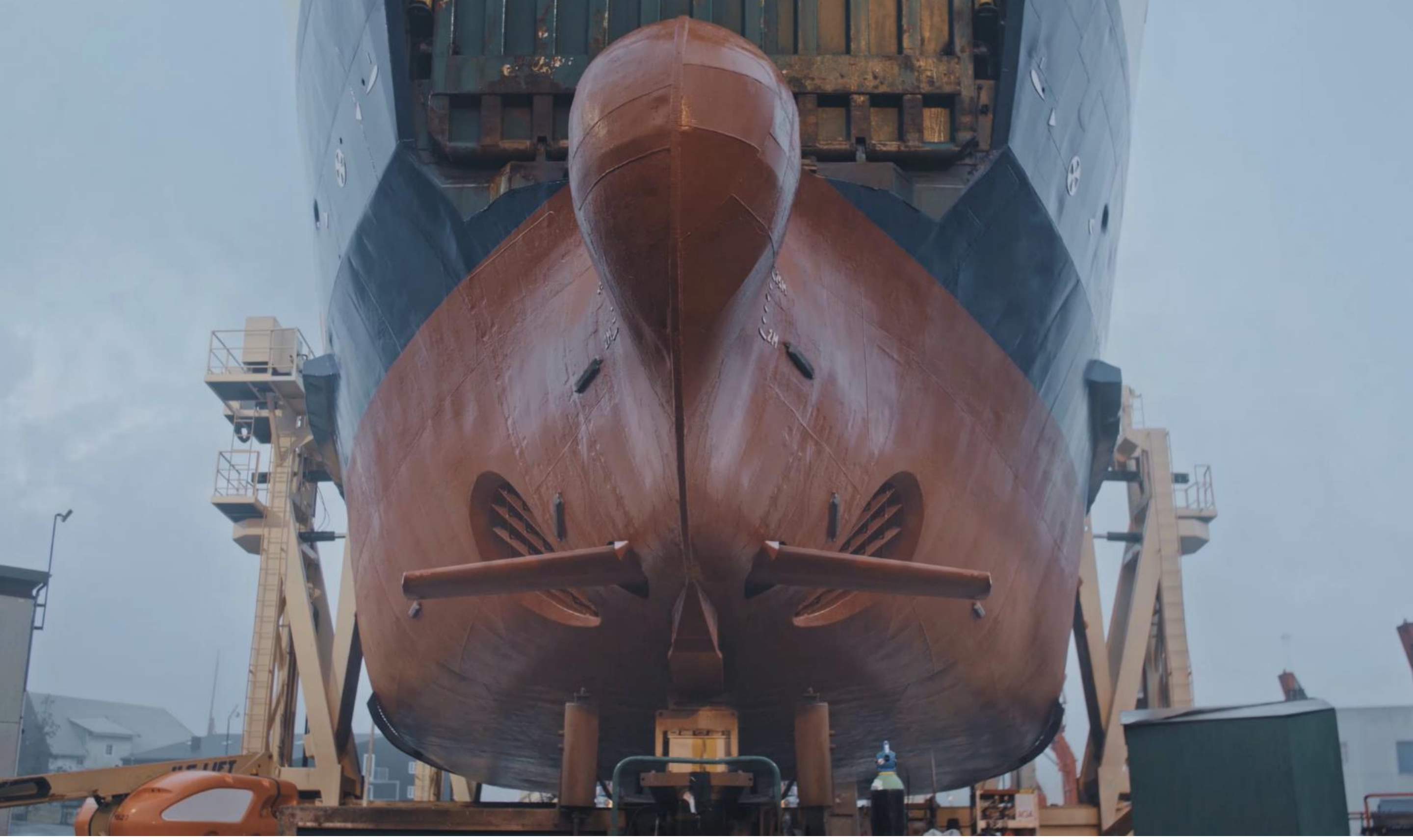

FULL-SCALE EXPERIENCE WITH RETRACTABLE BOW FOILS ON M/F TEISTIN

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ABSTRACT

This paper deals with design considerations, installation and experience with operating retractable bow foils on M/F Teistin. The comfort improvement was stated by the crew immediately after the installation. After nearly three months of operation, data for the fuel consumption indicates an average fuel saving in the order of 10%. In the coming months, DNV GL will give a third-party assessment of the fuel saving effect of the bow foils. The retraction mechanism has worked according to expectations, also with forward speed of the vessel and in waves.

