Design of the Two-Wheeled Vehicle using Metal Hydride Vessels

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Abstract— *Article describes the issue of hydrogen storage in the structure of metal alloys, solves design of metal hydride pressure vessel and solves the design of the concept of prototype two-wheeled vehicle powered by fuel cell with designed metalhydride pressure vessels.*

Keywords— metal hydride, hydrogen, two-wheeler, fuel cell.

I. INTRODUCTION

Hydrogen is receiving more and more attention in Europe and around the world. The most important aspect is the fact that the energy recovery of green hydrogen in fuel cells produces no air emissions. Thus, it represents a possible solution to partially decarbonize industrial processes and economic sectors.

In the field of transport infrastructure, it is necessary to focus on alternative fuels and systems that will be created from renewable energy sources. Of course, these systems will also support the reduction of greenhouse gases. Currently, two technological platforms appear as long-term fuel sources, for example electromobility and hydrogen transport systems. Today, Slovakia has a commitment that more than 20% of vehicles in public administration should be free of combustion emissions in 2021.

Currently, hydrogen fuel is stored at extremely high pressures of 35-95 MPa. Today, there are options for storing hydrogen in various compounds that provide better storage options.

The implementation of hydrogen technologies with metal hydride reservoirs provides scope for increasing the safety and storage of H2 at lower pressures. To be able to use this type of hydrogen storage, it is necessary to design a reservoir that will meet the working conditions.

II. DESIGN OF METALHYDRIDE PRESSURE VESSEL

When designing the pressure vessel, it is necessary to work with standard STN EN 13322-2. This standard provides a specification for gas transport vessels, the design and manufacture of refillable steel transport welded gas vessels, in this case the medium that will be used in the vessel is hydrogen.

This European standard describes the minimum requirements for the design, material, production processes and production tests of gas transport vessels welded from stainless steel with a water volume ranging from 0.5 to 150 litres for liquefied dissolved and compressed gases. The standard is only applicable to stainless steel vessels with a maximum tensile strength of up to 1100·106 Pa. The design of the reservoir consists of two main parts, and the primary reservoir, which contains the hydrogen-absorbing metal hydride alloy and the casings (Fig. 5). Between the primary reservoir and the case there is an intermediate space in which the coolant flows. Stainless steel type 1.4404 or 316L was chosen for the construction of the metal hydride reservoir with the mechanical properties listed in tab. 1. The use of the type of steel is prescribed by the standard.

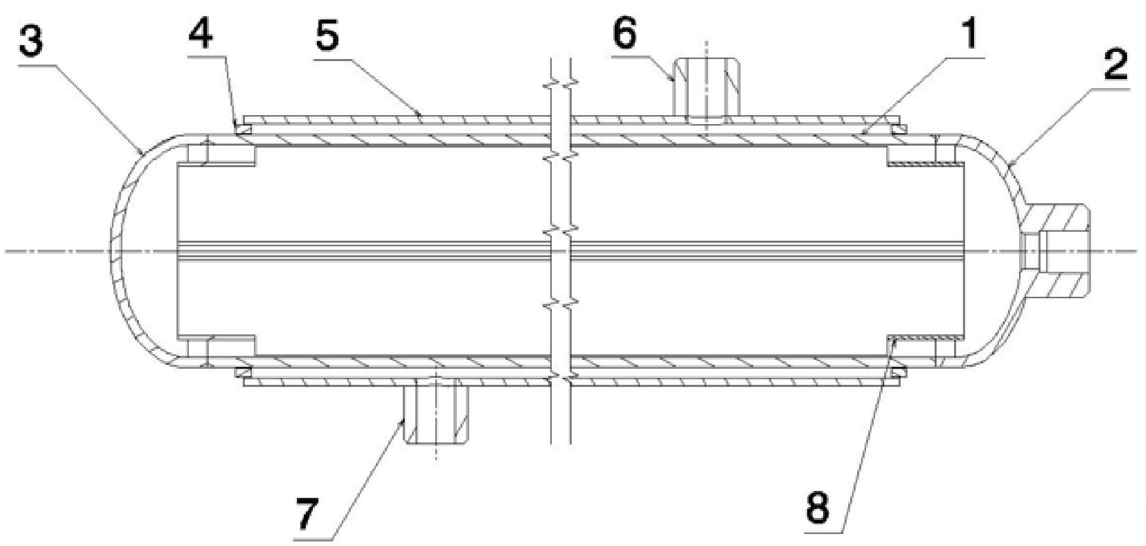
TABLE 1
MECHANICAL PROPERTIES OF STAINLESS STEEL 1.4404

0,2% Re(MPa)	Rm(MPa)	ρ(kg·m^3)	μ	E(MPa)
200	500-700	8000	0,3	$2{,}1\cdot 10^5$

Where Re- Yield strength (MPa), Rm- tensile strength (MPa), ρ- density (kg·m^3), μ- Poisson's number (-) and E- Young modulus of elasticity (MPa).

