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DESIGN OF WFOIL 18 ALBATROSS WITH HYDROGEN TECHNOLOGIES

ZASNOVA PLOVILA WFOIL 18 ALBATROSS Z VODIKOVIMI TEHNOLOGIJAMI

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Abstract

This article discusses the design of fuel cell propulsion for 18 albatross foil vessels. The purpose of this article determined the economic viability of such propulsion. WFoil 18 Albatross was chosen for a high-speed, low-power propulsion system.

The hydrogen propulsion system for the Albatross vessel consists of the following parts:

- Electric motor (Emrax 188) to convert electricity into mechanical energy;
- Battery (LG RESU 3.2EX | LG Battery System), which provides electricity in case of emergency or adds the necessary energy to run the engine at maximum power;
- Controller (EmDrive 500), which provides enough energy to pass between the elements of the propulsion system;
- Fuel cell (Hydrogenics HYPM-HD 30 POWER MODULE), which is the primary source of energy;
- The tank (tank for hydrogen gas type 3) stores fuel, which in our case is hydrogen.

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The brackets indicate the parts that have been selected for the hydrogen propulsion system. The approximate weight of all these parts is about 249.1 kg and the price of all these parts is about 55254 €. All prices are from 2020 and are subject to change.

The main idea in the construction of this charging station is the use of seawater and solar energy or renewable energy sources for hydrogen production. The components of the charging station are Solar cells (LG NeON 2), Desalination (CRYSTAL EX PURE), Electrolysis (Nel C Series C10), and Charging station (Haskel (Version with air compressor)).

The brackets indicate the parts that have been selected for the charging station. The approximate weight of all these parts is about 10236 kg and the price of all these parts is about 517664 €. All prices are from 2020 and are subject to change.

Povzetek

Ta članek obravnava zasnovo pogona na gorivne celice za 18 plovil albatrosa. Namen tega članka je določil ekonomsko upravičenost takšnega pogona. WFoil 18 Albatross je bil izbran za pogonski sistem visoke hitrosti in nizke moči.

Pogonski sistem na vodik za plovilo Albatros je sestavljen iz naslednjih delov:

- Elektromotor (Emrax 188) za pretvorbo električne energije v mehansko;
- Baterija (LG RESU 3.2EX | LG Battery System), ki zagotavlja elektriko v nujnih primerih ali doda potrebno energijo za delovanje motorja z največjo močjo;
- Krmilnik (EmDrive 500), ki zagotavlja dovolj energije za prehajanje med elementi pogonskega sistema;
- Gorivna celica (Hydrogenics HYPM-HD 30 POWER MODULE), ki je primarni vir energije;
- Rezervoar (rezervoar za plin vodik tip 3) hrani gorivo, ki je v našem primeru vodik.

Oklepaji označujejo dele, ki so bili izbrani za pogonski sistem na vodik. Približna teža vseh teh delov je približno 249,1 kg, cena vseh teh delov pa je približno 55254 €. Vse cene so od leta 2020 in se lahko spremenijo.

Glavna ideja pri izgradnji te polnilnice je uporaba morske vode in sončne energije oziroma obnovljivih virov energije za proizvodnjo vodika. Sestavni deli polnilne postaje so sončne celice (LG NeON 2), razsoljevanje (CRYSTAL EX PURE), elektroliza (Nel C serije C10) in polnilna postaja (Haskel (različica z zračnim kompresorjem)).

Oklepaji označujejo dele, ki so bili izbrani za polnilno postajo. Približna teža vseh teh delov je približno 10236 kg, cena vseh teh delov pa je približno 517664 €. Vse cene so od leta 2020 in se lahko spremenijo.

1 INTRODUCTION

1.1 Platform

The basis of the platform is a trimaran to which four hydrofoils are attached: the main or rear pair of hydrofoils and the front or stabilizer pair of hydrofoils, as shown in Figure 1.

In principle, we can say that all four hydrofoils determine the whole, since they only work stably around the longitudinal and transverse axes of movement. The vessel maintains its position along these two directions and requires only vertical rudder to maintain course.

