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INFLUENCE OF CLOGGING TO THE FUNCTIONALITY OF PRE-PROPELLER ENERGY SAVING DEVICES

Finnish Transport and Communications Agency

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FOREWORD

In this report no 129, the Winter Navigation Research Board presents the results of a research project on influence of clogging to the functionality of pre-propeller energy saving devices. The project investigate how clogging of different types of energy saving devices influences the vessel and propeller performance. Performance is measured with model testing.

The Winter Navigation Research Board warmly thanks Teemu Heinonen for this report.

Helsinki

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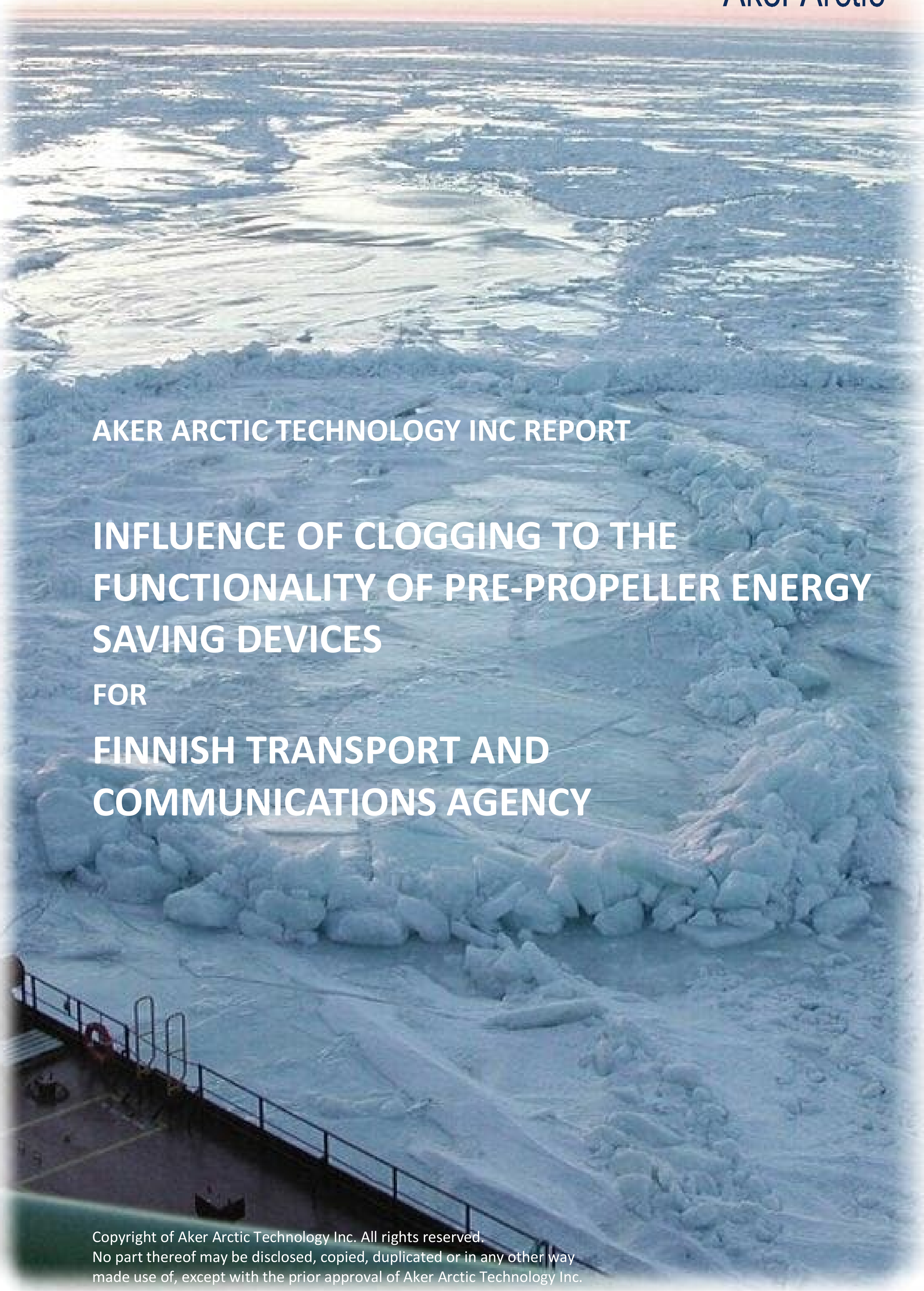

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INFLUENCE OF CLOGGING TO THE FUNCTIONALITY OF PRE-PROPELLER ENERGY SAVING DEVICES

FOR

FINNISH TRANSPORT AND COMMUNICATIONS AGENCY

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Summary:

Different type of energy saving devices (ESD) can be used to improve the propulsive efficiency of a ship. ESDs are installed to ice-classed newbuildings and retrofitted to existing ice-classed vessels and the ESD installations can be expected to increase in the future. The objective of this research is to investigate how clogging of different type of ESDs influences the vessel and propeller performance. The influence of clogging to the propeller performance has been investigated with open-water model tests. Two different WED duct alternatives were chosen for testing: Schneekluth-type duct and Becker Mewis -type duct.

The measurements conducted within this research indicate that the performance of the vessel will drop if the ESD is being clogged. The effects are greater and clearly significant with an ESD solution which is located closer to the propeller and therefore such ESD solutions are considered as potentially more critical in respect of the effects of clogging to the performance. In addition, solutions which consist both of fins and duct are considered potentially to clog more easily as smaller ice pieces can get stuck into them.

Even though clogging of the ESD is considered somewhat rare event, a small vessel in ballast condition operating in difficult ice conditions could potentially have the ESD clogged by ice. Probably the most efficient method to avoid clogging is to have the stern loaded deep enough. Therefore, it is important that attention is paid to the minimum drafts in which the ice-classed vessel equipped with an ESD is allowed to operate in ice.

Keywords:
Winter navigation; Open water propulsion; Energy efficiency; Ducted propeller

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ABBREVIATIONS

A_0 .... Propeller Disc Area
$A_{blocked}$ .... Blocked area of the ESD
D .... Propeller diameter
J .... Advance number
K_Q .... Torque coefficient
K_T .... Thrust coefficient
K_{Tnet} .... Thrust coefficient based on net thrust
L_{DEX} .... Axial distance between propeller plane and trailing edge of duct
n .... Propeller revolutions
Q .... Torque
T .... Shaft thrust
T_{NET} .... Net Thrust
V .... Speed

η_0 .... Propeller efficiency in open water
ρ .... Water density

CII .... Carbon Intensity Indicator
CLT .... Contracted Loaded Tip
EEXI .... Energy Efficiency Existing Ship Index
ESD .... Energy saving device
FSICR .... Finnish-Swedish ice class rules
PSS .... Pre swirl stator
RPM .... Revolutions per minute
WED .... Wake equalizing duct

1 INTRODUCTION

Different type of energy saving devices (ESD) can be used to improve the propulsive efficiency of a ship. Installations of ESDs has increased in recent years as ships' energy efficiency has become more critical issue. ESDs are also installed to ice-classed newbuildings and retrofitted to existing ice-classed vessels. The ESD installations can be expected to increase in the future both due to economic factors and tightening environmental regulations (e.g. EEXI, CII). As the number of ESD installations grow in the ice-classed tonnage, it is important to understand the possible drawbacks of the ESDs to the merchant vessels' ice-going capability and therefore to the fluency of the winter navigation system.

ESDs can be divided into devices which are installed before the propeller (e.g. pre-swirl fins and wake equalizing ducts), at the propeller (e.g. hub cap fins) and after the propeller (e.g. rudder bulb, post-swirl fins). The ESDs are designed to improve the propulsive efficiency in open water. There is very little or no information of their functionality in ice even though the devices are installed to ice-classed vessels. This research focuses to investigate the influence of ice interaction to the functionality of pre-propeller energy saving devices.

Clogging of a propeller nozzle in ice is well-known phenomenon which can dramatically reduce the performance of an ice-going vessel. Also, a pre-propeller ESDs could be potentially clogged in ice which influences the performance of the propeller. However, the effects of clogging of an ESD most likely differs from the effects of clogging of a regular nozzle as the ESD is located in front of the propeller and the size of the ESD does not always correspond to full propeller diameter.

The objective of this research is to investigate how clogging of different type of ESDs influences the vessel and propeller performance.

2 LITERATURE REVIEW

ESDs can be divided into devices which are installed before the propeller (e.g. pre-swirl fins and wake equalizing ducts), at the propeller (e.g. hub cap fins) and after the propeller (e.g. rudder bulb, post-swirl fins). The pre-propeller energy saving devices could potentially be clogged due to ice and therefore this research focuses on these solutions. The basic principles of different ESD solutions are presented in following subchapter.

2.1 OVERVIEW OF ENERGY SAVING DEVICES

There are different categories of energy saving methods. The main energy saving principles are direct drag reduction, reducing propulsion losses, use of renewable energy and operational saving [1]. Here we concentrate the techniques to reduce propulsive losses, thus all underwater energy saving devices are targeting to reduce those.

Table 2-1: Methodologies to reduce propulsive losses. [1].

Methodology	Technique-1	Technique-2
Pre swirl stators	Bilge vortex recovery	Hull-propeller interaction
Vortex generators	Hull-propeller interaction	Bilge vortex recovery
Contra-rotating propellers	Reducing rotational energy in the propeller wake	
Reaction rudder	Reducing rotational energy in the propeller wake	Hub vortex recovering
Rudder fin	Reducing rotational energy in the propeller wake	Hub vortex recovering
Hub fin	Reducing rotational energy in the propeller wake	Hub vortex recovering
Overlapping propeller	Reducing rotational energy in the propeller wake	Inflow management
Rudder bulb	Hub vortex recovering	
Ducts	Inflow management	
Tip-fin propeller	Reduce tip vortex	
Tip-rake propeller	Reduce tip vortex	
CLT propeller	Reduce tip vortex	

Many of the devices presented in Table 2-1 are located behind the propeller and targeting for reducing rotational energy in the propeller wake or hub vortex recovering. Some techniques are propeller local design features for reducing propeller tip vortex and thus making it possible to increase propeller loading close to the tip. All these solutions are excluded in this study since they don't have risk for ice clogging.

The devices which are located before the propeller and thus effecting to the propeller inflow are pre-swirl ducts, fins and wake equalizing ducts and combinations of these. This study concentrates on these solutions since these devices have in principle the possibility for ice clogging and thus reduction in propeller thrust in ice operations.

A Pre swirl stator (PSS, Figure 2-1) consist of number of fins, usually 3 to 5, which are mounted directly in the front of the propeller (mainly on the portside in case of righthanded propeller). The PSS increases the total propulsion efficiency by decreasing the propeller slipstream's swirl energy via generating or improving the rotational flow in advance. [2].