INTRODUCTION

It is known that ships may benefit from significant motion damping and fuel saving by installing bow foils [1, 2, 3, 4, 5]. For smaller boats and ship models it has also been shown that bow- and stern-mounted foils with spring-loaded foil pitch may provide enough propulsive thrust in waves for the vessel to be completely wave-powered at low speeds. A review of previous work on this topic is given in [3].

There are many reasons for having retractable bow foils, even for foils not exceeding the width of the vessel. Increased wetted surface area gives increased friction drag in calm water. Extreme loads in extreme sea states can be avoided by retracting the foils. It is also desirable to retract the foils when docking the ship, during fishing gear handling, in ice conditions etc. There are, however, a few ships with non-retractable bow foils welded to the hull. These foils typically have low aspect ratio to compensate for the drawback of lacking a retraction mechanism. Low-aspect-ratio bow foils reduce pitch motions but suffer from higher drag and lower lift than high-aspect-ratio foils and are therefore not suited for fuel saving.

Even though the benefits of bow foils have long been known, no practical retraction mechanism compatible with conventional ship design has been commercially available before now. Wavefoil's first full-scale retractable bow foils was installed in the 45 m long Faroese ferry M/F Teistin in September 2019. This paper gives more insight into the design considerations, testing of the retraction mechanism before installation, the installation itself and experiences from three months of operation.

RETRACTION MECHANISM

Retractable roll stabilizer foils are available on the market, but these foils are retracted horizontally and therefore require a lot of space in the longitudinal direction, which is not feasible in the bow region of a conventional ship. After studying several general arrangements of ships it was evident to the authors that retractable bow foils must be retracted vertically.

The foils are retracted into a steel module, hereby referred to as foil module, see Figure 1. The foil module consists of two foils connected to a common nut running along a threaded rod which is coupled to a motor, and rail plates. Wheels traveling inside the rails control the foil retraction/deployment when the threaded rod is rotating. The rails are shaped in a such a way that the foils penetrate the hull through an aperture slightly bigger than the foils' cross section. The motor and the sensors to measure the foil position, are mounted above water level and can easily be accessed for inspection. Further details about the retraction mechanism can be found in the patent application [6].

DESIGN CONSIDERATIONS

Bow foils will be exposed to extreme loads. Slamming must be expected for bow foils even in moderate sea states if the vessel is in resonance with the waves. Roll stabilizer foils will typically be submerged for all relevant sea states, so the probability of slamming differs bow foils from roll stabilizer foils. This must be accounted for in the design.