Figure 1: *Distribution of hydrogen propulsion elements throughout the vessel*

In addition to stability, the double "V" arrangement of hydrofoils has an advantage over classic vessels by enabling both calm sailing in rough, wavy seas and (due to the folding system, otherwise relatively long hydrofoils) the possibility of sailing in very shallow seas and even landing on sandy beaches. This makes the vessel an economical, comfortable and very useful platform for various types of vessels.

When sailing at high speed, the hulls are quite high above the surface of the water, so that the waves do not affect the sailing itself. The vessel has been tested in extreme conditions and has always offered calm sailing with much less strain on its structure. Figure 2 shows two different graphs of water resistance and speed for two different concepts, namely for the constantly wetted system and for the wFoil system.

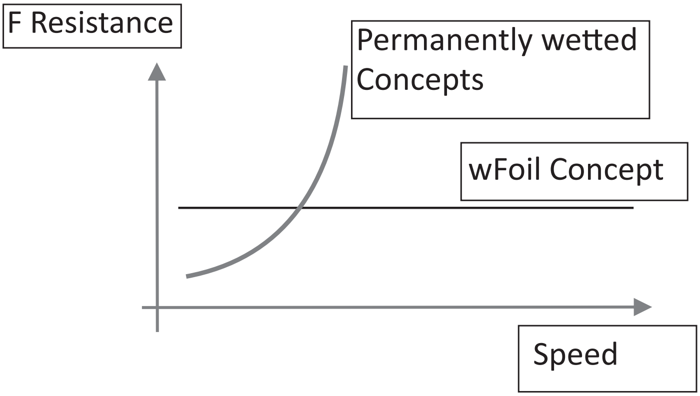

Figure 2: *Graph of water resistance and speed*

From the above description, we can understand that the wFoil platform offers the following properties, which are far ahead of the properties of classic vessels and also of other hydrofoil vessels:

- By increasing the sailing speed, the vessel rises above the water surface, so that the hulls of the vessel do not touch the waves. Hydrofoils are relatively long compared to the size of the vessel, which allows calm, fast, comfortable and safe navigation in rough seas.
- At higher speeds, the hydrodynamic resistance of the vessel is lower than that of other vessels - even vessels that use hydrofoils. This feature occurs because the wetted part of hydrofoils decreases with increasing sailing speed.
- wFoil vessel is also useful in very shallow waters. We can also land on sandy beaches, which is possible thanks to the unique system of folding the otherwise relatively long hydrofoils under the transverse supports of the platform structure.
- The wFoil platform, with its hydrofoil arrangement, only enables stability around the transverse and longitudinal axes of movement. This allows the vessel's platform to remain in a more or less horizontal position without the use of complicated systems to maintain stability.

1.2 Benefits

The main advantages of the wFoil platform are listed below:

- Directivity and stability of the vessel
- Smaller hydrodynamic resistance
- Greater range of useful vessel speeds
- Folding hydrofoils
- Wave compensation
- Economical construction and easy maintenance.

2. CONSTRUCTING A HYDROGEN PROPULSION

2.1 Conceptual design of a hydrogen drive

The hydrogen propulsion system for the Albatross vessel consists of parts as shown in Figure 3:

- Electric motor for converting electrical energy into mechanical energy;
- A battery that provides electricity in case of emergency or adds the necessary energy for the engine to operate at maximum power;
- A controller that provides enough energy to pass between the elements of the drive assembly;
- Fuel cell, which is the primary source of energy;
- The tank stores the fuel, which in our case is hydrogen.

Figure 4 shows the distribution of propulsion elements across the vessel.

