POAC'25
St. John's, Newfoundland and Labrador, Canada

Proceedings of the 28th International Conference on Port and Ocean Engineering under Arctic Conditions
Jul 13-17, 2025
St. John's, Newfoundland and Labrador
Canada

Ice Load Measurements of High Ice Class Azimuthing Propulsion Unit (Submission Nr 18)

Aki Kinnunen[1], Pirjo Määttänen[2]
[1]Vibrol Oy, Tuusula, Finland
[2]ABB Oy, Helsinki, Finland

ABSTRACT

Azimuthing propulsion unit full scale ice load measurements are essential for equipment dimensioning, dimensioning methods verification and ensuring the safe operation of the ship. Propulsion units are applied as main propulsion for various types of ships and to various types of ice conditions and operation. Propulsion unit ice loads differ according to ship type, operation and ice conditions. ABB has conducted several ice load measurements on azimuthing propulsion units. Results have helped to make adequate and safe dimensioning for the equipment.

A unique opportunity to make propulsion unit full scale ice load measurements is Ponant ice breaking cruise ship Le Commandant Charcot. The ship is a luxury cruise ship with high ice breaking capability. Delivered 2021, she is still the only ship built and operating with ice class PC-2. She has been operating successfully in e.g. North Pole, Antarctic waters, Northwest Passage, North-East Greenland and Trans Arctic Voyage. Ponant offers platform onboard for scientists all around the world.

The ship starboard propulsion unit was instrumented in 2021 with strain gauges and accelerometers, system was updated 2024. Ships speed, propulsion power, steering angles and motor torque are recorded from both propulsion units. Valuable detailed ice condition data is available occasionally.

This paper describes ice operation and ice loads on azimuthing propulsion unit in various ice areas of the world. The results are applied for improving the design criteria and verification of prevailing ice dimensioning guidelines.

KEY WORDS: Ice Loads; Azimuthing Propulsion; Full-scale ice load measurements; Ice Conditions; Icebreaking,

INTRODUCTION

Azimuthing Propulsion

There are many types of azimuthing propulsion units, mechanical and electrical. Power for propeller is produced by electric motor, but motor can be inside the azimuthing unit or inside the ship, in which case power is transferred via gears. This paper study is concentrating on ABB Azipod podded propulsion units, where electric motor is on the same shaft as pulling propeller. Since the overall principle is the same, the results are valid for all pulling propeller type azimuthing propulsion units.

Pod Load Measurements – general

First azimuthing units for ship's main propulsion were introduced in the 1990's. At that time there was no guidance or class rules for azimuthing propulsion dimensioning, requirements were usually based on ship hull or rudder loads. Azimuthing propulsion unit design and dimensioning was made with co-operation with research institutes, classification societies and shipbuilders. To verify the dimensioning, full-scale load measurements were essential.

At first a few full-scale measurements were done onboard ships at Bay of Bothnia, duration usually one winter. The results gave adequate information, and design safety could be assured. However, ice conditions vary greatly between the winters, and one winter measurement gives a limited view for the loads the structures are facing. Several long-term full-scale measurements for Azipod propulsion units have been made since 2006. Usually new ice load measurement projects are started, when new technology or ship concept specific propulsion unit loading needs verification, e.g. icebreaker Polaris with azimuthing propulsion unit on the bow of the ship. Full scale propulsion ice load measurements from the beginning of 2000 are presented in Table 1.

Table 1. Full scale ice load measurements on high ice class Azipod propulsion units (RMRS Arc 7 corresponds to IACS PC-3)

Ship type	Ship name	Azipod propulsion	Ice class	Operation area	Full scale measurements
Icebreaker	Botnica	2 x 5 MW Azipod V16	DNV ICE-10 IB / PC-4+	Bay of Bothnia	2001
IBSV	Fesco Sakhalin	2 x 6.5 MW Azipod VI1600	DNV ICE-10 IB / RMRS IB 7	Okhotsk Sea	2006 - 2008
Cargo	Norilsk nickel	1 x 13 MW Azipod VI2300S	RMRS Arc 7	Yenisei, Kara Sea	2006 - 2008
Icebreaker	Polaris	1 x 6 MW, 2 x 6.5 MW Azipod VI1600	LRS PC-4+	Bay of Bothnia	2017 - 2023
Tanker	Yuriy Kuchiev	2 x 11 MW Azipod VI2300S	RMRS Arc 7	Ob Bay, Kara Sea	2020
Cruise	Le Commandant Charcot	2 x 17 MW Azipod VI2300L	BV PC-2	North Pole, NWP, Antarctica, Greenland	2021 ->