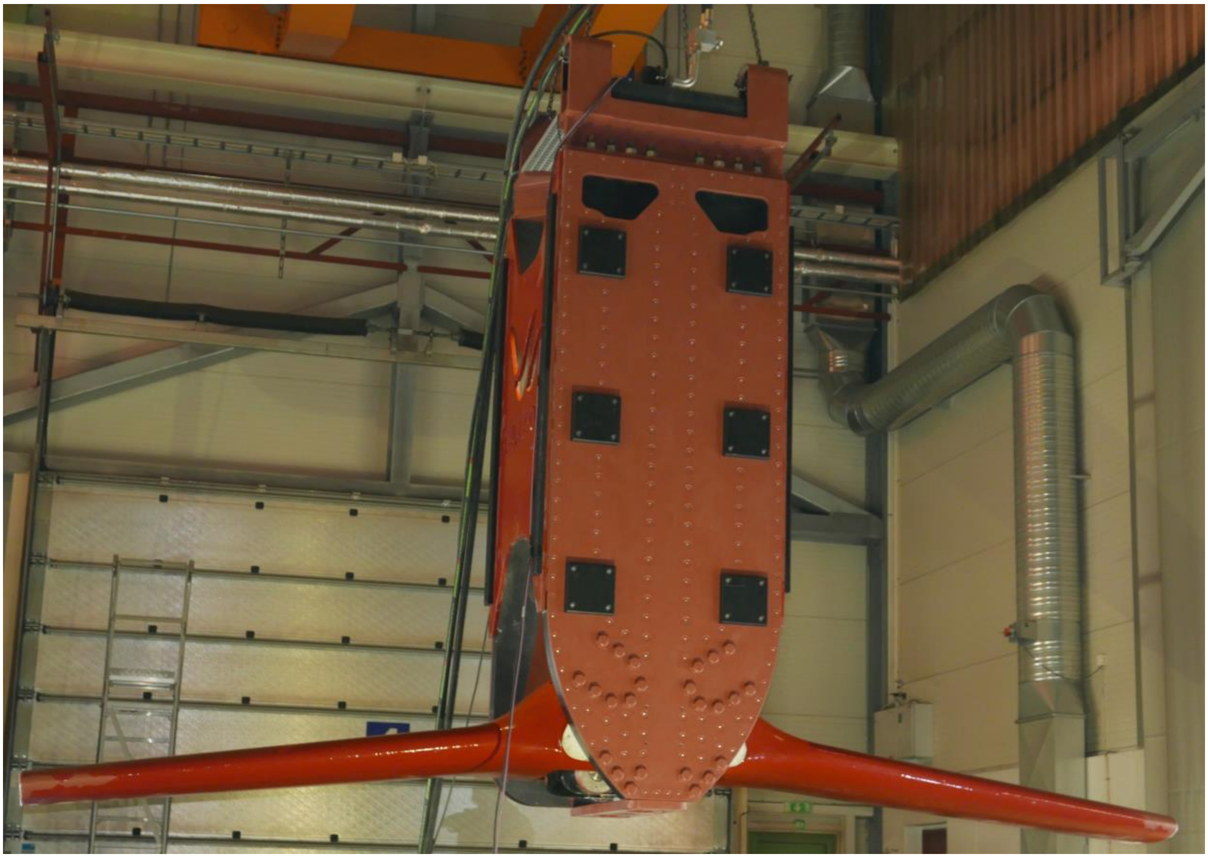

Figure 1: The foil module that is installed on M/F Teistin.

As found in [3], fixed bow foils perform almost as good as pitching bow foils unless the ship speed is low. Also, it is evident that a pitching shaft located inside the foil profile will be exposed to extreme bending stress. Thus, it was decided at an early stage to proceed with fixed (non-pitching) foils.

The next step to withstand the slamming forces was to introduce composite foils in order to obtain sufficient flexibility. The foils will experience high slamming pressures, but the forces transferred to the foil module is clearly a result of a dynamic system. The main key to reduce the slamming load is to tune the natural period of the foil bending so that it is much longer than the duration of the slamming impulse. If this is satisfied, the response of the dynamic system will be less than the response for a corresponding static load. The slamming duration is a function of impact speed and impact angle. The maximum impact speed can be predicted by use of a vessel motion analysis. The impact angle, often referred to as deadrise angle in slamming literature, depends on the local wave topography where the foil hits the surface. Thus, one must expect all impact angles between 0° and 90°. The local slamming pressure acting on the foil will reach a maximum for small impact angles, but smaller impact angles also implies shorter duration of the slamming event, leading to a surprisingly small dynamic response for these cases. Simulations with a numerical differential equation solver have shown that impacts angles in the order of 10° are more critical with respect to dynamic response, due to a moderate slamming duration in combination with high slamming pressures.

The slamming pressure is proportional to the relative velocity between the foil and the water surface squared [7]. The relative velocity decreases when the foil deflects, leading to a significant pressure drop due to the relative velocity squared term. These hydroelastic effects have also been verified in a coupled CFD and FEM analysis performed by cDynamics [8]. Hydroelastic effects are complicated, but there is no doubt that hydroelastic effects are positive in the case of bow foils.

All mechanical components in the foil module will be exposed to numerous fatigue cycles. A significant effort has been made to avoid high stress level zones. The foil module design has been further developed after the pilot module (the foil module on M/F Teistin) was sent to production. Now, all welded parts have been replaced by massive casted parts of much greater dimensions than feasible with welding.