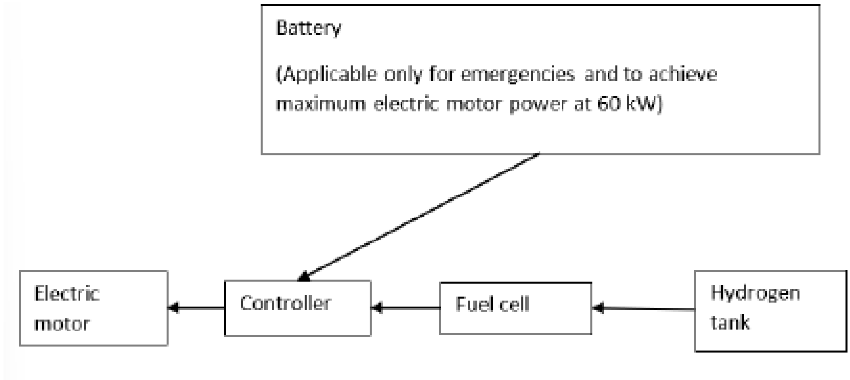

Figure 3: *Scheme of the hydrogen drive.*

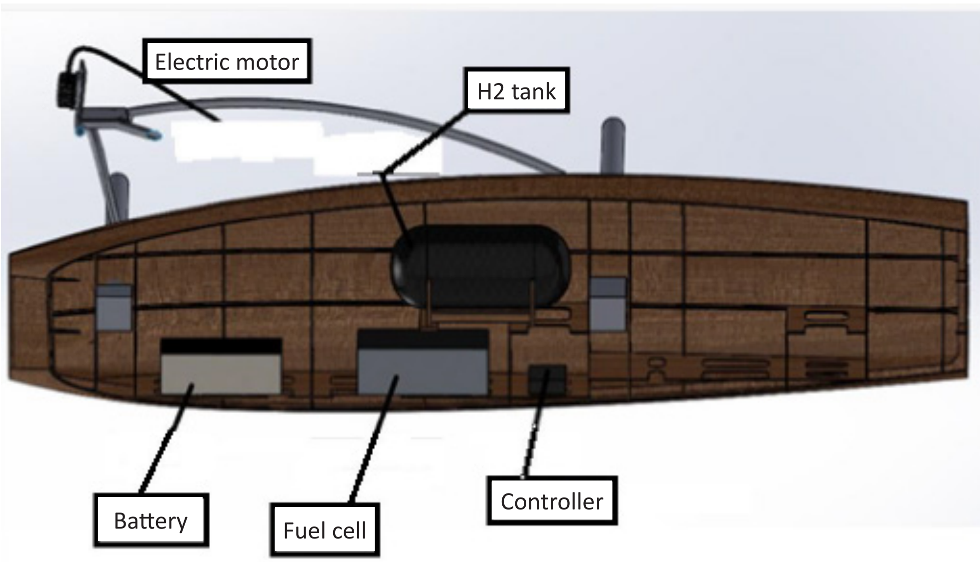

Figure 4: *Distribution of hydrogen propulsion elements throughout the vessel*

2.2 Components

Electric motor: Emrax 188
Battery: LG RESU 3.2EX | LG Battery System
Controller: EmDrive 500
Fuel cell: Hydrogenics HYPM-HD 30 POWER MODULE
Reservoir H2: Reservoir for hydrogen gas type 3

Table 1: *Hydrogen propulsion components*

	Electric motor	**Controller**	**Fuel Cell**	**H2 Tank**	**Battery**	**Total**
Voltage [V]	110	30 - 125	60 - 120	/	45,2 – 58,1	/
Current [A]	0 - 800	0 - 800	0 - 500	/	/	/
Dimensions [mm]	$\emptyset\, 188 \times 77$	$78 \times 310 \times 205$	$719 \times 406 \times 261$	$\emptyset\, 460 \times 991$	$230 \times 664 \times 165$	/
Mass [kg]	7,2	4,9	75	102	60	249,1
Efficiency [%]	96	96	53	/	85	/
Price [€]	3.700	1.900	39.000	5.090	5.564	55.254
Model	Emrax 188 (LV)	EmDrive 500	HD30	SHC 90L 700 bar	LG RESU 3.2 EX	/

2.3 Calculation for the hydrogen propulsion system

Calculation of the total weight of the hydrogen propulsion system for the Albatross

$$7{,}2\ kg + 4{,}9\ kg + 75\ kg + 102\ kg + 60\ kg = 249{,}1\ kg \quad (2.1)$$

Calculation of total efficiency for operation on fuel cells

$$0{,}96 + 0{,}96 + 0{,}53 = 0{,}488 \quad (2.2)$$

Calculation of total efficiency for battery operation

$$0{,}96 + 0{,}96 + 0{,}85 = 0{,}78 \quad (2.3)$$

Calculation of the final price of all elements in the drive

3700€ + 1900€ + 39000€ + 5090€ + 5564€ = 55254€ (2.4)

2.4 Comparison between a gasoline engine and a hydrogen engine

Figure 5 shows a comparison between gasoline engine and hydrogen drives. The figure includes the fuel for both drives, the yields and the products produced by the drives.