Full scale measurements include several strain gauges, accelerometers, displacement sensors, shaft speed indicators and data storage inside azimuthing propulsion unit steel structure. To get thorough understanding, also propulsion data and ship speed and heading are recorded to combine with measurement data. Ice conditions and properties are only available during ice trials, where the environment is fully recorded. Long term measurements give information about ships' normal operation loading. That provides data for maximum loading and load distribution, which in most cases is relevant enough for equipment design, even no exact information about ice properties is available.

Azimuthing propulsion unit ice loads are related to e.g.:

- Ship hull lines (how the ice moves towards propulsion unit/propeller)
- Ship operation (work or leisure ship)
- Propeller geometry and diameter
- Ship speed
- Displacement
- Ice
    - Thickness
    - Type
    - Strength (first-year ice, multi-year ice, ..)
    - Size of broken ice
- Direction of the ice loading (azimuthing angle can differ from flow direction)

Long term measurements on various types of ships in different ice conditions assures, that equipment design loads – both extreme and repetitive – are defined correctly, even though detailed ice conditions data is not available. Due to randomity of ice loading, ice loads cannot be simulated in every operation type and ice environment, that is why verified simple analytical load calculation methods are needed for equipment design. Design loads include good safety margin compared to measured loading, if no ice induced damage has happened, overall design can be concluded to be in safe level.

Results during the past twenty years have given very good understanding about nature and magnitude of the loads, including load distribution. Early design loads were very much affected by exposed area of the structure, that led to high design loads for propulsion unit side direction (transversal loading) and lower loading for longitudinal direction e.g. propeller cap and hull leading edge. Full-scale ice load measurement proved this idea not to be correct. Longitudinal maximum loads measured have proven to be higher and more frequent compared to transversal loads. This is mainly due propulsion unit steering angle and ship speed. At higher ship speeds also ice impacts are high, and usually propulsion unit is parallel to ship's moving direction. Transversal loads appear usually in maneuvering situation, where ship's speed and propulsion power are lower. Main loading cases applied to design are presented in Figure 1. These loads are applied for equipment design together with blade loading. Azimuthing propulsion unit design ice loads have mainly been defined according to DNV Class Guideline DNVGL-CG-0041. Results from full-scale measurements have been well below design loads in all cases. /1/, /2/, /3/

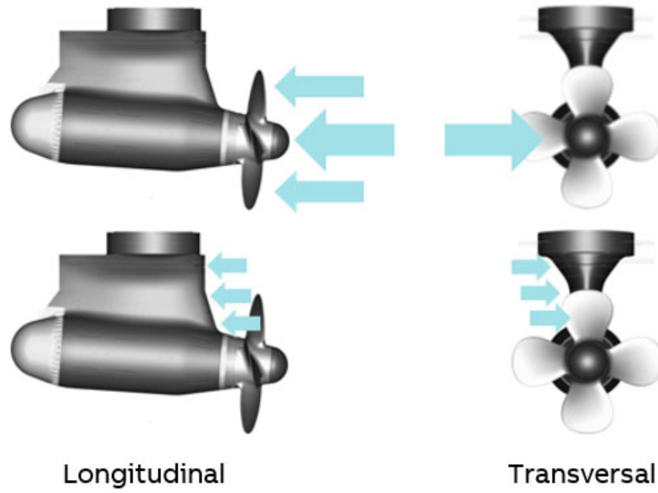

Figure 1. Main loading cases for propulsion unit hull

Ship Le Commandant Charcot

Latest full scale ice load measurements are ongoing in one of the azimuthing propulsion unit of Le Commandant Charcot. Le Commandant Charcot can be described as a high class luxury cruise ship with powerful ice operation capability or powerful icebreaker with inbuilt high end hotel facilities and service, including unique excursions and live lectures given by scientists.

The ship is 150 meters long with 28 m beam. She is designed for Polar Class 2 and capable of breaking 2.5 m multi-year ice. Main engines can operate on both oil fuel and LNG, in addition there is 5 MWh battery pack installed for zero emission and silent operation. Ship's 6-meter propellers are power by two 17 MW Azipod units.

