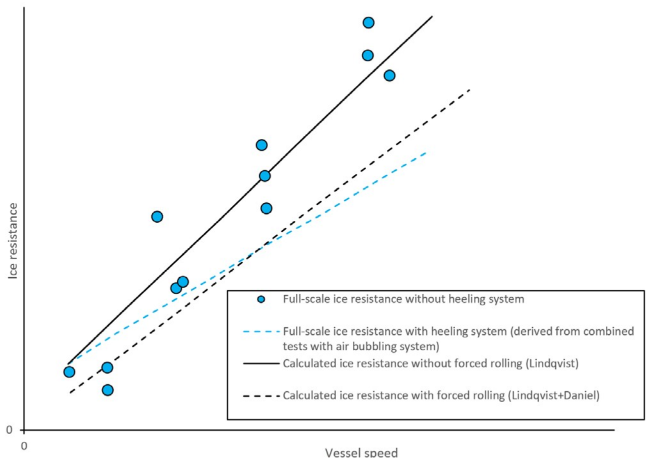
When the active heeling system was activated, the model started moving - even at a reduced propulsion power level that otherwise would not have been enough to sustain continuous icebreaking. Thus, an active heeling system reduces the likelihood of the vessel becoming beset in ice.

Advantages of calculation method

The calculation method developed in this research project takes both the added resistance of the heeled hull, as well as the motion energy of the rolling vessel into account.

The former is estimated by expanding Gustav Lindqvist's well-known semi-empirical ice resistance prediction formulas to consider the asymmetric icebreaking geometry of a heeled hull. The latter includes solving coupled equations of motion (roll and yaw) using two external excitation factors: heeling moment from the active heeling system (energy brought into the system) and hull-ice contact forces in the bow region and channel sides (energy dissipated into the surrounding ice). The result is additional resistance from the rolled state of the vessel as well as additional vertical icebreaking force on the surrounding ice.

In addition to ice model tests, the calculation method was evaluated against data from the full-scale ice trials of the Finnish icebreaker Otso. Although the vessel was not operating near the limit of its icebreaking capability in the 80-centimetre level ice where the tests were conducted, the calculations nonetheless lined fairly well with full-scale data points.



The calculation method was evaluated against data from the full-scale ice trials of the Finnish icebreaker *Otso*.

Icebreaking toolbox

Although icebreaking auxiliary systems are no longer as prevalent as a few decades ago, the active heeling system remains a simple yet effective option to improve a vessel's ice-going capability without increasing its propulsion power. This research project has demonstrated the system's effectiveness with modern icebreaking bow geometries. The new design tools can be used to optimize system parameters by avoiding oversized heeling tanks and pumps.

While modern escort icebreakers are designed to maintain high average speeds in all prevailing ice conditions, other ice-going ships such as polar research vessels may sometimes find themselves operating close to the limit of their continuous icebreaking capability. In such situations, the active heeling system may be the decisive factor that prevents the vessel from getting stuck.

"One possibility is to combine the active heeling system with an anti-rolling tank," notes Daniel. ■

Johanna Marie Daniel is a Naval Architecture and Ocean Engineering student (M.Sc.) at Hamburg University of Technology (TUHH) in Germany, and will graduate at the end of 2020. She visited Aker Arctic during an excursion to Finland in 2018, and decided to apply for a research project as part of her Master's programme.