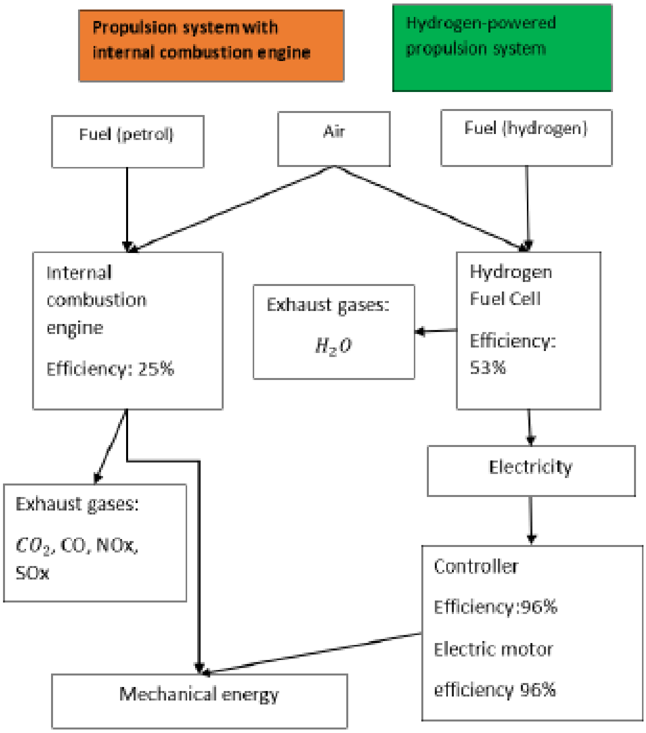

Figure 5: *Comparison of energy conversions*

Calculation for a gasoline engine:

$$0{,}75\,\frac{kg}{l} \times 25\,l = 18{,}75\,kg \quad (2.5)$$

$$12\,\frac{kWh}{kg} \times 18{,}75\,kg = 225\,kWh \quad (2.6)$$

$$225\,kWh \times 0{,}25 = 56{,}25\,kWh \quad (2.7)$$

Calculation for hydrogen propulsion:

$$33{,}33\,\frac{kWh}{kg} \times 3{,}5\,kg = 116{,}66\,kWh \quad (2.8)$$

$$116{,}66\,kWh \times 0{,}53 = 61{,}83\,kWh \quad (2.9)$$

$$61{,}83\,kWh \times 0{,}96 = 59{,}35\,kWh \quad (2.10)$$

$$59{,}35\,kWh \times 0{,}96 = 56{,}98\,kWh \quad (2.11)$$

3. CONSTRUCTING A HYDROGEN CHARGING STATION

3.1 Conceptual design of the charging station

The main idea in constructing this charging station is the use of seawater and solar energy or renewable energy sources for the production of hydrogen. Figures 7 and 8 show the process for obtaining and storing hydrogen. Figure 6 shows the charging station, which was made in the computer program Solidworks.

Figure 6: *Charging station*

For proper use, seawater must be desalinated. Electricity is obtained from solar cells, and in case of bad weather from the electricity grid. When water is desalinated, it goes through electrolysis, yielding hydrogen, which serves as our fuel. The next step is to increase the pressure to 700 bar and store it in a pressure vessel until the next filling.

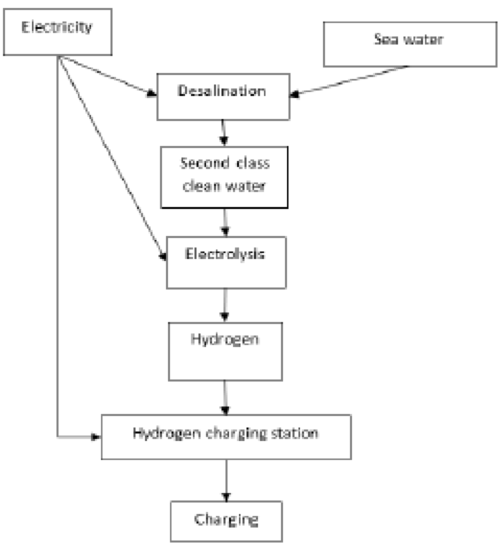

Figure 7: Scheme of the charging station

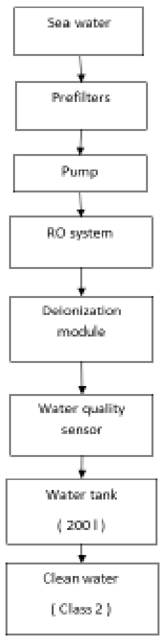

Figure 8: Sheme of the desalination proces.