Figure 2-1: An example of PSS design, Daewoo pre-swirl stator fins [3].

As a wake equalizing duct, the most known is Schneekluth Duct with over 3000 installations (Figure 2-2 and Figure 2-3). The purpose of the wake equalizing duct is to redirect flow to upper portion of the propeller plane, making the wake more homogenous. The duct also accelerates the flow, and the duct can have beneficial effects by reattaching possible separated flow to the hull close to the duct. Typically, these ESDs are used in slow cargo vessels with high block coefficient.

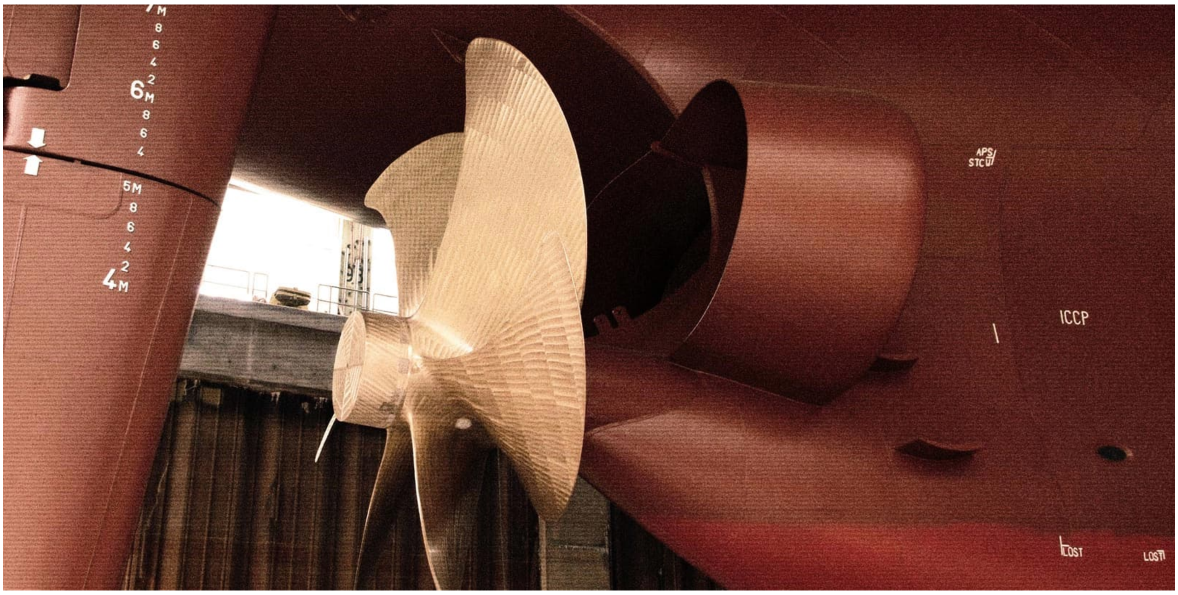

Figure 2-2: An example of installed Schneekluth Duct (source: www.schneekluth.com).

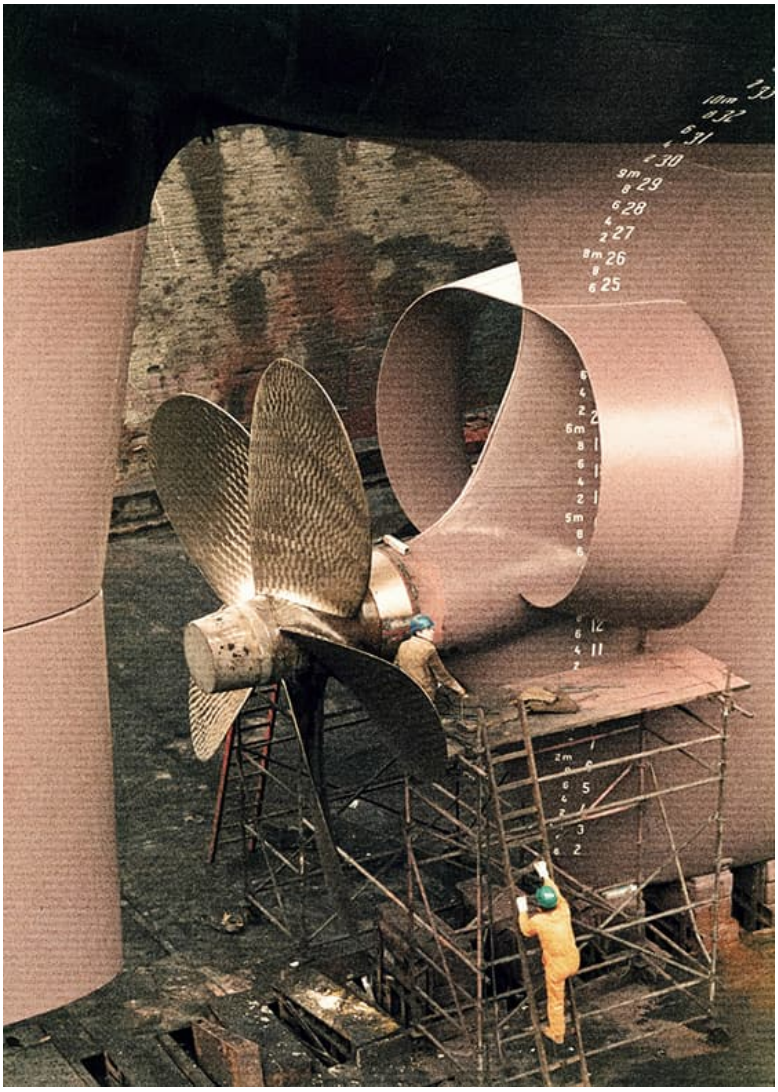

Figure 2-3: Schneekluth -type WED (source: www.schneekluth.com)

The combinations of pre-swirl stators with accelerating ducts have several manufacturers including Mitsui integrated ducted propeller, Hitachi's Zosen Nozzle, Sumitomo's Integrated Lammeren Duct and Becker's Mewis Duct. The duct can be non-axis-symmetric to equalize the axial wake component. However, the duct also increases the efficiency of the pre-swirl fins by providing a better water inflow to the stator. In addition, the duct contributes to the total thrust by virtue of the lift created by the accelerating flow over its walls. Integrated stator-duct devices are normally installed on full hullforms [4]. Two examples of Becker Mewis Ducts are presented in Figure 2-4and Figure 2-5.

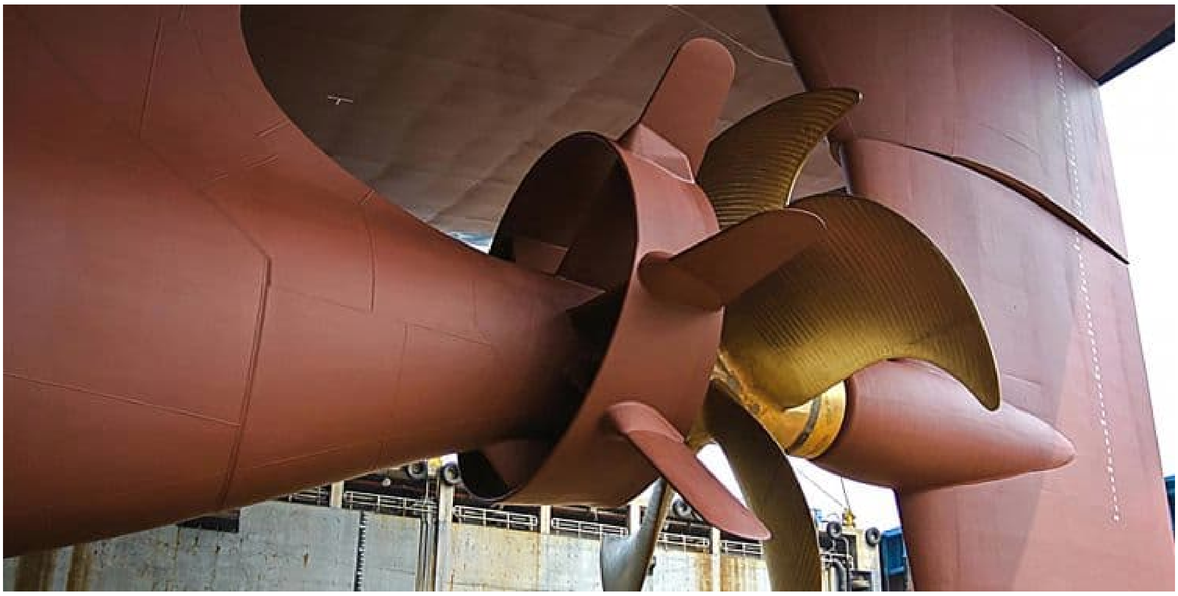

Figure 2-4: A Becker Mewis Duct with inner and outer fins. (source: https://www.becker-marine-systems.com/files/content/pdf/product_pdf/Becker_Energy-Saving_Devices.pdf)

Figure 2-5: Becker Mewis -type of duct (source: https://www.becker-marine-systems.com/products/product-detail/becker-mewis-duct.html).

2.2 CLOGGING OF DUCTED PROPELLER AND ESD

Clogging of a ducted propeller with ice is a well-known phenomenon which has been studied mainly for icebreakers. For ducted propellers, following preconditions shall be fulfilled for the clogging to occur:

- Ice is directed into the duct / propeller
- Ice pieces are so big that they do not fit to go through the duct without getting stuck against it
- Ice pieces are strong enough that they do not fail when hit against the duct or due to the suction of the propeller

In principle the same preconditions apply also for the ESDs. However, there are two fundamental differences when comparing probability of clogging a ducted icebreaker propeller and an ESD installed into ice-classed cargo ship:

- The probability for the ice to be in contact with the duct
- Size of the duct in relation to the size of ice pieces it encounters

The probability for the ice being in contact with the duct depends on the hullform (mainly draft for the cargo vessels) and on the ice conditions. Bigger cargo vessels operate at such deep drafts (clearly more than the icebreakers) that it is basically impossible for the ice to be in contact with the propeller / duct. In addition, with deep draft also the propeller is big meaning that the possible duct is so big that it is unlikely to meet big enough ice pieces to cause clogging. However, most of the cargo vessels operating at Bay of Bothnia are small, around 5000 DWT, which typically have loaded draft of ~6 meters. By assuming that the propeller diameter is approximately 60% of the loaded draft and the stern draft in ballast condition is approximately 70% of the loaded draft, the clearance between the propeller and surface can be around 0.5 meters, in some loading conditions even less. In these conditions it is in principle possible that the ice is in contact with the ESD.

