White Paper: Operational Performance of MV Maas

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Operational profile measurements of an inland container vessel and sizing of fuel cells and hydrogen storage

Figure 1. 3D image of the Maas in Rotterdam.

Abstract

We, Future Proof Shipping (FPS), chose to retrofit our inland vessel the *Maas* to full zero-emission technology by replacing the existing internal combustion engines with hydrogen fuel cell technology. Proper sizing of fuel cells is crucial for this project. We measured the power profile of the vessel for several months to ensure that we had a deep understanding of the operations. The power profile includes power demand of the main propulsors together with hotel load and auxiliary power demand. This white paper shows the results of our measurements and presents the basis for the selection and sizing of the

fuel cells and hydrogen storage. These results can also be used as reference values for other similar inland container vessels.

Introduction

Converting an existing vessel to zero-emission technology is exciting and novel, but also complex, with numerous technical and economic challenges intersecting. The sizing of main components for zero-emission technology needs to be carried out carefully so that unnecessary costs are avoided, and the vessel can continue to operate safely. Thus, our retrofit of the *Maas* started with operational measurements to determine the power requirements for the future power configuration based on zero-emission technology. Next, the measurements were used to size the fuel cells, battery packs and hydrogen fuel tanks. This paper gives an overview of the vessel specifications, measurement setup and sailing route. We also present the results of our measurements, followed by our choices regarding the installed power for fuel cells and the amount of hydrogen required on the route.

Vessel

Future Proof Shipping (FPS) envisions a zero-emissions shipping world, and the *Maas* is the first vessel to set sail on this ambitious course.

Figure 2. The Maas will be retrofitted with PEM fuel cells and hydrogen fuel storage.

The *Maas* is a typical inland container vessel suitable for sailing on the Rhine and has the following specifications:

- Length: 109,8 m
- One main diesel engine: 1468 kW
- One bow thruster diesel engine: 367 kW
- One main propeller with two rudders
- One bow thruster with steering slides that allow thrust in 4 quadrants
- Two diesel generators for hotel and auxiliary power: 48 kW and 32 kW

Measurement setup

The vessel will be converted to zero-emission technology by replacing current diesel engines and diesel generators with fuel cells and batteries. The sizing of the fuel cells and batteries is crucial for the success of the project because overestimating power requirements will introduce additional costs while underestimating them could cause safety issues in the operation of the future vessel.

We performed a measurement campaign where we recorded the power of main onboard consumers in real operational conditions. The main consumers were: main propeller, bow thruster, hotel load and auxiliary consumers.

Figure 3: Measuring set up on the main shaft with rpm sensors and strain gauges.

The propulsion power of the main shaft was obtained by recording the torque and rotational velocity. Figure 3 shows the measurement setup with the same approach applied for the bow thruster. Regarding the hotel load and auxiliary power, the measurements included delivered electrical power to the electrical grids from the two generator sets.

Sailing region

Currently, the *Maas* transports containers between the Netherlands, Belgium, and Germany.

Figure 4: The representative route for the Maas between Rotterdam port and terminals in Belgium.

In the future, the ship will sail on the route between Netherlands and Belgium shown in Figure 4. The route is approximately 200 km long and there are four locks on the way.

Measurement results

The measured power profile is shown in Figure 5. The ship was fully loaded, and the current was in the opposing direction, thus the result can be considered 'worst-case conditions' on this route. Figures 6 and 7 are the recorded power profiles of the bow thruster and gensets from the representative route that corresponds to the worst-case conditions. According to the logbook, the ship sailed off from Geel in Belgium loaded with heavy 152 containers and arrived in Eemshaven with the current against its course. During the voyage, the following features of the power profile were recorded:

- Average total power: 436 kW
- Maximum total power: 1230,7 kW
- Average power main propeller: 485 kW
- Maximum power main propeller: 1222,5 kW
- Total duration of power peaks above 750 kW: 163 sec (0,2 % of total voyage)
- Average hotel power: 8,5 kW
- Maximum hotel power: 28,6 kW
- Average power at design speed: 650 kW