Le Commandant Charcot is following the ice, not avoiding it. Due her excellent icebreaking capability, she can enter the harsh ice areas when other exploration cruise ships need to wait for easier conditions. Operation areas together with voyage seasons and observed ice conditions from the ship crew are described in Table 2. One calendar year position map is presented in Figure 1. Ship operates in ice probably more than any other ship, about 200 days per year.

Table 2. Ice conditions and sailing season in different sea areas

Area	Season	Ice conditions – Ship crew observations
North-East Greenland	Spring and summer	Heavy sea ice, hummocks, big floes, glacial ice
North Pole / Svalbard	Summer	Very variable sea ice, glacial ice
North-West Passage	Early autumn	Multi-year ice, glacial ice
Trans Arctic	Early autumn	Very variable sea ice, old heavy ice on coasts of Canada and Greenland (avoided)
Antarctica	Autumn, winter , spring	Sea ice including multi-year ice, glacial ice

Figure 2. Le Commandant Charcot partial position map Oct 2022 – Jan 2024 (positions from public AIS).

Instrumentation

The ice load measurements on board Le Commandant Charcot have been active since June 2021. Main data processing for this paper is from 2021 to late 2024.

Load measurement is usually realized by using strain gauges and utilizing the structure as load sensor. For dynamic loads, like ice impacts, it is also feasible to use vibration acceleration as load indicator. Given that the structure dynamics and mass are known, dynamic load components are available from acceleration. The only limitation being quasi-static and static loads are not detected, e.g. propeller thrust and slower ice loads, like ramming through ice ridges for example. The vibration sensor-based load signal has been very well in line with the strain gauge-based load signal.

Strain gauges, accelerometers and data collection devices were installed inside the propulsion unit, the instrumentation setup is presented in Figure 3. The data is continuously recorded to local data storage onboard, data is transferred from propulsion unit via WLAN connection. To understand relations between loading and ship operation, the operational parameters are collected from the propulsion control system. Parameters include ships speed and heading, propulsion power, shaft speed, motor torque and steering angle from both propulsion units.

The measurement system was improved by adding more strain gauges early 2024. The early instrumentation gave only partial results, and conclusive analysis with reliable results was not possible. Additional strain gauges were installed near thrust bearing to get more accurate understanding of loading via propeller. Other strain gauges were installed on the propulsion unit neck to record overall loading of propulsion unit hull, both longitudinal and transversal directions.