Dynamic lift is generally lower than static lift for a given angle of attack below stall, due to vortex shedding in the wake. However, above the angle of attack where the foil stalls in static conditions, a phenomenon called dynamic stall becomes relevant. In static conditions, stall typically occurs at about 15° angle of attack, depending on the applied foil profile. In dynamic conditions, however, the lift may continue to increase for higher angles of attack for a short time. Exactly for which angle of attack the lift breaks down is not fully understood, but literature suggests that stall angles larger than 30° can occur in some dynamic lift cases [9]. The dynamic stall phenomenon is clearly a benefit regarding the effect of the bow foils as a motion damping and fuel saving device, but it also results in higher mechanical stress. Still, slamming will in most cases give the design load for bow foils.

RELIABILITY TESTING

The pilot foil module was produced by Norwegian subcontractors during the winter of 2018/19. After delivery, the foil module was sent to Fosen Yard for reliability testing, see Figure 2. A mounting bracket was constructed by the shipyard so that the foil module was partly submerged in sea water as it is when installed in a vessel. The retraction mechanism was actuated automatically by the control system in predefined intervals. The scope of the tests was not only to test the mechanical system, but also to optimize the control system including logging, remote control, alarms, calibration etc.

The reliability of the retraction mechanism is essential, for instance when a vessel enters a port of limited depth, or when the wave conditions exceeds a certain limit. A potential increase in thread friction due to tribological effects was addressed as a risk element. The threads were originally coated with Xylan as a solid lubrication. After about 200 retraction cycles we found that the Xylan coating was mostly damaged. An automatic lubrication system was then introduced as a backup solution. A food industry grease based on vegetable raw materials was applied. This lubrication system worked properly, but there are still reasons to believe that solid lubrication can be applied for future foil modules. Firstly, grease was applied as an auxiliary lubrication. However, the grease may have had a negative impact, since the sand blowing around by the wind on the shipyard was stuck to the grease working as sandpaper against the threads. Secondly, other types of Xylan coating have better lubricating performance than the type we applied.

The thrust bearing where the threaded rod is supported has turned out to be a critical component. As a starting point, a composite bearing with a teflon layer was sliding against a stainless-steel washer. The teflon layer failed after about 150 retraction cycles. The combination of relatively high rotational speed and the weight of two foils and the threaded rod itself pushes the limits for these maintenance free bearings. However, our torque (hydraulic pressure) measurements showed that the torque increase when the bearing begins to fail is surprisingly small, which implies that the consequence of a failing teflon layer is not critical in this case. It is worth mentioning that the bearing is easy to replace, since the critical bearing is unloaded when the foils are deployed. On M/F Teistin, the thrust bearing was replaced by a similar bearing with a smaller outer diameter, which probably improves the lifetime of the bearing due to a reduced peripheral speed for a given RPM.

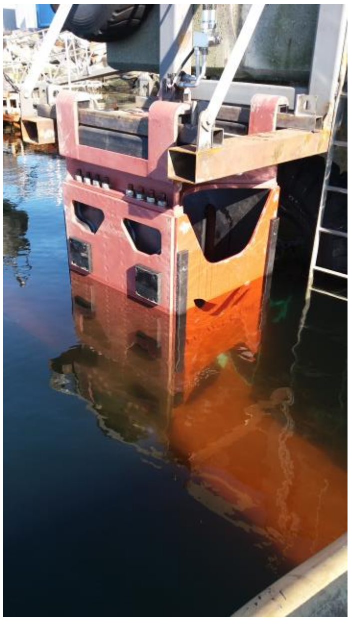

Figure 2: The foil module for M/F Teistin during reliability testing at Fosen Yard.

Measurements showed a negligible correlation between the number of retraction cycles and required torque as long as the thrust bearing discussed above was intact. However, the torque was measured to be slightly higher for the first retraction cycle after some days waiting time. The reason may be the temperature of the hydraulic oil, but marine growth may also have played a role since the tests were performed in April-June. Retractable foils must, as other movable equipment submerged in sea water, be kept alive by regular use.

