APPLICATION OF HYDROGEN PROPULSION IN INLAND NAVIGATION

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Abstract: Today, alternative drives are a key segment of international research. The aim of the present paper is to examine one of these, the hydrogen drive, from a technical point of view. In addition, the aim is to examine how the propulsion of a Hungarian lake ferry could be converted from an internal combustion engine propulsion to a hydrogen propulsion, in line with international trends, while maintaining its suitability for its current task. We also discuss the infrastructural transformation required for inland hydrogen propulsion in inland waterway transport and tangentially in other transport systems.

1. INTRODUCTION

The primary caveat regarding fuel cell vehicles is that they will take up much more space in the vehicle than the original drivetrain. In the case of ships, especially in passenger transport, the key issue is to be able to accommodate as many people (and/or their vehicles) as possible in accordance with the strict regulations. In addition, determining the volume of the hydrogen tanks is also an important step because this value is closely linked to the future operation of the ship, since the tank volume determines when and for how long it must be filled. For this reason, the schedule can also change a lot.

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1.1 A subsection

Based on the information we have received, the Gábor Baross ferry has two Caterpillar 3406 DITA engines, their consumption standard with a safety factor:

$$B_s = 4\frac{l}{h}$$

Between Szántód and Tihany on Lake Balaton, the journey time of this ferry is officially 20 minutes there and back.

$$t = 20\ min$$

Based on these, the norm for a round trip:

$$B_{trip} = t * B = 15.667\ l$$

The heating value of the currently used fuel (LHV, Lower heating Value):

$$LHV = 35.94 * 10^6 \frac{J}{l}$$

The energy consumption of the engine and the auxiliary operation based on these:

$$E = LHV * B_{trip} = 5.631 * 10^8\ J$$

The engine normally runs at 1500 RPM. The equipment The motor normally operates at 1500 RPM. On the data sheet of the equipment, you can read that here is the BSFC (Brake-specific fuel consumption) value for full load:

$$BSFC_{tt} = 205 \frac{g}{kWh}$$

It can be seen that consumption increases by a maximum of 10% due to utilization of 75%. Assuming the worst case (exactly 10% deterioration):

$$BSFC = BSFC_{tt} * 1{,}1 = 225 \frac{g}{kWh}$$

We hace to calculate with a maximum of 20 grams of extra fuel per kWh.

The internal efficiency of the engine based on specific consumption is 37%, i.e.:

$$\eta = 0{,}37$$

The specific fuel flow:

$$B_f = 0.783\,\frac{l}{min}$$

The input energy:

$$E_{in} = B_{trip} * LHV = 5.631 * 10^8\,J$$

Furthermore, the energy used for the drive:

$$E_{drive} = \eta * B_{trip} * LHV = 2.083 * 10^8\,J$$

The average value of the heat input:

$$Q_{in} = B_f * LHV = 469.017\,kW$$

Based on this, the average power requirement is:

$$P_e = \eta_e * Q_{in} = 173.536\,kW$$

Based on the energy demand, knowing the processes taking place in the hydrogen fuel cell, the released energy can be calculated using chemical calculations. The efficiency of the PEMFC cell preferred in the vehicle industry and the losses of the motor can be used to calculate how much energy the drive provides.

The cathode reaction (reduction):

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

The anode reaction (oxidation):

$$2H_2 \rightarrow 4H^+ + 4e^-$$

It can be seen that the gross reaction is nothing but a hydrogen combustion process, the amount of heat released from it is based on the properties of the material:

$$\Delta H = 572000\,\frac{J}{mol}$$

The choice of tank pressure depends on the chosen storage method and pressure. The two most common methods of these are hydrogen stored in the gas state and in the liquid state. In the gas state, we can choose between 350 bar and 700 bar versions according to the current rules and standardized tanks.

Stored in a gaseous state at a pressure of 700 bar based on the general gas law:

$$V_{11} = \frac{n * R * T}{P_1} = 0.067m^3$$

Stored in a gaseous state at a pressure of 350 bar based on the general gas law:

$$V_{12} = \frac{n * R * T}{P_2} = 0.133m^3$$

As a result, we separated 3 cases: two-sided refueling, one-sided refueling, 1 refueling per day. The results are shown in Figure 1.

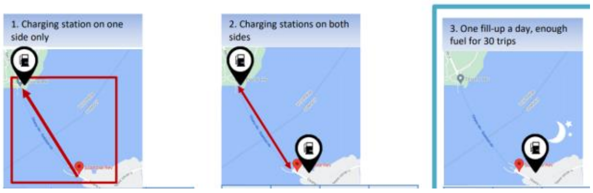

Fig. 1. Logistic cases

2. PROCEDURE FOR PAPER SUBMISSION

2.1 Review Stage

During the surface survey of the ship, it was revealed that the tank capacity is significantly larger than the tank volume that was calculated during the planning phase. Figure 2 shows the interior of the ferry.

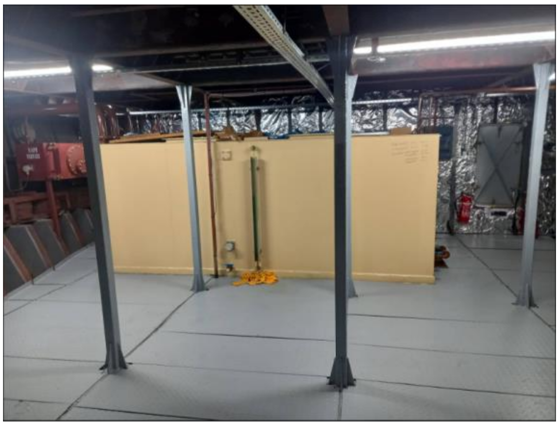

Fig. 2. Interior of the ferry

With its more than 7-meter length, 2-meter interior height, and hull width, the bow section alone is enough volume for the ship to not only buy one day's fuel from hydrogen gas, but also to maintain the habit of only buying fuel once a week.