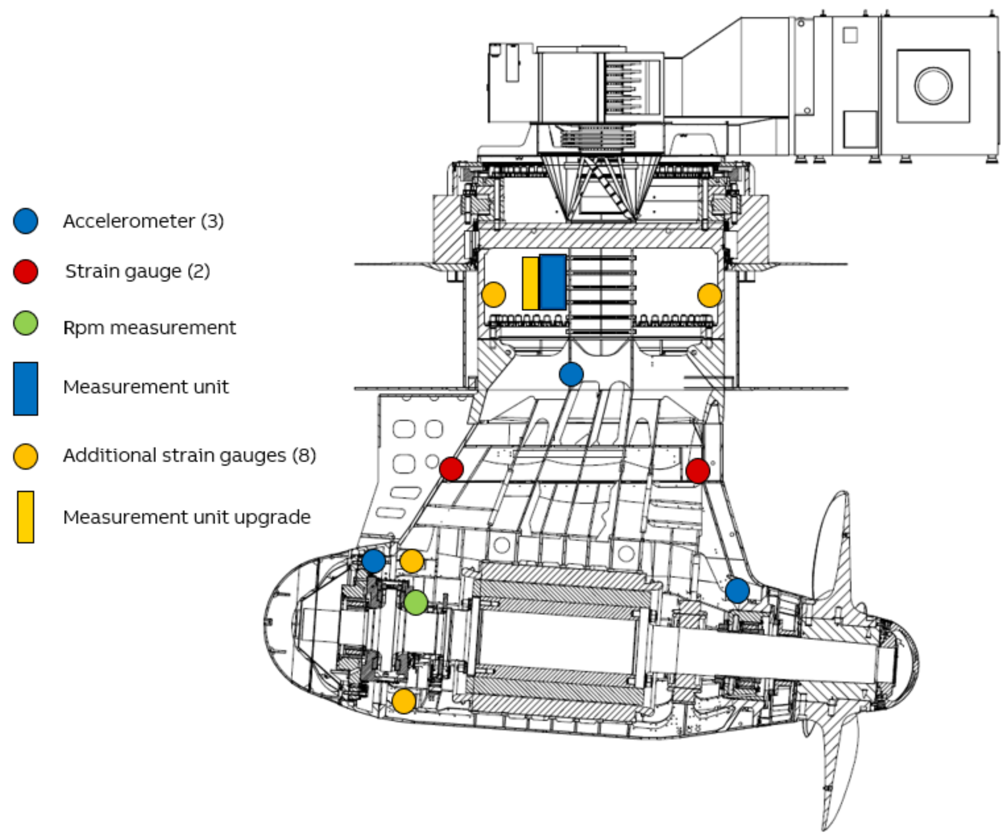

Figure 3. Overview of sensor installation.

Results

In Figure 4, the ship speed, propulsion power per propulsion unit, propulsor longitudinal and transversal load are presented on the period of 4/2024 to 9/2024. The period contains operations in Greenland area in spring and early summer and North Pole in July. The load levels and power levels are marked with helper lines on the graph, as well as the graph is marked with the operational areas where the data is from.

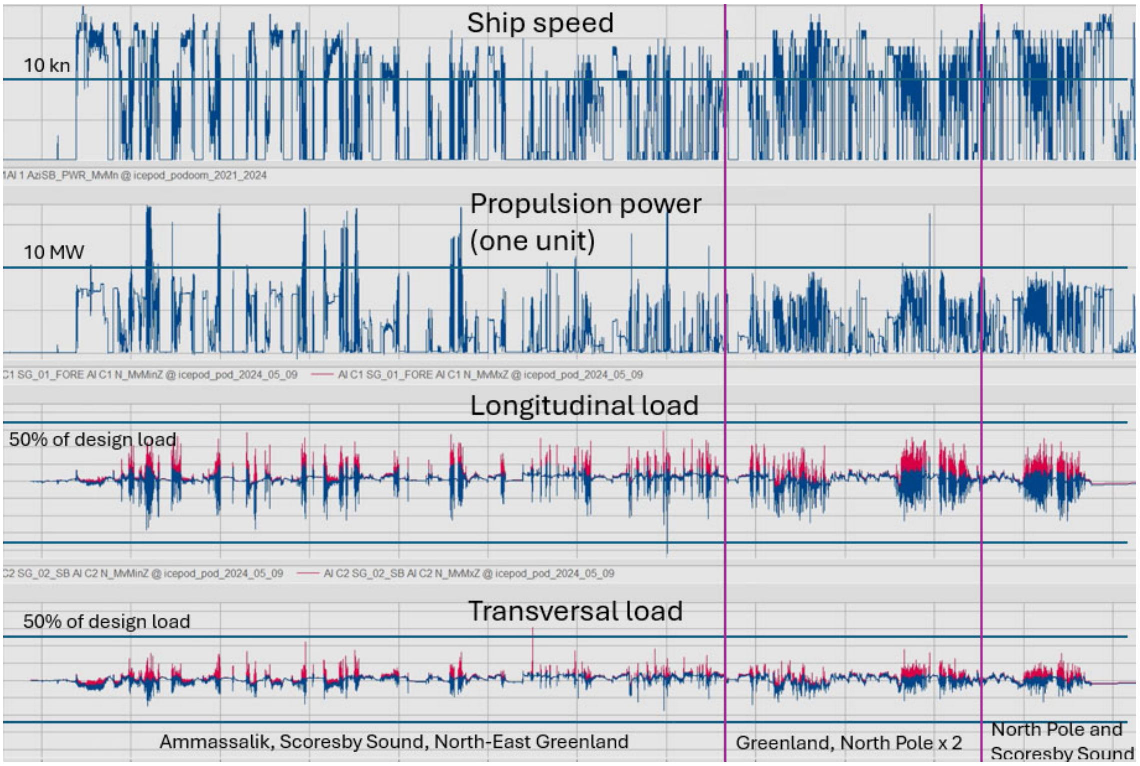

Figure 4. Ship speed, propulsion power per propulsor, longitudinal load and transversal load April 2024 - September 2024.

