Model of a Hydrogen Vehicle Driven by a Fuel Cell and Metal Hydride Materials

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Abstract

The present article describes the structure of the model of a vehicle driven by a fuel cell and using metal hydride alloys. The model was created in the scale of 1:6 and was subjected to measurements of the real hydrogen consumption by a fuel cell; subsequently, the real power was compared to the theoretical power. The model of a hydrogen vehicle was developed with the aim of testing various types of metal hydride materials used for hydrogen accumulation in real conditions, at sudden changes in the amount of the collected hydrogen. The purpose of the designed model was to demonstrate the adjustment of a hydrogen drive to the burdening operating conditions of the vehicle and demonstrate the capacity of metal hydride materials to satisfy the requirements regarding accumulation and release of the required amount of hydrogen.

Keywords: metal hydride; fuel cell; hydrogen; automobile;

1. Introduction

An automobile is one of the important inventions throughout the history of mankind. Due to decreasing reserves of fossil fuels and growing problems with environmental pollution, approximately thirty years ago humans began to search for alternative energy sources. A primary objective was to find energy sources with minimum negative environmental impacts that would facilitate the long-term development of transport and haulage. As for the transport, there are currently several options of alternative fuels to choose from. Important alternatives to gasoline and diesel, that are nowadays predominantly used, intended for the application as the fuel for the means of transport are the fuels based on hydrocarbons in form of compressed gases and liquids, as well as hydrogen fuels. At present, there is a boom of electrical and hybrid fuels.
The enforcement of the application of these alternative fuels is accompanied with several problems related to the power, accumulation, electric range, as well as the costs related to the transport infrastructure.

2.VehicleStructure

The main component of the vehicle is the welded structure consisting of duralumin profiles with a rectangular cross-section of the EN AW6060 type with the T6 heat treatment. The structure is attached to eight arms that provide suspension of axles. The arms are manufactured using the additive technology – 3D printing from aluminium. The arms are attached to the main structure by attachments made of 11 500 steel. In order to relieve the vehicle, suspension components are manufactured using the technology of 3D printing from ABS plastics. The chassis suspension is constructed using bicycle shock-absorbers with springs than were made to measure.

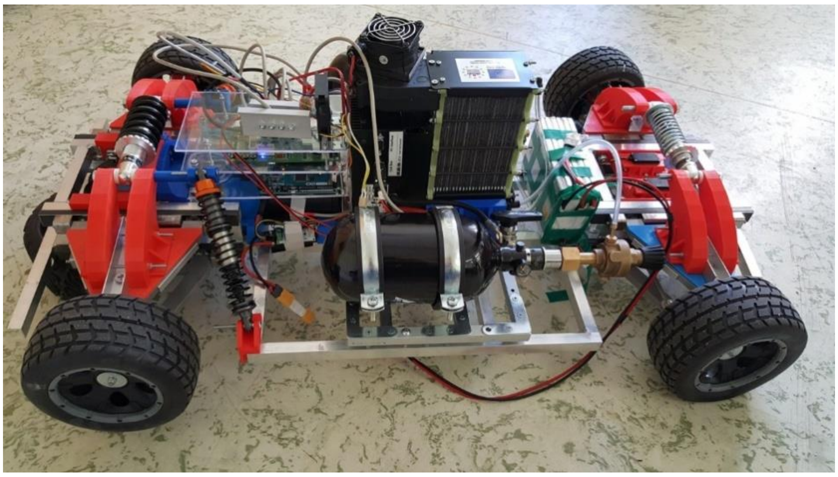

Figure 1. Chassis of the vehicle model with the controlling modules.

Figure 2. Model of a hydrogen vehicle including the body.

2.1 The Used Concept of the Vehicle's Drive

The used concept of the drive consists in the use of a fuel cell, electric motor, and lithium batteries. The mechanical concept of the drive consists of a DC motor with the power of 200 W at the voltage of 12 V. This electric motor was selected in order to achieve the required power for the vehicle model. With regard to the concept of the drive, it is possible to choose from different vehicle operation modes. A vehicle can be operated as a mere electric vehicle (operated using the set of lithium batteries with the capacity of 16 Ah). Another option is the use of a fuel cell as the primary source of electric power for the electric motor. Fuel cells are suitable for mobile applications working at low operating temperatures. One of their benefits is achieving higher thermodynamic efficiency of the electrochemical reaction, as compared to the efficiency of the transformation of energy from a chemical bond into electrical energy using heat engines. The model was driven by the PEM DEA_0.5 fuel cell with the power of 500 W, providing the voltage of 12 to 16 V.

Low-pressure metal hydride tanks were primarily used; they contained 0.4 kg of intermetallic alloy consisting of LaCeNi and their hydrogen storage capacity was 1.43 % at the pressure of 1 MPa.

The volume of the metal hydride tank was 1.1 L. A single metal hydride tank can be used to store 42 L of gaseous hydrogen at the pressure of 1 MPa that facilitates approximately 40 minutes of vehicle operation. A pressure tank without the metal hydride alloy, but with the same parameters as the metal hydride tank, can be used to store only 10 L of gaseous hydrogen at the pressure of 1 MPa.