TEST VESSEL: M/F TEISTIN

The foil module was installed on M/F Teistin, see Figure 3, a ferry sailing between Gamlarætt, Skopun and Hestur in the Faroe Islands. Table 1 gives some technical information on M/F Teistin, taken from the website of Strandfaraskip Landsins (SSL), the ship owner (https://www.ssl.fo/fo/um-ssl/alment/ferjur/mf-teistin/):

Build year	2001/2012
Passengers	288
Cars	33 (or 2 trailers + 12 cars)
Length between perpendiculars (Lpp)	40.00 m
Length overall (Loa)	45.00 m
Breadth	12.50 m
Draught	3.10 m
GT	1260
NT	378

Table 1: Technical information on M/F Teistin

Figure 3: M/F Teistin sailing out of Skopun harbor in the Faroe Islands.

INSTALLATION IN M/F TEISTIN

M/F Teistin sailed to MEST Shipyard in Tórshavn, Faroe Islands, for retrofit on September 2, 2019. The foil module was installed in a prefabricated steel structure approved by DNV GL. The foil module is connected to the structure via two massive beams with a rectangular cross section. The beams are connected to the foil module by shock dampening pads of synthetic rubber, and the beams are welded to the steel structure by use of knee plates.

Skin plates and stiffeners were removed from the bottom and starboard side of the forepeak tank. The steel structure with the foil module was then installed and welded to the surrounding structure, see Figure 4. Parts of the original collision bulkhead was replaced by the aft plate of the steel structure.

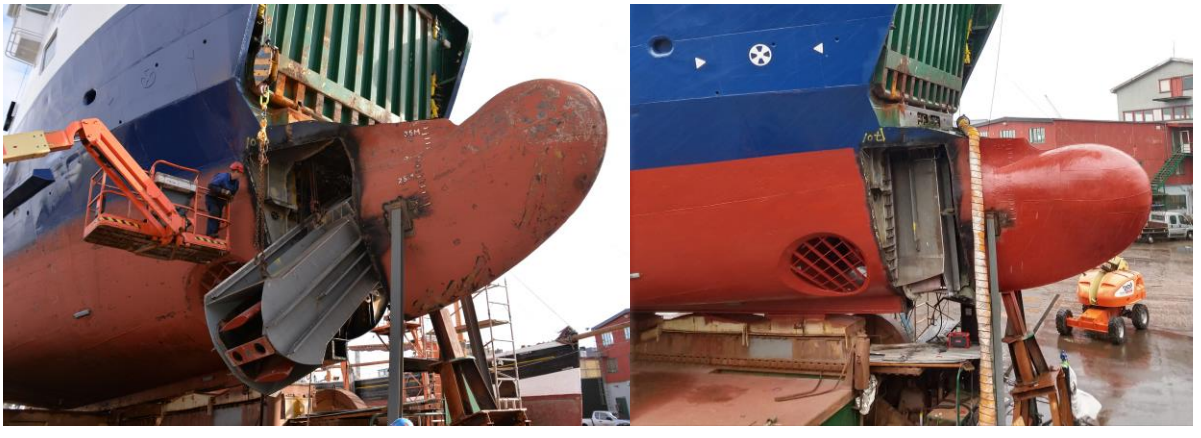

Figure 4: Installing the prefabricated structure with the foil module inside in the forepeak tank of M/F Teistin.

Original skin plates were reused, and the apertures for the foils were cut in the bottom plate, see Figure 5. The apertures for the foils were adapted manually during deployment testing to ensure correct tolerance. Deflectors were welded in front of the apertures to lead the flow smoothly around the apertures. The foil tips were cut flush relative to the hull in retracted position. This was in fact the only adaptation made for the foil module to fit this specific ship.