The ice-classed merchant vessels operate mainly in channels under icebreaker escort. In old channels the ice pieces are mainly small and rounded. In addition, the thickness of the channel mass (at the center of the channel where the operation mainly happens) is somewhat small, typically less than 1 meter. Therefore, in normal channel conditions it is highly unlikely or impossible that the ESD would be clogged as the ice pieces are too small for being stuck against it. However, in case of difficult ice conditions (especially in ridges) the ice mass extends very deep and consist of clearly larger pieces (especially in case of consolidated pieces) than in channels. Despite the icebreaker operating in front of the cargo vessel, in these conditions (especially at ballast condition) it is possible that ice is in contact with the ESD and also it is possible to encounter big enough pieces being stuck against the ESD.

For the ice to be stuck against the duct (or ESD), the ice piece shall be big enough to be stuck against it. As the ESDs are smaller than the propeller, it is possible to have large enough pieces to get stuck against the device. In addition, if the ESD contains combination of fins and duct, the necessary size of the ice piece being stuck is further reduced. However, in case the ESD consists only of fins, the likelihood of ice piece being stuck is considered smaller as the ice piece can move more easily (when compared to fin and duct combination) in the radial direction and free itself.

3 TEST SETUP

The influence of clogging to the propeller performance has been investigated with open-water model tests. Two different WED duct alternatives were chosen for testing:

- Schneekluth-type duct which is installed clearly in front of the propeller into the stern frame above the propeller shaft and without any fins (Figure 2-3).
- Becker Mewis -type duct which is installed directly in front of the propeller around the stern tube/propeller shaft (Figure 2-5). Fins are installed inside into the duct.

Both alternatives are such solutions which could be installed into a slow-steaming ice-classed cargo vessel which needs icebreaker assistance (e.g. general cargo ship, tanker, bulk carrier). In addition, both alternatives are considered to be devices which could potentially be clogged. For the Becker Mewis -duct the potential for clogging is higher as it is a combination of fins and duct meaning that a smaller ice piece can be stuck against the unit. For the Schneekluth -type duct the ice piece needed for clogging shall be larger. On the other hand, the Schneekluth -type duct is located closer to the surface where ice is located and therefore could potentially get more ice-interaction.

These two alternatives are considered to give following information about the influence of clogging to the propeller performance (summary of the relative positions of the tested ESDs is presented in Table 3-1):

- Distance of the clogged duct to the propeller. The Becker Mewis duct is closer to the propeller than the Schneekluth duct.
- Size of the duct in relation to the propeller. The Schneekluth duct is positioned above the propeller shaft while the Becker Mewis duct is positioned around the propeller shaft and is larger in size. In addition, the amount of clogging has been varied in the tests.

The influence of clogging is investigated by conducting open-water model tests with a model of a slow-steaming cargo vessel. Conditions relevant for ice-operation were investigated by conducting overload tests at 5 knots speed (the design requirement speed for different ice classes according to the FSICR) and at bollard pull condition (zero knots speed, demonstrating a situation in which the vessel is stuck and should get moving). Both the Schneekluth and Becker Mewis types of ducts were installed into the model and gradually clogged. Following situation were tested (Figure 3-4 to Figure 3-12):

- Open duct, no clogging
- Upper half of the duct’s port side clogged: 25% of the unit’s total projected area
- Portside of the duct completely clogged: 50% of the unit’s total projected area
- The duct completely 100% clogged

Following quantities were measured from the model:

- Model speed
- Propeller shaft RPM
- Propeller shaft torque
- Propeller shaft thrust
- Towing force / Net thrust

Table 3-1: Summary of the relative position and size of the blocked area of the tested ESDs in relation to the propeller size.

		25% blockage	50% blockage	100% blockage
ESD type	L_{DEX}	$A_{blocked}$	$A_{blocked}$	$A_{blocked}$
Schneekluth	~0.26*D	~0.08*A_0	~0.18*A_0	~0.36*A_0
Becker Mewis	~0.08*D	~0.10*A_0	~0.20*A_0	~0.40*A_0

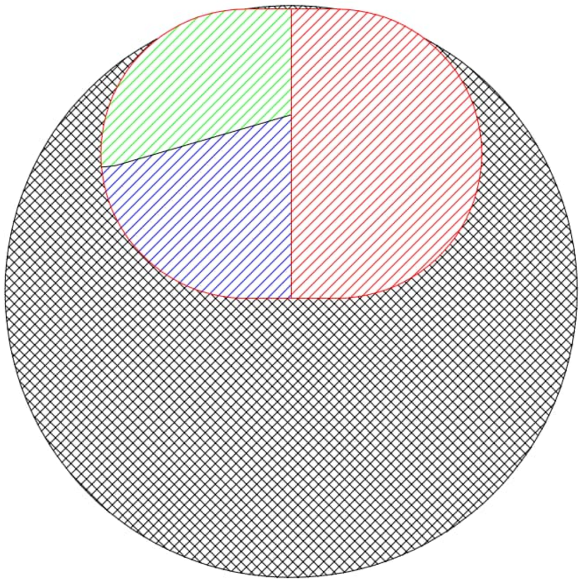

Figure 3-1: Schematic presentation of the size and position of the Schneekluth-type ESD in relation to the propeller disk. The black area refers to the propeller disk; green area to 25% blockage, green + blue = 50% blockage; green + blue + red areas = 100% blockage.

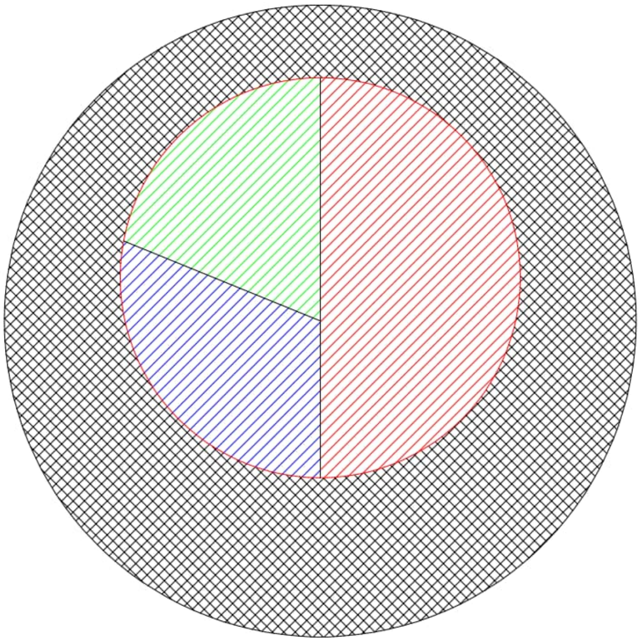

Figure 3-2: Schematic presentation of the size and position of the Becker Mewis -type ESD in relation to the propeller disk. The black area refers to the propeller disk; green area to 25% blockage, green + blue = 50% blockage; green + blue + red areas = 100% blockage.

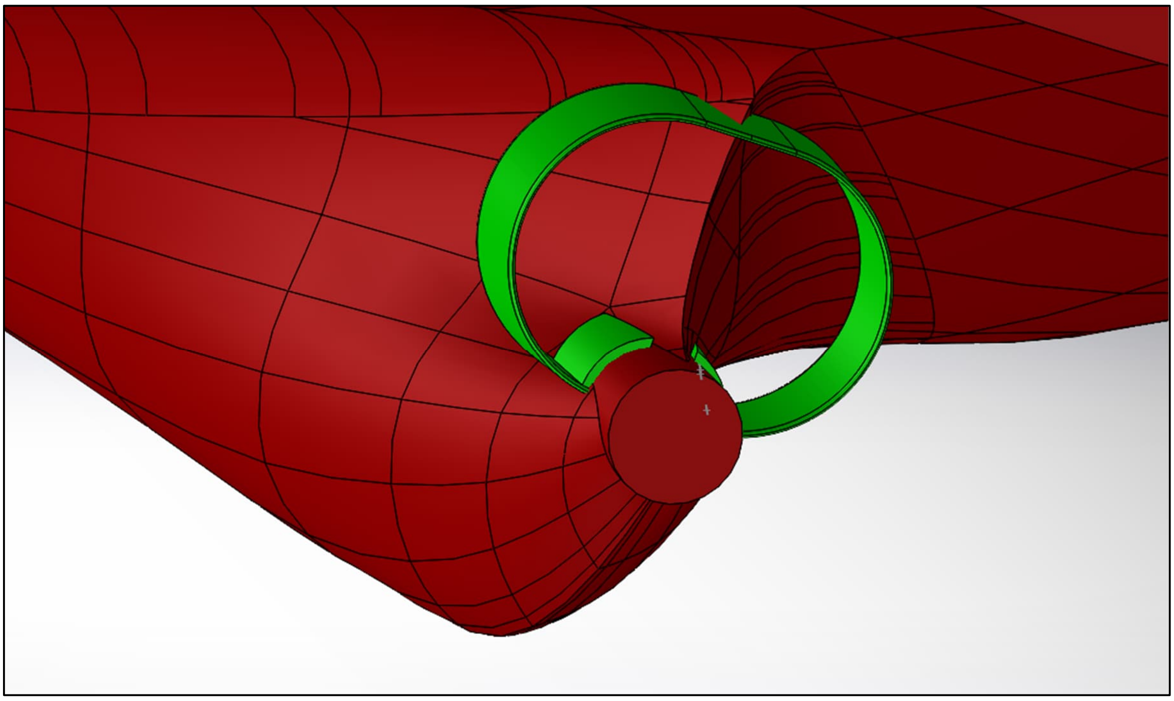

Figure 3-3: The Schneekluth -type duct does not contain any fins and is located above the propeller shaft.

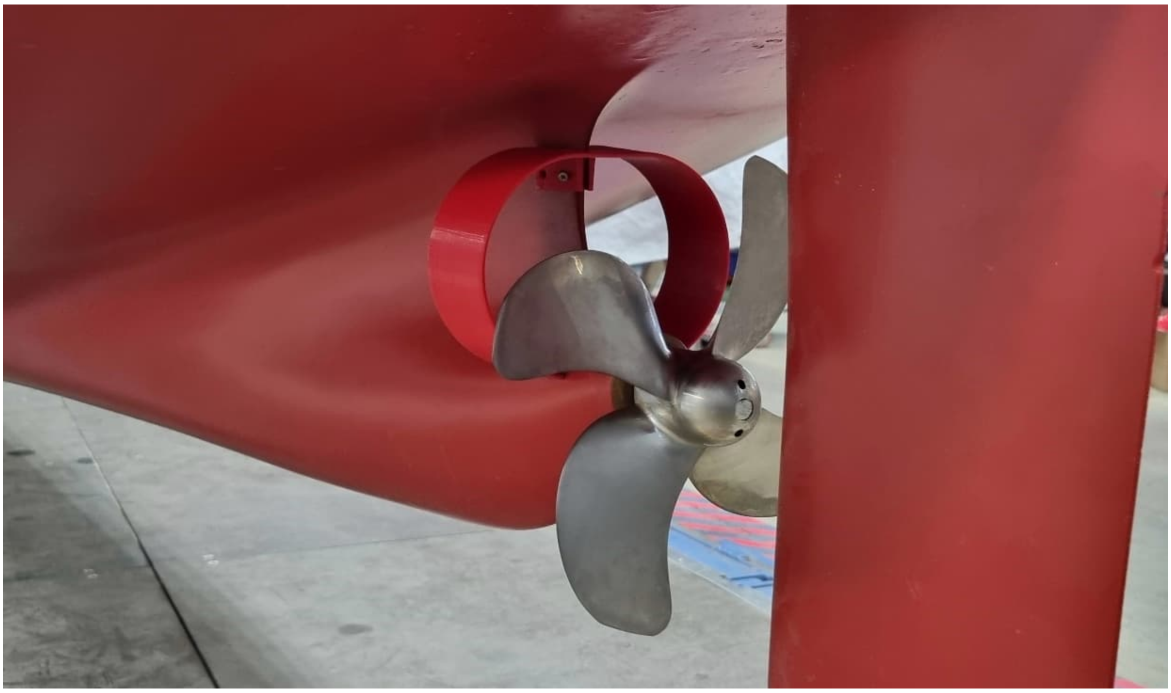

Figure 3-4: The Schneekluth -type duct completely open without any clogging.