Another change is that the location of the current diesel engines would not be in the middle of the hull, but closer to the two ends of the hull. As a result, a shorter axle can follow the electric motors, reducing losses, and freeing up more space for the hydrogen tanks in front.

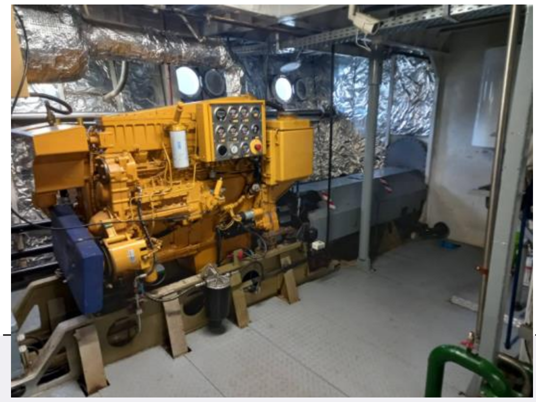

Fig. 2. Current diesel engine

It is often criticized that the hydrogen drive requires effective cooling around both the cells and the batteries. This is done on ships by fixed cooling circuits adapted to old engines. On Balaton ferries, the engine room is cooled by a two-circuit system located in the engine room floor. The outer circuit uses water from the lake and has its effect on the entire area of the engine room. Thus, the cooling does not need to be redesigned due to the future hydrogen drive.

An additional concern against the method is that the tanks contain explosive gases, which may explode in the event of a collision or impact load experienced during mooring. This concern can be dispelled based on the lessons learned from the on-site survey: the double-walled steel reinforcement has been proven to withstand impact loads for many years, and even the equipment installed relatively close to each other has never been damaged.

In practice, the technology in shipping is safer from this point of view than, for example, in road vehicles, where the tank is placed at the front, in the crumple zone.

It should be considered that a much larger space than expected is used not for the sake of a larger tank volume, but for the sake of lower pressure. By transporting tanks with a pressure of 250 bar instead of 700 bar, we save energy for the entire transport task, since it is enough to compress the gas to a lower pressure.

2.2 Battery case

For comparison, We examined what values are obtained with the same vehicle, with the same transport task, if the vehicle operates with accumulators. The technology can be compared to another propulsion method, which is an alternative to diesel. In the event that the batteries located in the drive chain are charged on shore, there are also no local emissions, and similarly to hydrogen gas, the electric power providing the same amount of energy is cheaper than the corresponding diesel oil. From a technical point of view, the change in volume and mass is expected to be the decisive difference here, so it is worth examining this case as well. In this case, the engine, the auxiliary generator and the total consumption are the same as in the previous case (since the starting point is the same engine).

With the power requirement calculated above and the related electrotechnical calculations, we can expect the following required battery mass for a daily driving task:

$$m_{akk3} = \frac{E_{\text{dailyDrive}}}{C_f} = 14{,}73t$$

Since no specific type was selected in the thesis due to the calculated large battery weight, We could only use approximations regarding the charging time, and We also did not deal with the electrical power available in the ports. I also did not take into account the time course of the charge, We only checked the charging power and whether the battery can absorb it continuously. In the case of a "traditional" fast charger (3 phases, 32 A), the maximum power that can be transferred is 22 kW. Thus, the charging performance time:

$$T_{22\,kW} = \frac{E_{\text{dailyDrive}}}{P_t} = 60{,}25\,h$$

It can be seen that this solution does not perform better than the hydrogen drive, because it causes a disruption in the schedule and large changes in the draft (and thus in the resistance). If, of course, this solution proves to be more cost-effective instead of the hydrogen drive, charging at night can also be solved, the time of which does not burden the timetable.

2.3 Construction

The requirements are that the construction with the new drive chain does not or does not produce a significant increase in immersion, i.e., in the end, an increase in resistance. In this case, a design spiral begins, since the mass of the hydrogen tank leads to increased immersion, which results in greater resistance, and from this a high thrust requirement, which potentially results in it being larger (meaning mass). I calculated the weights of the commercial items based on my own CAD model and data bases. Additional centre of gravity coordinates were chosen in consultation with Kontakt-Elektro Kft. Based on this, the total weight of the power electronics, fuel cell, cooling and bottles is 238 kg per 120kW. However, since in domestic planning only small boats have been made with these data so far, We will take the higher tank mass calculated above for the tanks.

It can be observed that the draft has increased from 1.25m to 1.513m (due to the batteries, control and hydrogen tank). This is a value for a daily refueling.

The change was made based on a general layout, based on the on-site survey of the specific ship, it was found that several large items such as auxiliary machines and spare tanks are removed / transferred in a more modern, lighter design. In addition, compared to the current diesel engine, the electric version would weigh less in terms of power per unit.

6. CONCLUSIONS

The purpose of the thesis was to show what aspects can be used when considering the conversion of a ship's drive to a fuel cell solution, and if this has already been decided (perhaps due to environmental protection restrictions), then what parameters should be taken care of in the pre-planning phase. The thesis did not address the economic aspects, so this consideration may still be the subject of further investigations. It can be concluded that, in this case, hydrogen, which is significantly cheaper and cleaner in terms of fuel price, is a legitimate option in the establishment of a new commuter ferry, but to determine whether it is cost-effective in the short term, further investigations are necessary with the involvement of an economic expert. In addition, it must be seen that the technical tests included in the document are also essential for these economic calculations.

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