3.2 Components

Solar cells: LG NeON 2
Desalination: CRYSTAL EX PURE
Electrolysis: Nel C Series C10
Charging station: Haskel (Implementation with the help of an air compressor)

Table 2: *Components of the charging station*

	Solar cells	Desalination	Electrolysis	Charging station	Total
Consumption	29,26 MWh/year	27,5 kWh/m^3	68,9 kWh/kg H2	1.680 kWh/day (max)	
Dimensions [m]	/	$0{,}4 \times 0{,}35 \times 0{,}55$	$2{,}52 \times 1{,}16 \times 2{,}01$	$3 \times 3 \times 3$	
Mass [kg]	1.386	216	2.734	6000	10.236
Product	Electricity (AC)	Clean Water (Class 2)	Hydrogen gas at 30 bar	Hydrogen gas at 700 bar	
Price [€]	30.550	3.114	240.000	244.000	517.664
Model	LG and Fronius	Crystal Ex Pure	Nel C10	Haskel air driven option	

3.3 Calculation for the charging station

Calculation of the mass of the charging station:

$$1386\ kg + 216\ kg + 2734\ kg + 6000\ kg = 10336\ kg \tag{3.1}$$

Calculation of the charging station price:

$$30550€ + 3114€ + 240000€ + 244000€ = 517664€ \tag{3.2}$$

Nominal power of the system:

$$355\ W \times 75 = 26625\ kW \tag{3.3}$$

Amount of expected annual production:

$$26625\ kW\ \times 1100\ kWh = 29288\ MWh \tag{3.4}$$

$$364€ \times 75 = 27300€ \tag{3.5}$$

Total prices of inverter and solar panels:

$$27300€ + 3234€ = 30534€ \tag{3.6}$$

How much hydrogen is produced per hour?

$$\frac{10}{22,4} = 0,45\ kmol/h \tag{3.7}$$

$$0,45\,\frac{kmol}{h} \times 2 = 0,9\ kg/h \tag{3.8}$$

How much energy do we get from 1 kg of hydrogen?

$$33,33\,\frac{kWh}{kg} \times 0,488 = 16,27\ kWh/kg \tag{3.9}$$

How much energy do we get from a full tank of hydrogen?

(The amount should be comparable to 25 liters of gasoline, which is enough for about 2 hours of sailing).

$$16,27\,\frac{kWh}{kg} \times 3,5\ kg = 56,59\ kWh \tag{3.10}$$

How many kilograms do we need to fill the tank four times?

$$3,5\ kg\ \times 4 = 14\ kg \tag{3.11}$$

How long does it take to produce the necessary fuel?

$$\frac{14\ kg}{0,9kg/h} = 16\ h \tag{3.12}$$

How many liters of water are needed to produce fuel?

$$9\,\frac{l}{h} \times 16h = 144\ l \tag{3.13}$$

How much electricity do we need for such production?

$$68,9\,\frac{kWh}{kg}\ \times 14\ kg = 964,6\ kWh \tag{3.14}$$

4. CONCLUSION

The current fuel cell technology is suitable for propulsion of the wFoil 18 Albatross, but it is not economically comparable to a petrol engine.

Another drawback is the heavier weight than the internal combustion drive. Until material and production prices are reduced, hydrogen technologies will remain uncompetitive with internal combustion engines. However, they are environmentally friendly and have higher efficiencies than conventional propulsion systems.

Additional problems arise when setting up the system and obtaining appropriate approvals. To continue research for an alternative drive for the wFoil Albatross, batteries only are recommended, but this is also likely too heavy for the vessel's current limitations.

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Nomenclature

(Symbols)	(Symbol meaning)
%	percent
NOx	Nitric oxide
CO2	Carbon dioxide
SOx	Sulfur oxides
CO	Carbon monoxide
H2O	water
€	euro