Figure 3-5: The Schneekluth -type duct 25% clogged.

Figure 3-6: The Schneekluth -type duct 50% clogged. In 100% clogged situation the starboard side is also clogged.

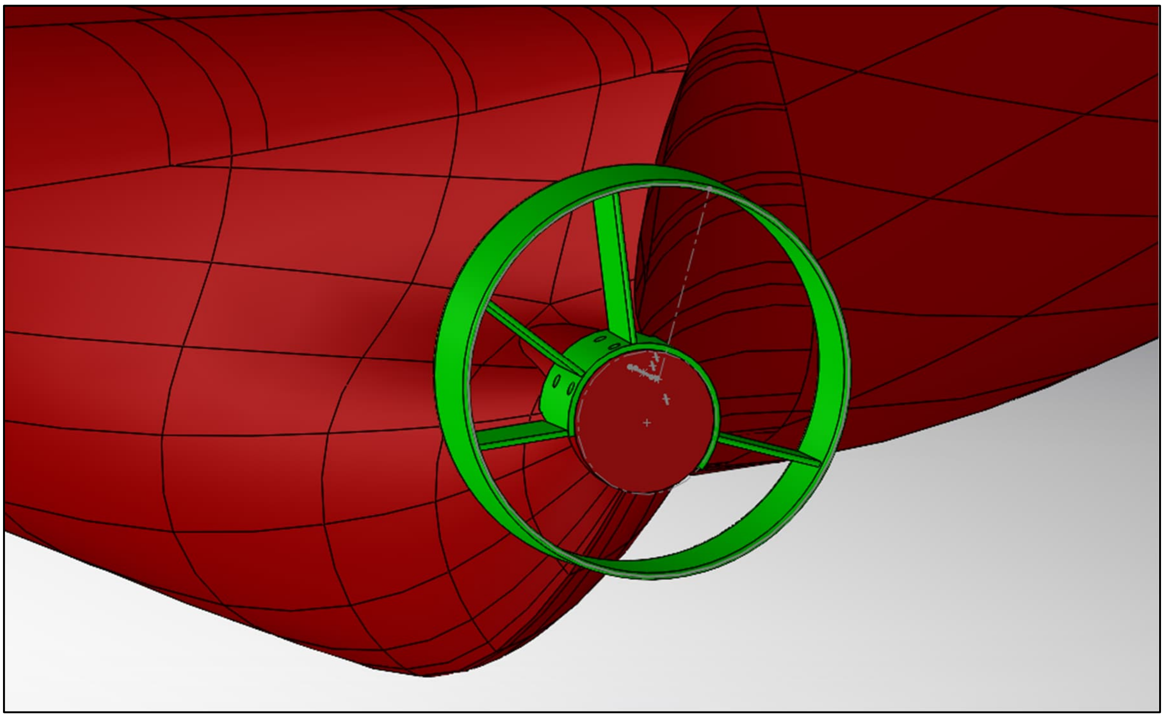

Figure 3-7: The Becker Mewis -type duct had in fins inside the duct (3 fins on the portside, 1 fin on the starboard).

Figure 3-8: The Becker Mewis -type duct was positioned directly in front of the propeller.

Figure 3-9: The Becker Mewis -type duct completely open without clogging.

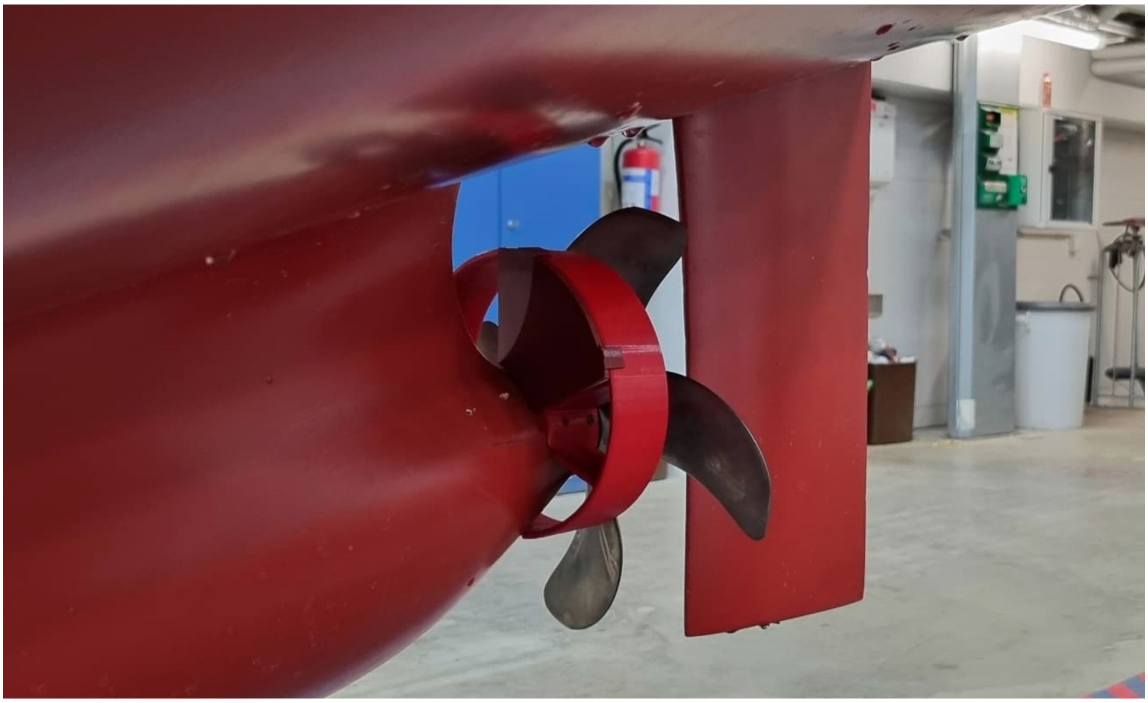

Figure 3-10: The Becker Mewis -type duct 25% clogged.

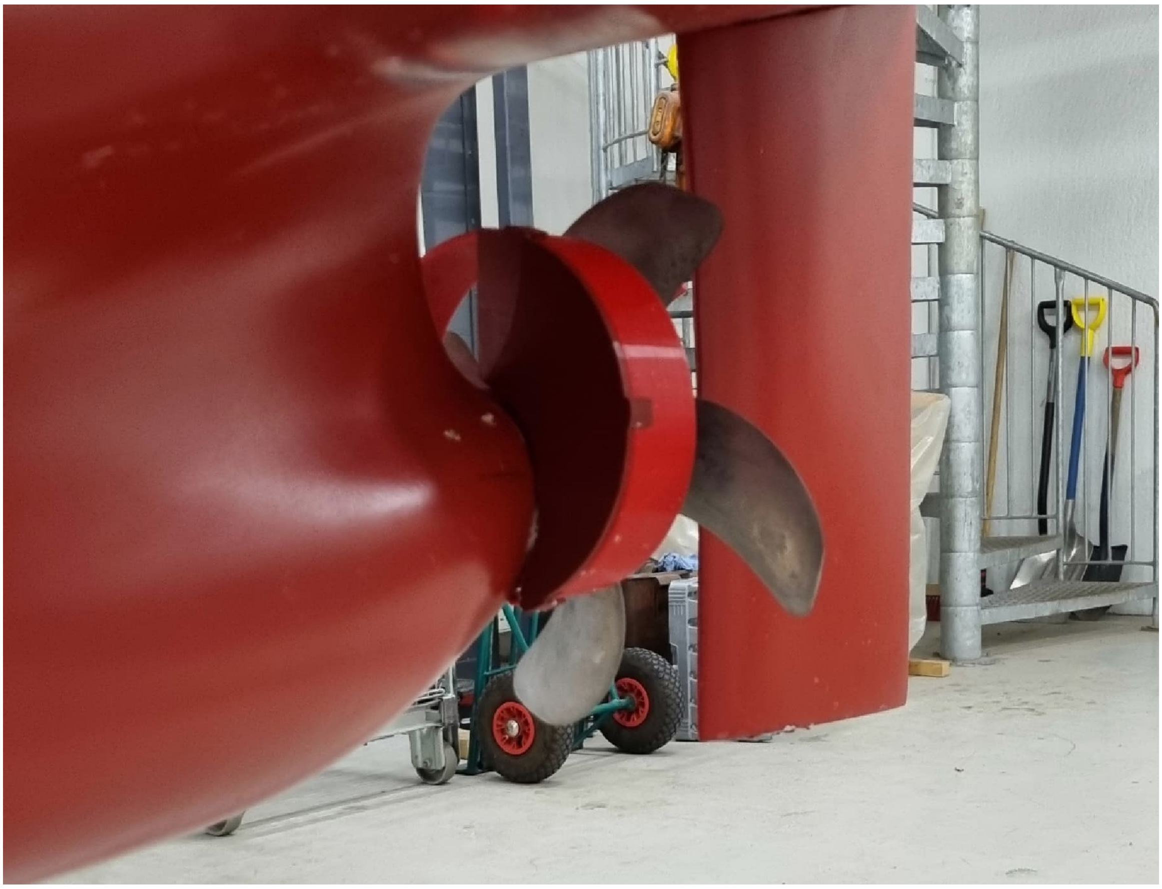

Figure 3-11: The Becker Mewis -type duct 50% clogged.

Figure 3-12: The Becker Mewis -type duct 100% clogged.