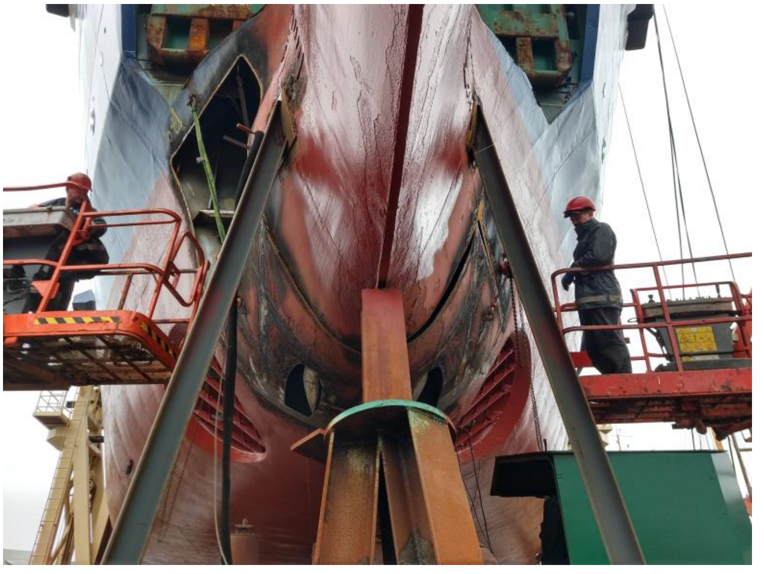

Figure 5: Bottom plate with aperatures for the bow foils cut out. The white foil tips can be seen in the apertures.

A hydraulic power pack was installed in the bow thruster room in proximity of the control cabinet. Two sets of buttons were installed on the bridge wings, one on each side. In addition, a touch monitor was installed on the bridge to handle settings and alarms, see Figure 6. The monitor also shows an animation of the retraction which is synchronized to the real foil position.

Figure 6: The 7-inch screen for changing settings, monitoring etc. installed in a central position on the bridge. In this picture, the foils are retracted before M/F Teistin enters Hestur harbor, the most confined port in her route.

The "foil room" is easily accessed through a manhole in the car deck. A ventilation pipe was installed to ensure approximately atmospheric pressure inside the foil room. A foil symbol was welded to the ship side, see Figure 7. Camera and lights were mounted in the ceiling of the foil room, and the camera is very useful for daily inspection. Inspection and maintenance routines have been prepared for the crew.

Figure 7: The bow foils deployed at sea. Note the foil symbol on the ship side.

OPERATIONAL EXPERIENCE

On September 25, 2019, M/F Teistin resumed its normal schedule with Wavefoil's foil module installed. Wavefoil was present on the vessel until September 28, and in this period the foil deployment mechanism was thoroughly tested. On the first day of testing the bow foils the ship was exposed to a significant wave height of 2-3 m, and the comfort improvement was stated by the crew immediately. Later, Teistin has sailed in 4-5 m significant wave height with the foils deployed. The crew has the freedom to choose when the bow foils shall be used, and they have been trained to retract the foils if the foils are in danger of coming out of water. We see that the crew sails with the foils deployed almost all the time. Per Dec. 17, 2019, the foils have been retracted 115 times in normal operation and the retraction mechanism has worked according to our expectations, also with forward speed of the vessel and in waves.

Wavefoil receives Teistin's fuel consumption data from Strandfaraskip Landsins once per month. Fuel consumption depends on a lot of factors, but we see that the average fuel consumption of October and November 2019 is 10% lower than the average fuel consumption in the period January 2016 to August 2019. DNV GL will in the coming months give a third-party assessment of the fuel saving effect of the bow foils, accounting for various factors given the data available.

Teistin sails a route that is exposed to strong tidal currents, with current speeds up to more than 5 knots, and the crew compensates for the current with the heading of the ship on every voyage. This means that no two voyages are identical, as can be seen from an AIS track history of the ship on a website like Marinetraffic.com. There is also a strong interaction between the current and the waves, meaning that every time the ship is in approximately the same position with approximately the same heading, which occurs with at least 85 minutes apart, the wave conditions will be somewhat different. Therefore, long-term testing must be applied to compare the vessel's performance with and without bow foils.

CONCLUSION

Wavefoil's first full-scale foil module has so far been a success. The ship owner experiences that the vessel is more comfortable and data for the fuel consumption indicates that there is a significant fuel saving.

ACKNOWLEDGEMENTS

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