The process of hydrogen absorption into the structure of the metal hydride alloy is an exothermic reaction, during which heat energy is generated. Therefore, it is necessary to effectively cool the reservoir during its operation.

The reservoir can be cooled with active and passive modules. The active cooling module is the cooling liquid, in this case water, which is in the interspace between the primary pressure vessel and the case. The passive cooling module is located inside the primary pressure vessel and is a heat transfer intensifier that serves to increase the heat removal from the core of the tank in the direction of the fins to the wall of the primary vessel, where the vessel is cooled by water. By changing the geometry of the intensifier, it is possible to improve heat dissipation, thereby improving the absorption process. When designing the heat transfer intensifier, aluminium is considered because it has good thermal conductivity ($237\ W \cdot m^{-1} \cdot K^{-1}$).

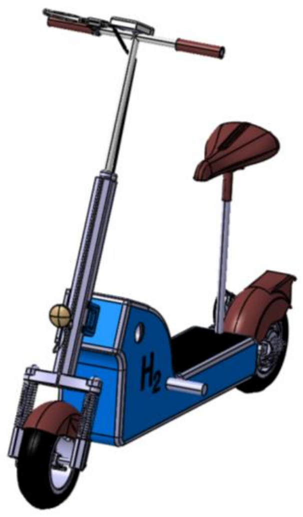


1- cylindrical part of the primary vessel, 2- elliptical bottom with NPT1/4"thread, 3- elliptical bottom, 4- flange for casing, 5-cylindrical part of casing, 6- flange with G1/2 thread, which serves as the coolant supply, 7- flange G1/2, which serves as coolant drainage, 8- heat transfer intensifier

FIGURE 1: Design of metalhydride pressure vessel

III. APPLICATION OF A METAL HYDRIDE STORAGE VESSEL TO THE CONCEPT OF A TWO-WHEELED VEHICLE

The designed vessel with an internal heat transfer intensifier according to the STN EN 13322-2 standard was subsequently used in the design of the concept of a two-wheeled mobile device, using metal hydride alloys and a fuel cell for propulsion. The proposed device is shown in Fig. 2. The device is a hybrid that is powered by electricity and a fuel cell. A fuel cell is an electrochemical device that converts the chemical energy of the fuel and oxidizer directly into electrical energy. A Horizon 500 PEM proton exchange membrane (PEM) fuel cell was used for the design of the mobile device. The parameters of the selected fuel cell in the two-wheeler concept are listed in table 2.



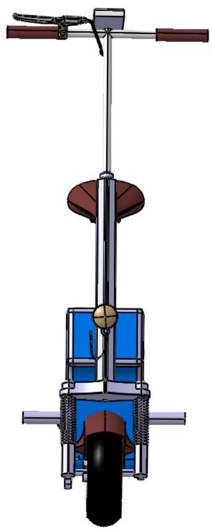


FIGURE 2: Concept of a hybrid two-wheeler powered by a fuel cell and an electric motor

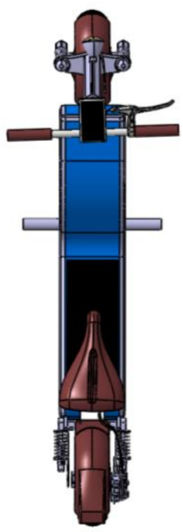


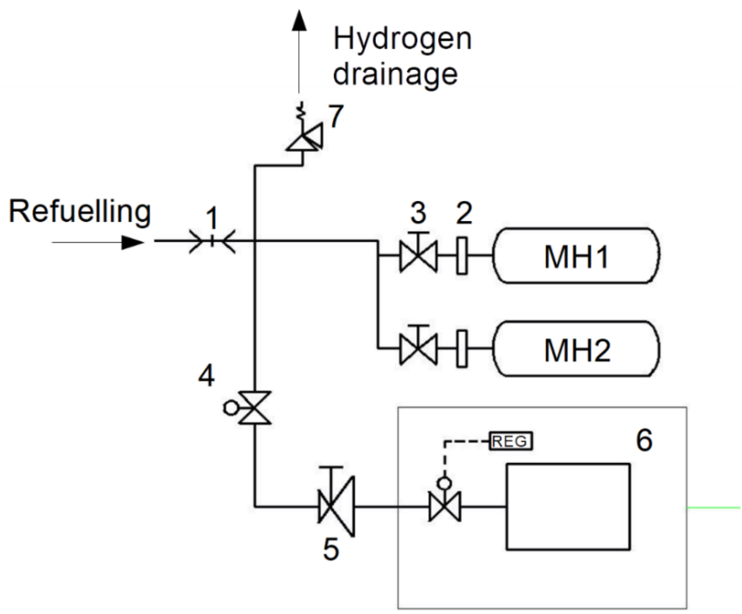
FIGURE 3: Top view of the designed device