4 TEST RESULTS

The influence of clogging is investigated by comparing different measured quantities of the clogged ESDs to the same ESD without any blockage and presenting the results as relative values. The results are presented for the tested levels of blockage in relation to the ESD's projected area. The tested ESDs are referred as Becker Mewis -type and Schneekluth -type ESDs in the results chapter. However, it should be noted that the tested ESDs are more or less general examples of ESDs and the main objective is to demonstrate the influence of ESD distance and area to the propeller. The Becker Mewis -type ESD is larger in size and closer to the propeller than the Schneekluth -type ESD.

The clogging influences on the propeller's thrust and torque properties by changing the wake as well as to the thrust deduction of the vessel. The influence of clogging to the net thrust of the vessel is demonstrated in Figure 4-1. The net thrust is the total propeller thrust (including the thrust deduction) minus the open-water resistance, representing the excess thrust the vessel has to overcome the ice resistance. At zero speed the net thrust corresponds to the bollard pull capability of the vessel. From Figure 4-1 it can be seen that the performance reduction is larger with Becker Mewis -type ESD which is located closer to the propeller and is larger in size. With Schneekluth -type ESD, which is located further away from the propeller, the inflow to the propeller is not as obstructed and most likely the propeller is able to get water past the clogged ESD. In addition, the Figure 4-1 demonstrates that the performance reduction is larger when the vessel is moving for both tested ESDs when compared to bollard pull situation.

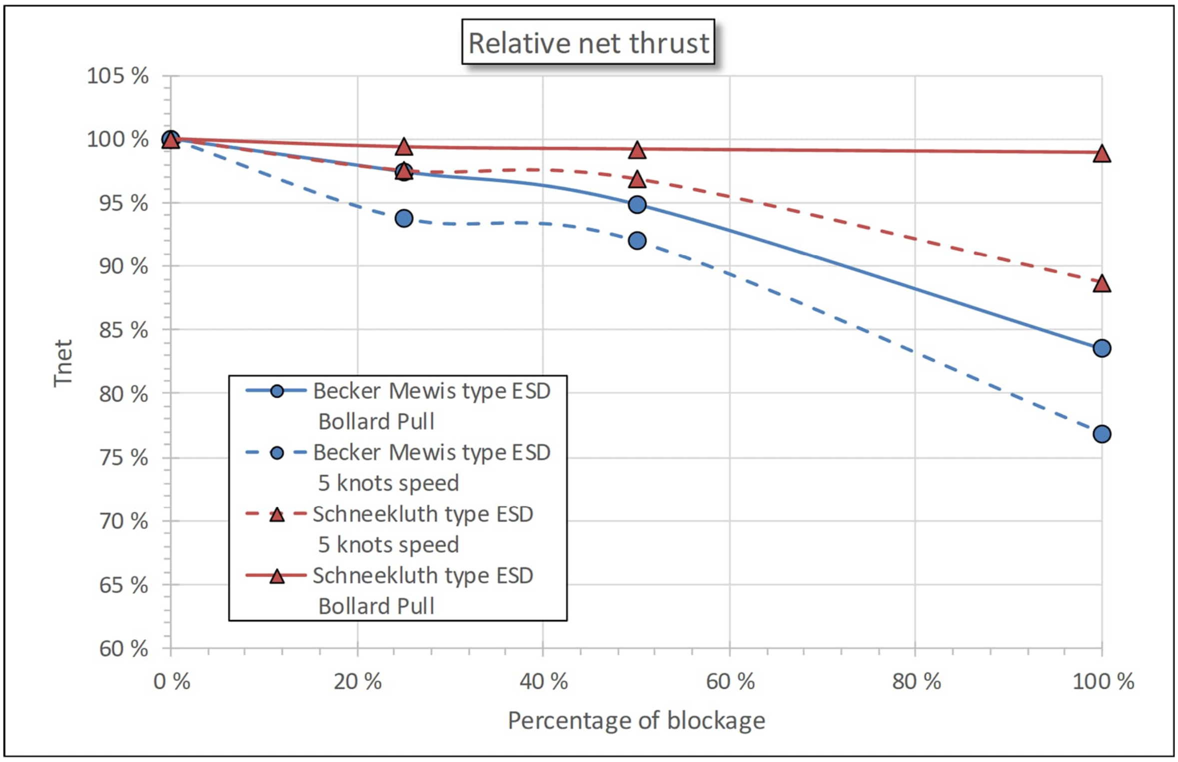

Figure 4-1: Influence of the clogging to the net thrust of the vessel. The net thrust values of the clogged ESDs are compared to the open ESDs at constant power level and at same speed. The percentage of blockage refers how much the ESD unit's area is being blocked.

The Figure 4-1 demonstrates the influence of clogging the net thrust of the vessel by taking the possible influences on the propulsion power into account by comparing the net thrust values at constant power level. Figure 4-2 and Figure 4-3 demonstrates the influence of clogging purely to the net thrust by calculating the thrust coefficient for the vessel based on the net thrust:

$$K_{T_{NET}} = \frac{T_{NET}}{\rho n^2 D^4} \quad (1.)$$

The thrust coefficient is presented as function of advance number:

$$J = \frac{V}{nD} \quad (2.)$$

It can be seen that the effects are more dramatic for the Becker Mewis type ESD which is located closer to the propeller and is also larger in size.

Figure 4-4 to Figure 4-7 presents the thrust and torque coefficients of the vessel based on values measured from the propeller shaft:

$$K_T = \frac{T}{\rho n^2 D^4} \quad (3.)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (4.)$$

It can be seen that both the propeller thrust and torque increase for both ESD solutions as the ESDs are being clogged. As the torque demand is increased, the performance of the vessel is eventually decreased as demonstrated in Figure 4-1. In real-life installation the performance drop could be even larger in case the torque demand of the propeller exceeds the torque limits of the main engine. Similar behavior of decreased performance is demonstrated in Figure 4-8 and Figure 4-9 which present the propeller efficiency calculated based on the net thrust:

$$\eta_0 = \frac{J}{2\pi}\frac{K_{T_{NET}}}{K_Q} \quad (5.)$$

It can be seen that efficiency drops as the ESDs are being clogged. The efficiency is somewhat the same for 25% and 50% clogged cases and dropping further when the ESDs are being fully clogged. Similar behavior is seen with both ESDs, however, the reductions in efficiency are greater with the Becker Mewis -type ESD.

The thrust and torque increase related to the clogging of the ESDs indicates that the clogging creates vibrations to the propeller and propeller shaft. Figure 4-10 to Figure 4-13 demonstrate how the clogging influences on the standard deviation of the measured shaft thrust. For the Schneekluth -type ESD there are no major effects except when the unit is fully clogged at 5 knots speed. However, for the Becker Mewis -type ESD there is significant increase in the thrust deviations especially when the ESD is unevenly clogged (25% and 50% blockage). This indicates that the uneven inflow to the propeller will create significant vibrations meaning that in case of partial clogging the vessel most likely has to stop even though it would be able to proceed in respect of performance itself.

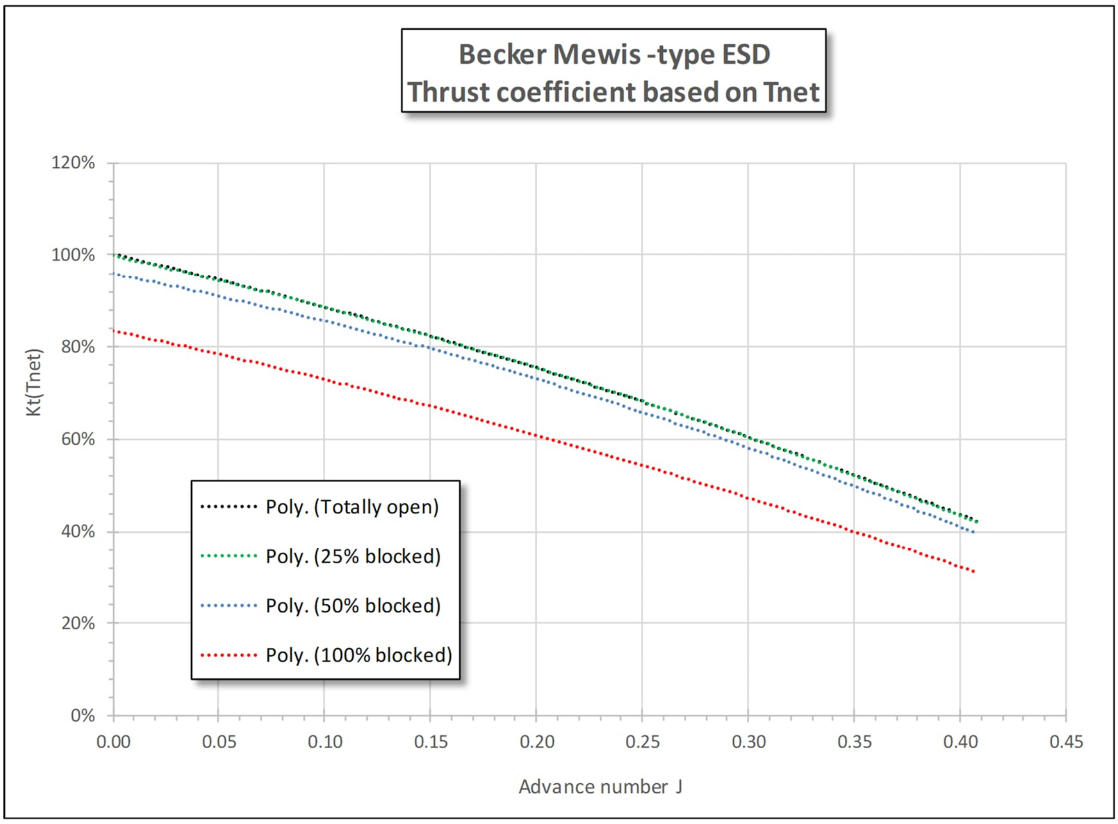

Figure 4-2: Influence of clogging to the thrust coefficient calculated based on the net thrust for the model equipped with Becker Mewis -type ESD.