The ice conditions in different areas have their distinctive features, and operating the vessel brings varying patterns in the ice loading according to the area and operation. Evaluation of data only from April 2024 onwards is discussed next, due more accurate data available after system upgrade.

For the Greenland coast operations, the typical is highest propulsion power usage, up to 100 % of available power. This is accompanied by intense loading on propulsor. Ice milling with the propeller is common. The ice milling events are generally indicated in the data as simultaneous occurrence of propeller rpm drop, torque increase, and clear dynamic loading occurring at blade passing frequency. When looking at the time signals, the milling events make the signal look like 'spiky' when observing longer time periods. Upon zooming in on the data, the true nature of the event is revealed. Even though the classification of loading events is not complete, the observation is that majority of the loading is through this type of propeller-ice interaction, and minority of loading through other ice contacts e.g. pushing into ice feature.

Voyages during April and May are the most intense with high power utilization and load levels. In June, loads appear to be less intensive, both in magnitude and in frequency of occurrence. The ship operation, as cruise vessel, is to transit between locations, and this brings like ‘daily’ cycle to power and loading. In this area, longitudinal propulsor loads have been higher than transversal.

Following Greenland are North Pole cruises starting in mid-July. There are clearly different propulsion power and load intensity patterns compared to Greenland. The power level is mainly below 60% of available power, with only a few instants close to 100%. Ship speed appears to be reasonably good for ice operation with this power level. The ice load levels are lower than in the Greenland area. Main difference is that during North Pole cruise, the active loading period is longer, lasting several days continuously. There are less ports to call at, resulting in longer transit time in ice. Also in this operation, longitudinal load component for propulsor is higher than transversal.

The Transarctic cruise for magnetic north pole and geographic north pole in September 2024 indicates lower propulsor load levels than the Greenland and North Pole operations earlier in the summer. The longitudinal load is clearly higher during this period than the transversal load. In the beginning, the load levels are lower, intensifying in magnitude to mid-voyage, and decaying towards the end.

The Antarctica was visited during 2021 December to 2022 February. At the time, the load measurement instrumentation was the original, less informative variant, and unfortunately the load sensor channels appeared non-functional during 12/2021 to 2/2022. The load intensity levels can be concluded by comparison to other areas through propulsion power: the power usage pattern in Antarctica is like the North Pole area, i.e. mostly max 60% propulsion power with few peaks to full power. Clearly, the Greenland region is most intense power-wise and where the data is available, for loads as well.

The general load levels are presented on Table 3.

Table 3. Sailing areas, seasons and propulsor maximum load levels compared to design loads in longitudinal and transversal directions

Area	Season	Propulsor longitudinal load	Propulsor transversal load
East Greenland	Spring and summer April-May 2024	65 %	60 %
North Pole / Svalbard	Summer July 2024	40 %	30 %
North-West Passage	Early autumn August 2024	N/A	N/A
Trans Arctic	Early autumn September 2024	50 %	30 %
Antarctica	Winter	Load data missing Propulsion power usage similar to North Pole	Load data missing Propulsion power usage similar to North Pole

CONCLUSION

Azimuthing propulsion units ice loading and design knowledge is in good level due decades of full-scale measurements and design load validation. Also zero ice induced damages indicates, that design in propulsion units are in safe level. Nature of loading, magnitude and load distribution are well known to design equipment strong and durable according to ship and ice class requirements.

Le Commandant Charcot propulsion unit ice load measurements give very important information about the differences in world's icy sea areas. Even though there is some data not yet analyzed, it is clear that North-East Greenland conditions in spring and early summer are most demanding, comparing to e.g. North Pole area. This is good example, that together with ice class requirements, it is essential to consider also ship type, operation and operation areas when designing ship and equipment.

REFERENCES

/1/ DNV Class Guideline DNVGL-CG-0041 *Ice strengthening of propulsion machinery, Edition March 2016*

/2/ Hänninen S., Kujala P., Määttänen P., Korsström A., Heideman T., Koponen J.: Azimuthing Propulsion in Ice Management, *Proceedings of the ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering OMAE2024*

/3/ Määttänen P., Hänninen S., Heideman T.: OTC-29119-MS Propulsion System Ice Load Measurements Onboard IB Polaris, *Arctic Technology Conference 2018*