TABLE 2
PARAMETERS OF SELECTED FUEL CELL

Number of cells	24
Nominal power	500 W
Power	14.4V 35A
Hydrogen supply valve voltage	12 V
Flush valve voltage	12 V
Fan voltage	12 V
Reactants	Hydrogen and air
Ambient temperature	5 - 30°C
Maximum device temperature	65 °C
Total weight of the device	2,5 kg

The base of the designed device is formed by a duralumin frame. In the device, a 500 W motor located in the rear wheel, a battery with a capacity of 48 V and 14.4 Ah and a control unit are considered. The concept envisages front and rear wheel suspension to minimize vibration of the base plate, which houses the fuel cell. The brake system is located on the rear wheel of the device. After adding up all the parameters, the total weight of the device is approximately 28 kg.

The metalhydride vessels used in the design of the device have length 300 mm and the diameter of vessel is 60 mm. In Tab. 3 shows the individual parameters of the vessels used in the draft concept. In Fig. 4 it is possible to see the designed hydrogen circuit in the device.



MH1 and MH2 represent the used MH vessels within the design, 1- refuelling neck, 2- filter, 3- manual valve,4 - Solenoid valve, 5- reducing valve, 6- fuel cell and regulation, 7- hydrogen drainage.

FIGURE 4: Hydrogen circuit in designed two-wheeler

TABLE 3
PARAMETERS OF USED METALHYDRIDE PRESSURE VESSELS

Volume of metalhydride	$1{,}232 \cdot 10^{-3}$ m^3
Weight of metalhydride	3,6 kg
Weight of stored hydrogen	0,05 kg
Volume of hydrogen	0,597 m^3
Generated heat	6154,43 kJ

Based on the values from Tab. 3, it is possible to calculate the maximum range of the designed device.

The maximum range of the designed device is obtained from equation:

$$m_{H_2} \cdot Q_m = X \quad \text{(kJ)} \qquad (1)$$

where: Q_m is calorific value of hydrogen (Q_m = 119 550 kJ), m_{H_2} is the mass of stored hydrogen in the metalhydride alloy, X is total heat generated in pressure vessels.

After substituting the mass of hydrogen and calorific value of hydrogen into equation (57), the total heat generated in the reservoirs is 6154,43 kJ. The efficiency of the used fuel cell is 0.5, which means that the total heat released from the fuel cell is 3077.22 kJ. The nominal power of the fuel cell is 0,5 kJ·s^{-1}.

$$t_p = \frac{Q}{P} \quad \text{(s)} \qquad (2)$$

where t_p- maximum time of operation of the fuel cell, Q- released heat from the fuel cell, P- nominal power of the fuel cell.

After dividing the heat released by the fuel cell and the nominal power (2), the obtained time is 102 min. This time represents the maximum operating time of the fuel cell.

The next step is the calculation of the maximum operating time of the device on the battery and electric motor. The battery capacity was determined from the equation:

$$c = Q \cdot U \quad \text{(Wh)} \qquad (3)$$

where: c is capacity (Wh), Q is electric charge (Ah), and V is a voltage (V). Battery in device has 14,4 Ah and 48 V.

After substituting the voltage and electric charge into equation (3), the battery capacity is 691.2 Wh. The maximum operating time of the electric engine was calculated from the equation (4):

$$t_e = \frac{c_{battery}}{P_{el.engine}} \quad \text{(s)} \qquad (4)$$

Where: t_e- maximum operating time of the electric engine and battery (s), $c_{battery}$- capacity of the battery (Wh), $P_{el.engine}$- power of electrical engine (W)

After substituting the battery capacity and the power of the electric motor into equation (4), the maximum operating time of the electric motor and battery is 80 min.

The maximum range of the device is obtained from the equation:

$$s = v \cdot t_c \quad \text{(km)} \qquad (5)$$

Where *s*- distance (km), *v*- average speed of device (km·h^{-1}) a t_c-total operation time (h).

The total operating time of the device is obtained as the sum of the maximum operating times of the fuel cell and the electric engine with the battery.

$$t_c = t_p + t_e \quad \text{(s)} \qquad (6)$$

Where t_c- the total operating time of the device.

The total operating time of the designed device is 3.03 h. The average speed of the device is 25 km·h^{-1}. After substituting the average speed and total operating time into equation (5), the maximum range of the device is obtained, which is approximately 75 km under optimal conditions. This means when there is no wind, at zero slope and at room temperatures.

IV. CONCLUSION

The main task of this work was to design a two-wheeled device that uses a type of hydrogen storage based on absorption into the metal alloy structure. It is also a hybrid two-wheeled device using a fuel cell and an electric motor, whose estimated range based on calculations is approximately 75 km. The next step of this work will be the construction of a real functional prototype and subsequent testing of the designed metal hydride vessels in this device.

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