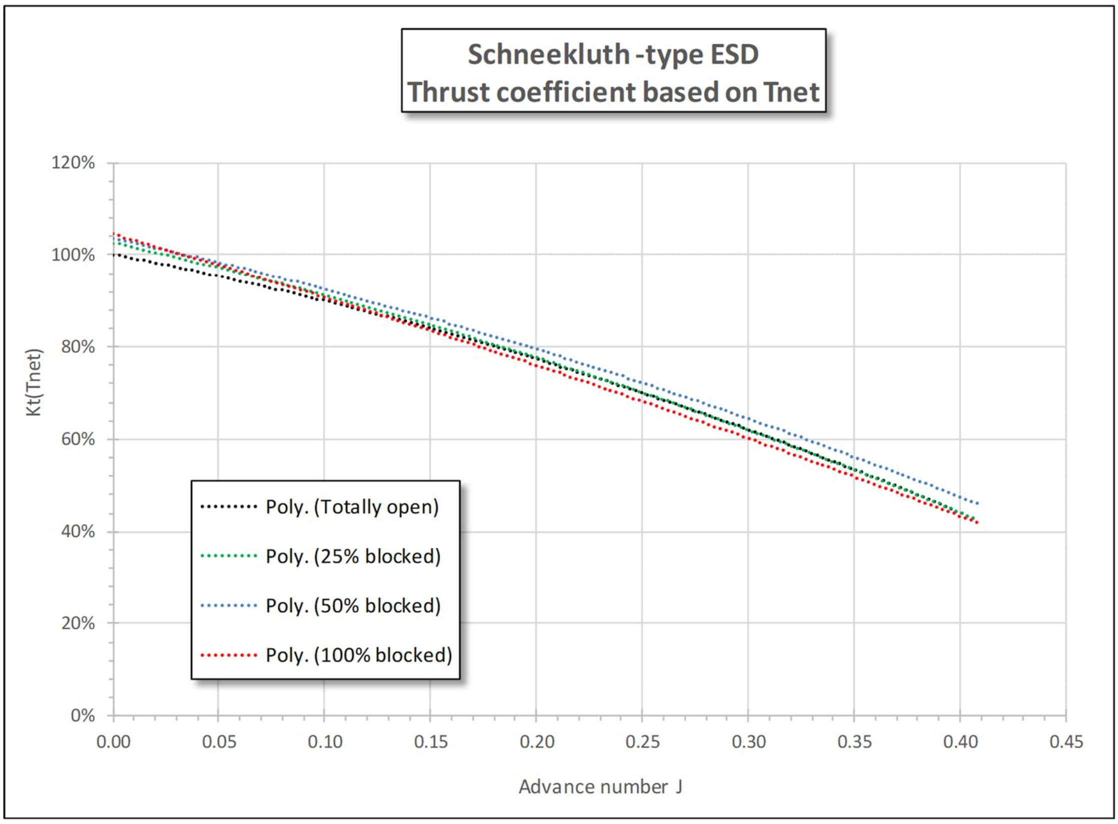

Figure 4-3: Influence of clogging to the thrust coefficient calculated based on the net thrust for the model equipped with Schneekluth -type ESD.

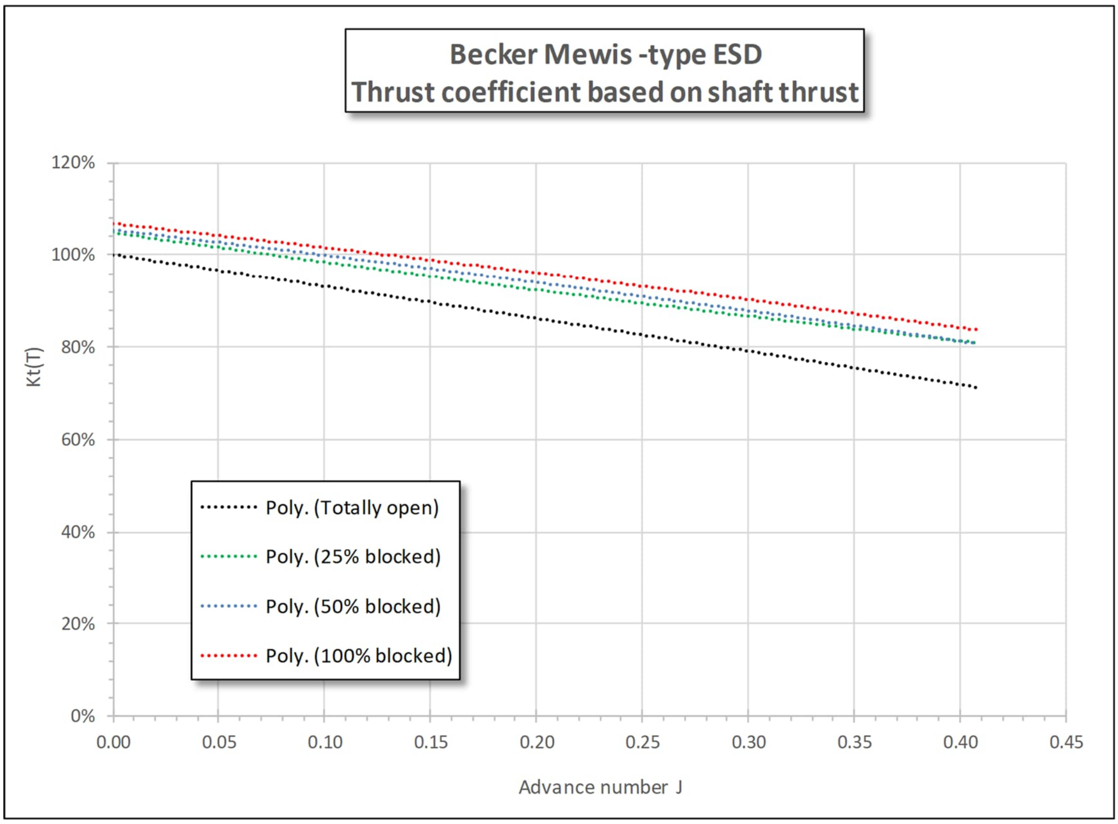

Figure 4-4: Influence of clogging to the thrust coefficient calculated based on the shaft thrust for the model equipped with Becker Mewis -type ESD.

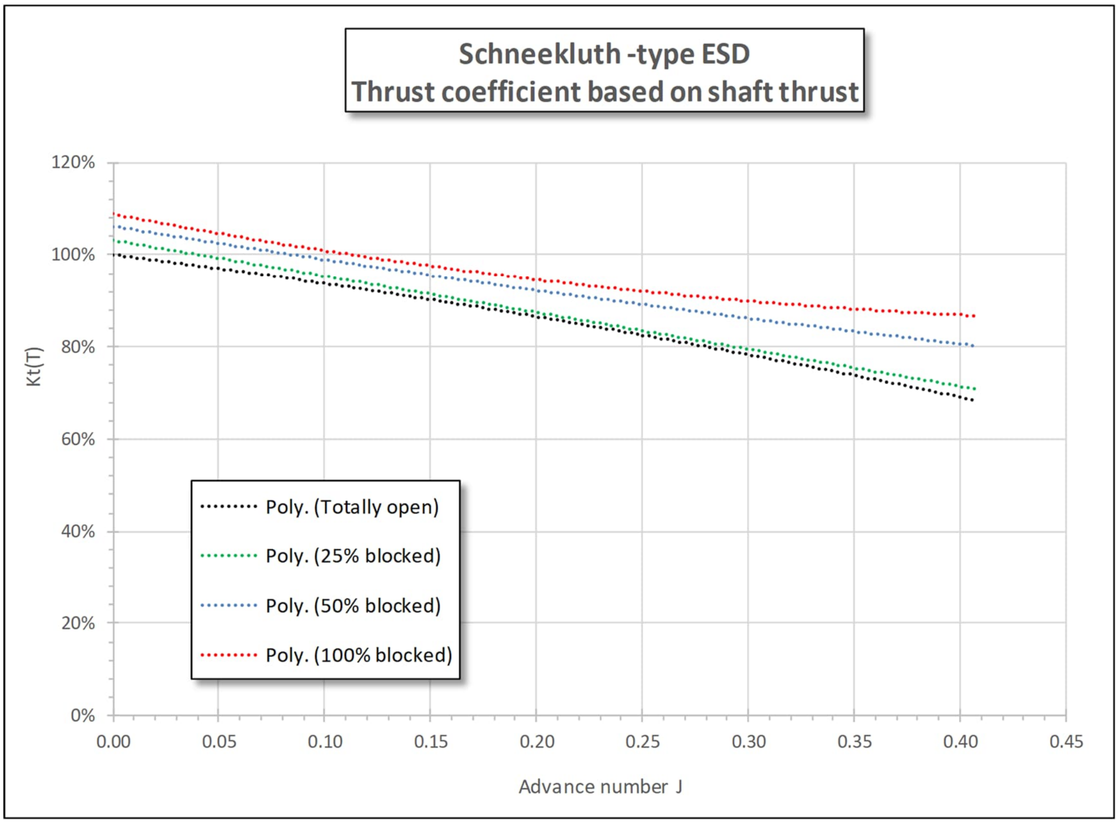

Figure 4-5: Influence of clogging to the thrust coefficient calculated based on the shaft thrust for the model equipped with Schneekluth -type ESD.

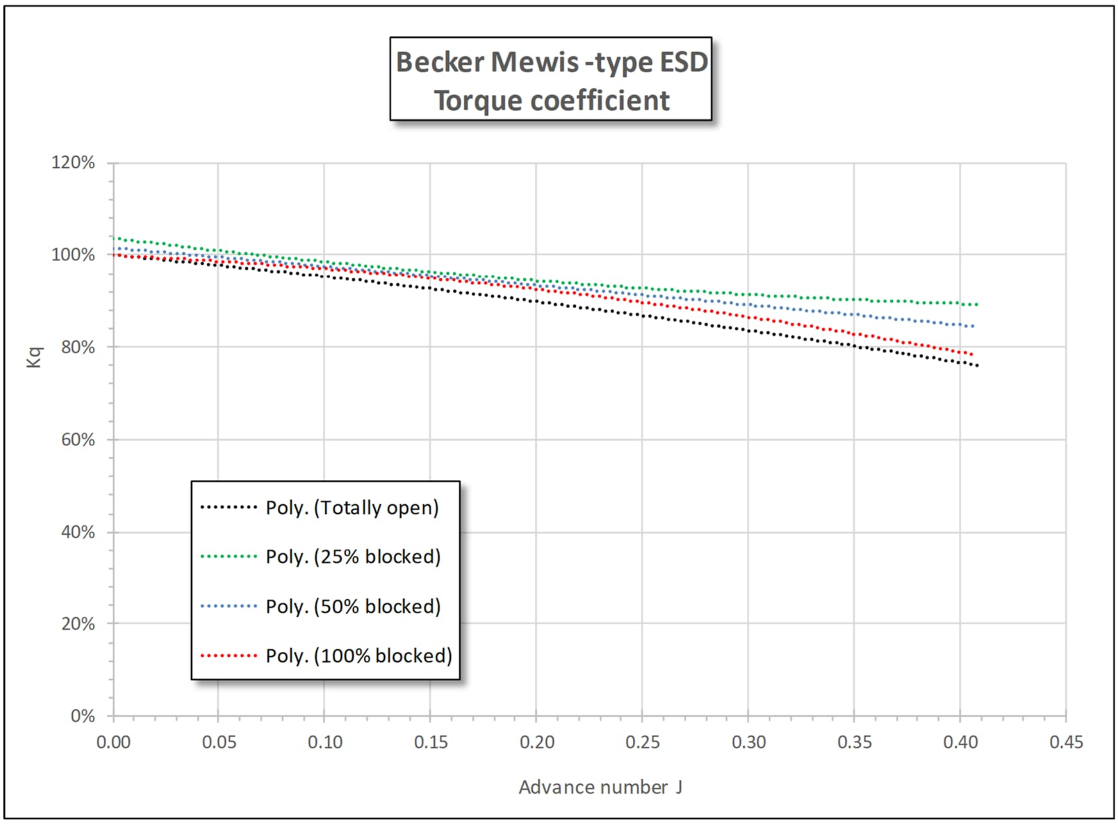

Figure 4-6: Influence of clogging to the torque coefficient for the model equipped with Becker Mewis -type ESD.