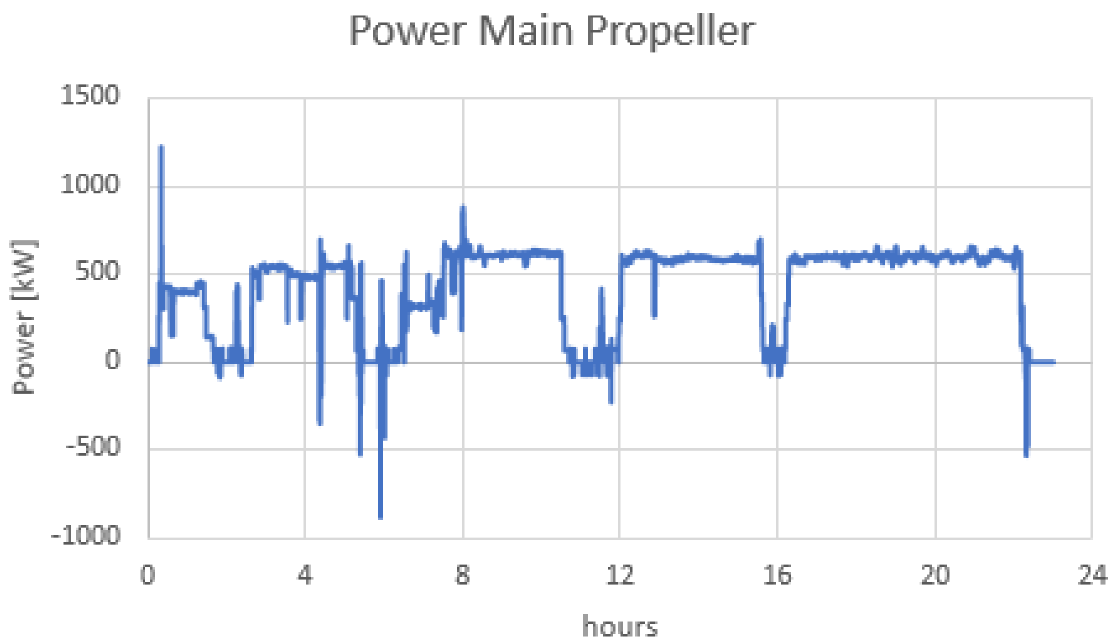

Figure 5. Recorded power of the main propeller shaft on the representative journey.

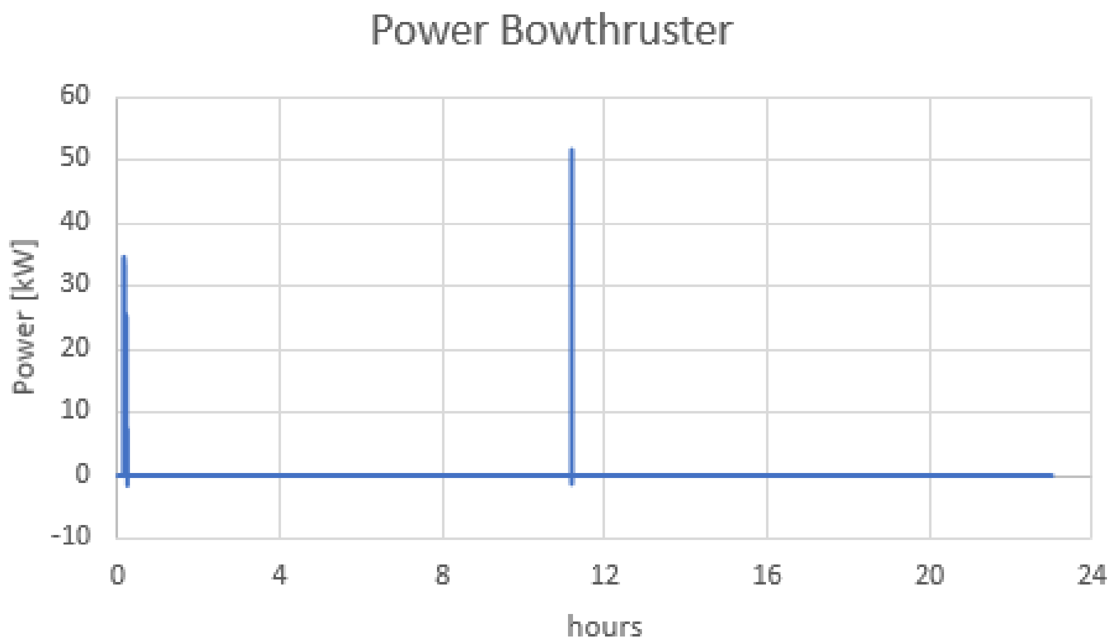

Figure 6. Recorded power of the bow thruster on the representative journey.