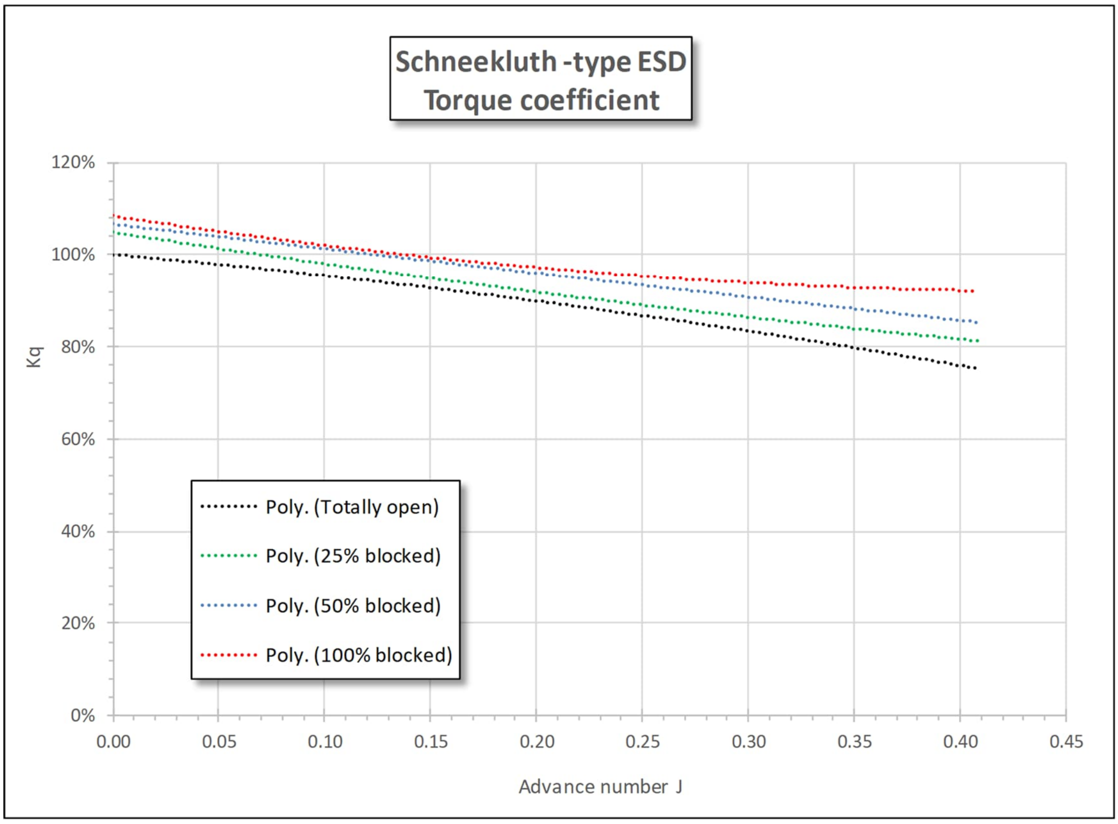

Figure 4-7: Influence of clogging to the torque coefficient for the model equipped with Schneekluth -type ESD.

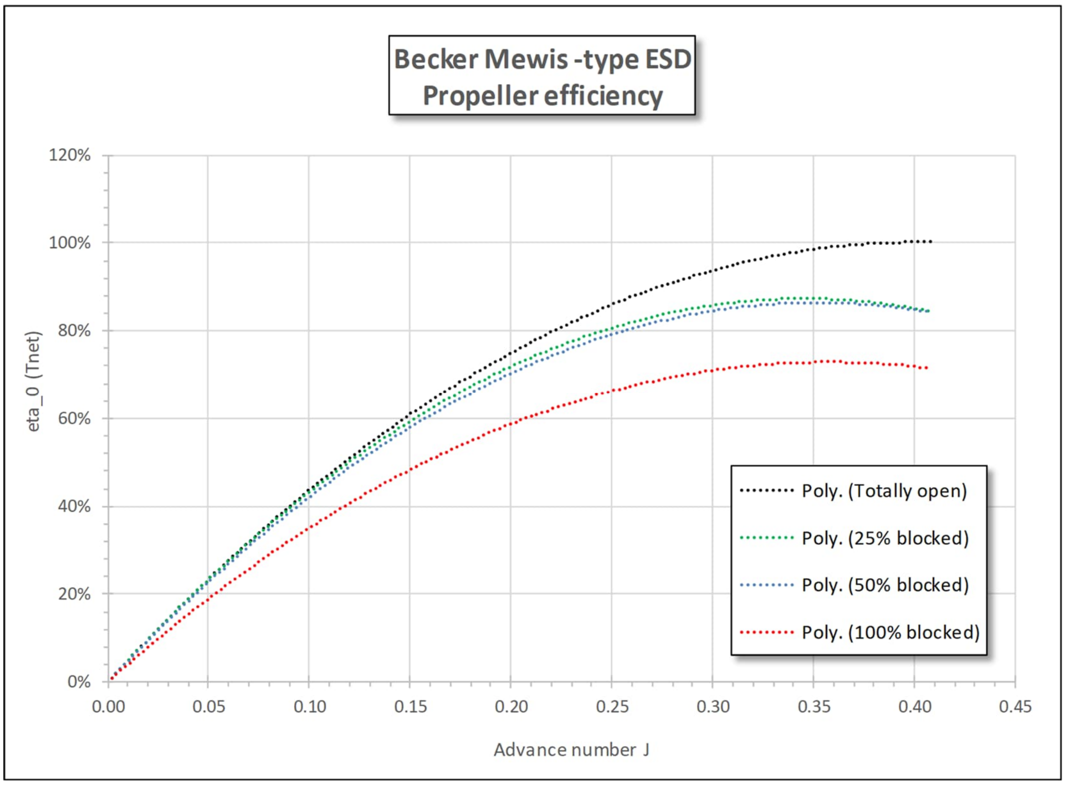

Figure 4-8: Influence of clogging to the propeller efficiency calculated based on the net thrust for the model equipped with Becker Mewis -type ESD. The efficiency represents relative efficiency when compared to the ESD without clogging.

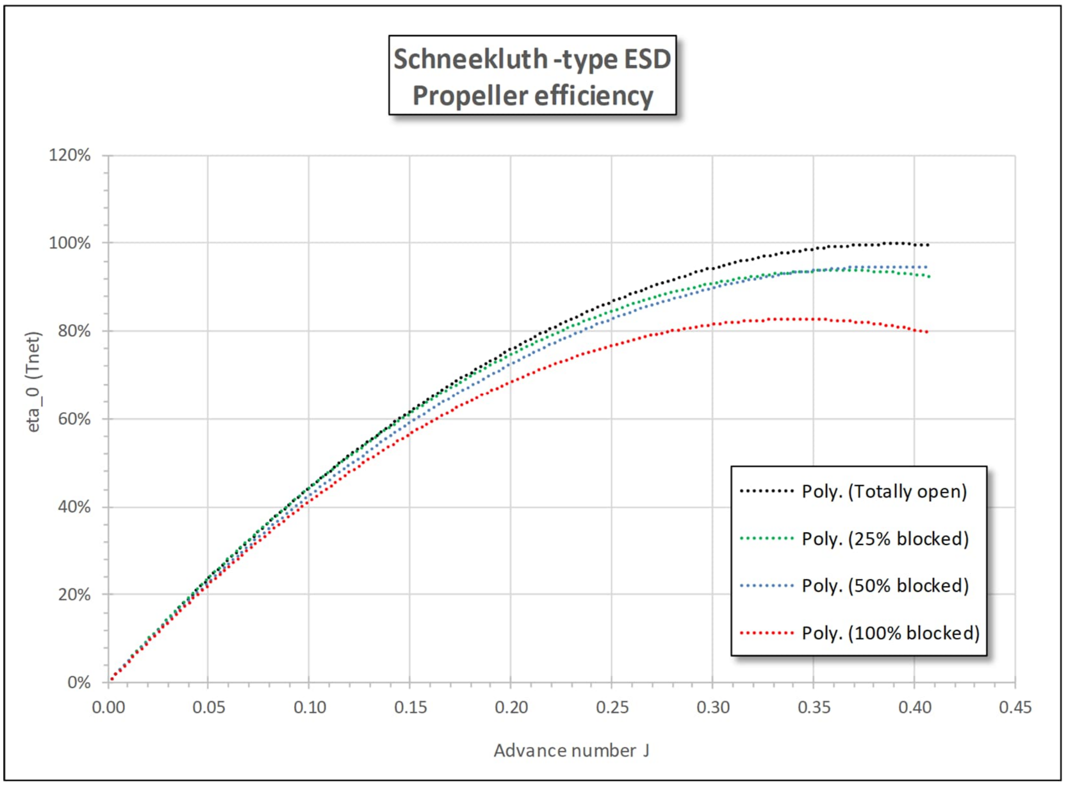

Figure 4-9: Influence of clogging to the propeller efficiency calculated based on the net thrust for the model equipped with Schneekluth -type ESD. The efficiency represents relative efficiency when compared to the ESD without clogging.

In Figure 4-10 to Figure 4-13 the relative thrust deviation is compared against relative power consumption. The 100% power refers to arbitrary power level which is used to define the maximum thrust used to obtain the relative standard deviation. The thrust values are presented with smooth spline fit across all measurement points as mathematical curve fitting is difficult due to some scatter in the measured values. The purpose of the figures is to compare relative differences between different levels of blockage in which the smooth spline fit works well.

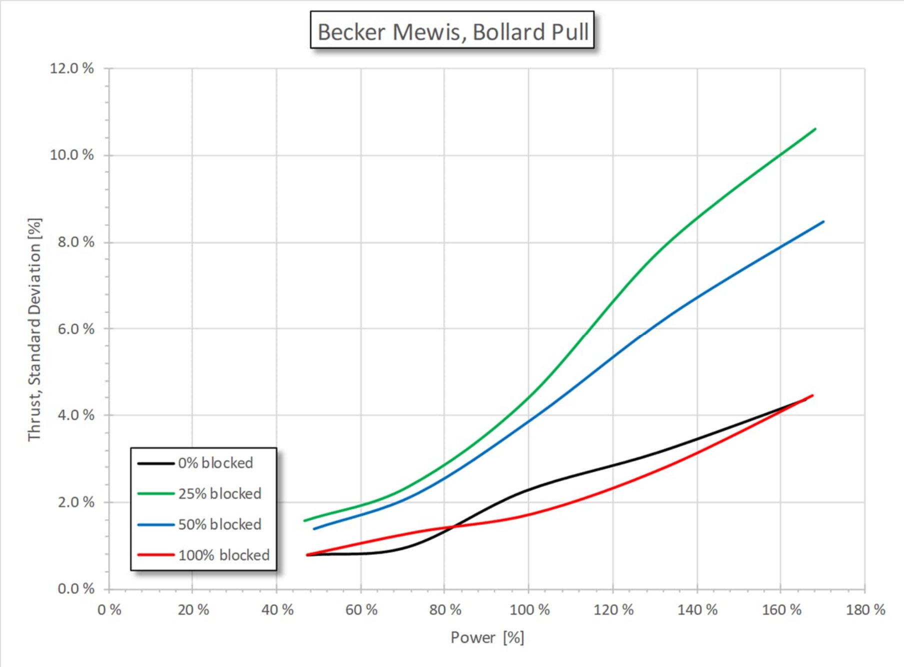

Figure 4-10: The impact of clogging to the relative standard deviation of the thrust for the Becker Mewis -type ESD at bollard pull condition.

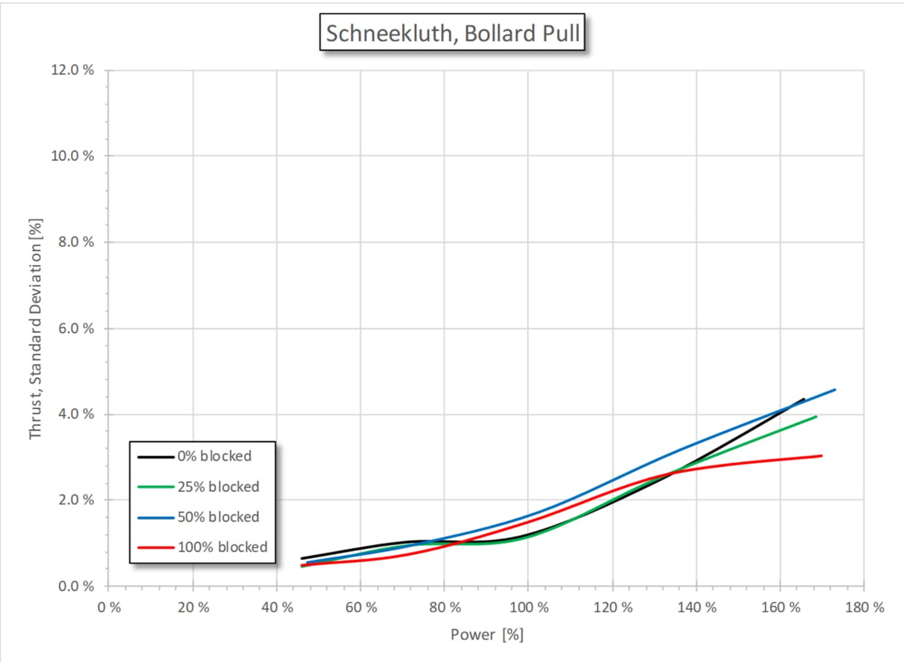

Figure 4-11: The impact of clogging to the relative standard deviation of the thrust for the Schneekluth -type ESD at bollard pull condition.

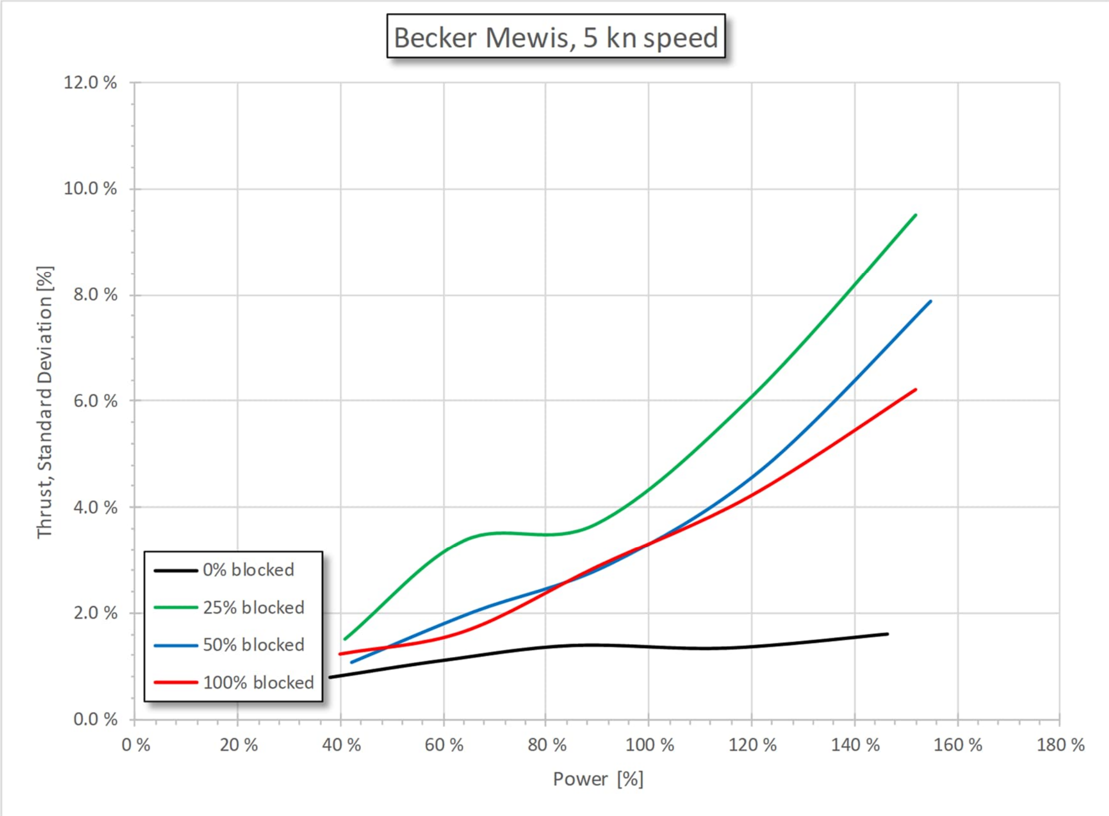

Figure 4-12: The impact of clogging to the relative standard deviation of the thrust for the Becker Mewis -type ESD at 5 knots speed.

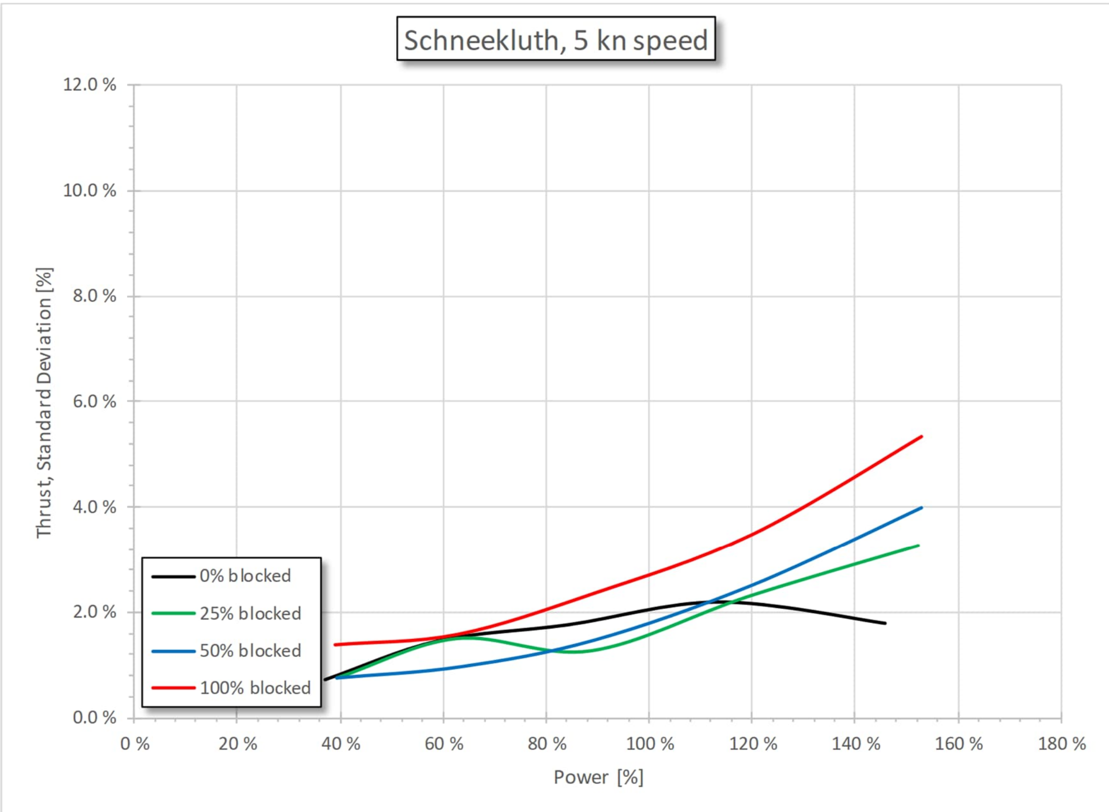

Figure 4-13: The impact of clogging to the relative standard deviation of the thrust for the Schneekluth -type ESD at 5 knots speed.

5 CONCLUSIONS AND DISCUSSION

The measurements conducted within this research indicate that the performance of the vessel will drop if the ESD is being clogged. The effects are greater and clearly significant with an ESD solution which is located closer to the propeller. In addition, the performance reduction is greater when the vessel is moving when compared to the bollard pull situation. As the effects of clogging are increase with speed, it is likely that the cargo vessel will stop in case of clogging event as it is not able to maintain sufficient speed. In addition, the vibrations will most likely stop the vessel in case of clogging. The vibrations are expected to be larger with ESD solution which is located closer to the propeller.

Generally, it is considered that clogging of an ESD is somewhat a rare event. However, a small vessel in ballast condition operating in difficult ice conditions could potentially have the ESD clogged by ice. Probably the most efficient method to avoid clogging is to have the stern loaded deep enough. Therefore, it is important that attention is paid to the minimum drafts in which the ice-classed vessel equipped with an ESD is allowed to operate in ice. ESD solutions which are located closer to the propeller are considered as potentially more critical in respect of the effects of clogging to the performance. In addition, solutions which consist both of fins and duct are considered potentially to clog more easily as smaller ice pieces can get stuck into them.

6 REFERENCIES

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