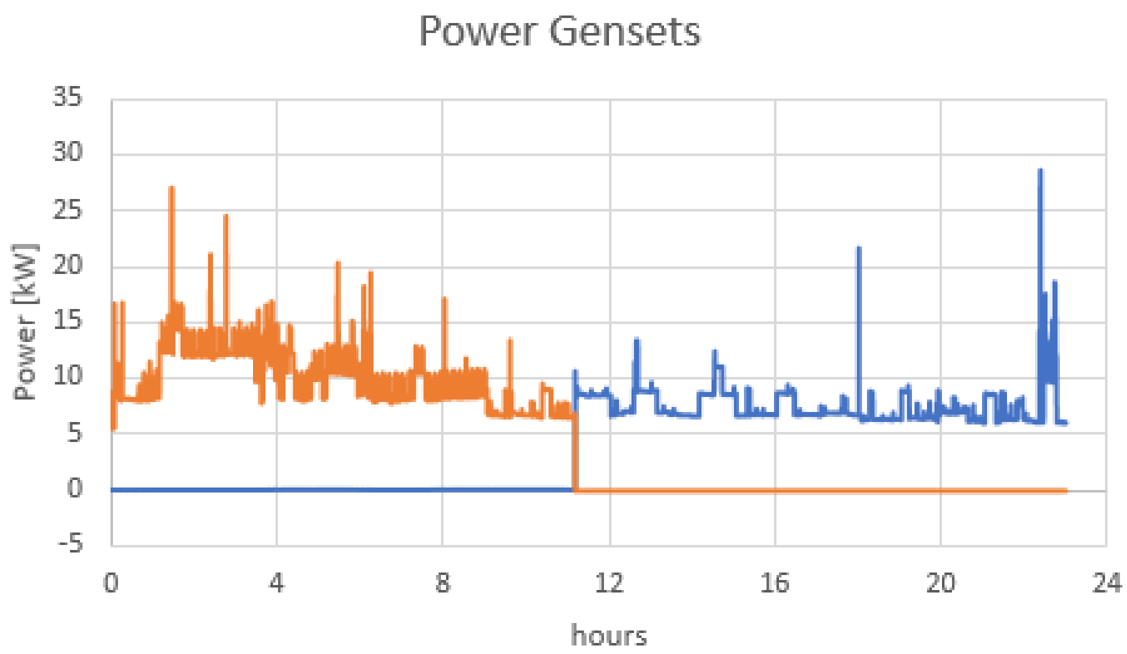

Figure 7. Recorded power of the gensets (hotel load and auxiliary power) on the representative journey.

The short power peak above 750 kW was caused by the operator and not related to functional requirements. Besides the measurements on the specified route, we also recorded measurements on different routes within the Netherlands and Belgium. For the sake of clarity, those results are not shown here but the recorded profiles highly correspond with the profile on the representative route (Geel – Eemshaven). It can be concluded that the propulsion power rarely exceeds 650 kW when sailing in the Netherlands or Belgium inland waterways. Somewhat different results are expected on the route to Germany where the currents are stronger.

Sizing of the fuel cells and hydrogen storage

Based on the measurements, we proposed to size the main electric motor at 800 kW and the fuel cell system at 825 kW (3 x 275 kWe). The rated power of fuel cells is considered as net delivered power to the system. In addition, two battery systems will be installed to power the vessel when the fuel cells are not in operation.

To estimate the required amount of hydrogen, it is necessary to integrate the power on the route and determine the required energy. Also, specific hydrogen consumption of the fuel cells is required and energy efficiencies of the components from fuel cells to the propeller need to be considered too. The mass of hydrogen required was calculated according to the following equation:

$$m_{H2\_route} = \frac{E_{route} \cdot shc}{\eta_{motor} \cdot \eta_{fd} \cdot \eta_{grid} \cdot \eta_{DC}}$$

Where:

- m_{H2_route} is the mass of hydrogen required for one way journey [g]
- E_{route} is the energy required for one way journey based on the measurements [kWh]
- shc is the specific hydrogen consumption of the fuel cells [g/kWh]

- η_{motor} is the efficiency of the main propulsion motor
- η_{fd} is the efficiency of the frequency drive
- η_{grid} is the electrical efficiency of the grid
- η_{DC} is the efficiency of the DC-DC drive of the fuel cells

The measured power profile corresponds to 9852 kWh and assumed specific hydrogen consumption is 60 g/kWh. The efficiencies of electrical components are assumed to be 99% for the grid, 95% for the frequency and DC-DC drive and 98% for the permanent magnet electric motor. The resulting amount of hydrogen for a one-way journey is 674 kg. The total amount of hydrogen was validated with a detailed calculation that is based on the exact values of hydrogen consumption at the beginning and end of lifetime of fuel cells and it was concluded that the abovementioned value is highly representative.

Discussion and Conclusions

Thanks to the measurements of the power profile, we were able to size the future fuel cell system optimally. The fuel cells will be typically loaded at between 70 and 75% and assumed specific hydrogen consumption of 60 g/kWh gives a representative (average) value of consumptions at the beginning and end of lifetime of fuel cells.

Due to the long route, the *Maas* will operate on high energy demand, therefore, it is clear that hydrogen remains our preferred choice. An all-battery alternative would require approximately two to four times more space because of its lower energy density. Another point of concern is the (current) unavailability of charging facilities in the ports the vessel will stop. For this vessel, a 1 MW charging installation would be required, and it would take 10 hours to charge the batteries.

With the diesel configuration having a rated power of 1200 kW and the power demand being around 650 kW, it is clear that the existing ship is highly overrated for the investigated route. However, different routes towards Germany might require higher power as the river current is stronger. In the future, we will measure performance on the routes to Germany and further east from the Netherlands, to design zero-emission ships that can successfully sail on those routes as well.

About Future Proof Shipping

Future Proof Shipping (FPS) (www.futureproofshipping.com), offers zero-emissions shipping services to enable players across the value chain make the transition to zero-emissions. As a zero-emissions vessel owner, FPS aims to build and operate a fleet of 10 zero-emission inland and short-sea vessels over the next five years which they will offer for charter to logistics service providers and cargo owners. FPS also facilitates other shipowners and stakeholders in the maritime sector who are ready to make the shift to zero-emissions, through technical, financial, and commercial support as well as project development and management.