Storing hydrogen in metal hydrides is performed using the principle of absorbing atoms of hydrogen into interstitial spaces of the crystalline lattice in metals while hydrogen becomes a part of the chemical structure of such metals. Because hydrogen is released from metal hydride materials at low pressures, such materials basically belong to the safest systems for hydrogen storage.

Figure 3. PEM fuel cell and metal hydride tanks with the attachment.

2.2Control of the Vehicle's Drive

The control of the model of a hydrogen vehicle driven by a fuel cell and metal hydride materials is based on the pair of microcomputers, each one of them having a specific function. Raspberry Pi3 micro PC represents the access point that controls the vehicle using the application programmed in C++. Also, Raspberry Pi3 streams a video recording from the camera located in the vehicle to its own sub-network from where the video is broadcasted either from the cabin of the vehicle or as the view from in front of the vehicle. Raspberry Pi3 is also used to communicate with Arduino micro PC, i.e., with the hardware. Arduino is used to control the servo drive, power regulator for the electric motor, fuel cell, lights, sensors recording the temperature, hydrogen leaks, and other devices.

A non-conventional control of the model, using microcomputers, facilitates more precise recording of the electric motor operation in order to control the driving direction and facilitate accurate measurements and recording of the measured data, such as temperatures, pressures, flow rates, etc.

The control system also includes HS-7955 TGHightorque servo drive that is intended for controlling the driving direction of the model. To control the model, two servo drives were selected. The reason of using two servos was to ensure a sufficient force for turning the wheels at the given weight of the vehicle.

2.3System for Measuring Fuel Consumption for the Hydrogen Vehicle Model

For the purpose of measuring the consumption, we chose the system within which the measurements are carried out for the pressure of hydrogen in tanks and current temperatures inside the tanks. The model of the vehicle was subjected to the measurements of hydrogen consumption in the fuel cell during the operation, including the driveway, driving, acceleration and subsequent stopping. The data from the fuel cell and the values of the electric motor power were recorded automatically every 10 seconds. The power was recorded as the average value of the power within the period of ten seconds.

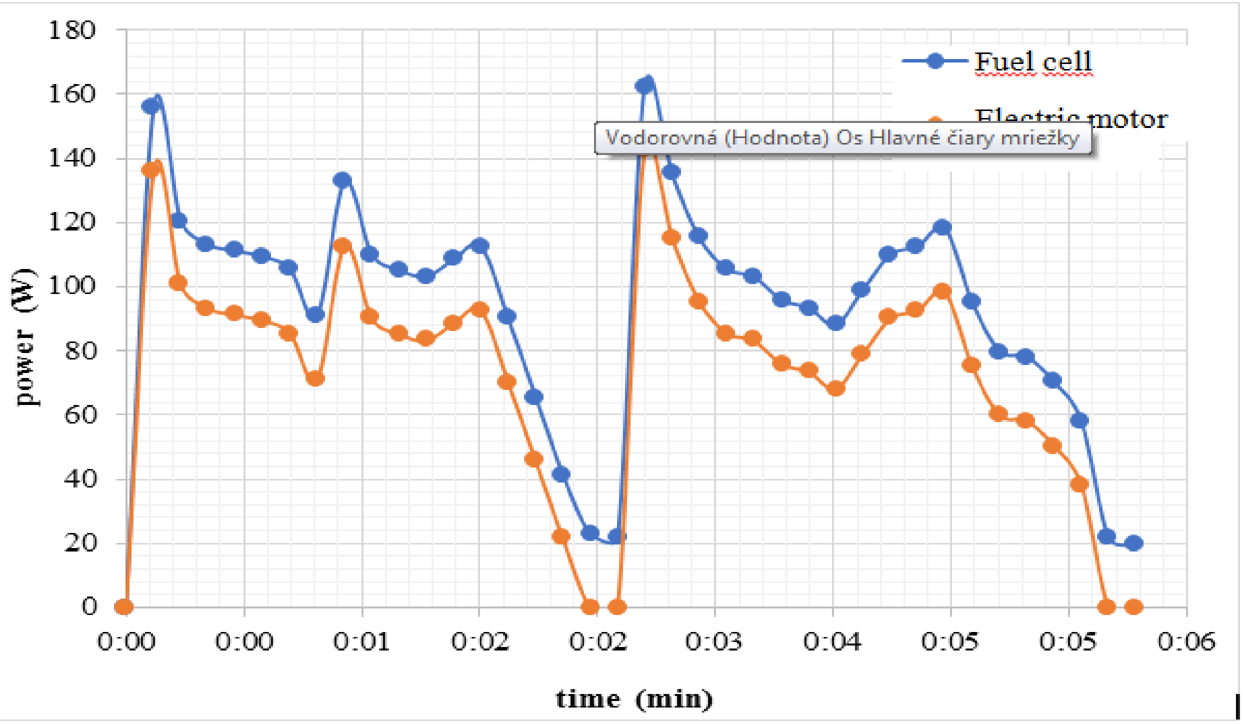

Figure 4. Curves of the fuel cell power and the electric motor power.

Following the measurements of the data regarding the fuel cell operation, it was possible to calculate the theoretical consumption of the fuel cell and the fuel cell operation time on the basis of the amount of H_2 and then compare such time with the real operation time.

The calculation was made to determine the weight of hydrogen contained in the tank which was identified as 2.7955 g at the temperature of 25 °C. On the basis of the subsequent comparison of the consumption figure and the amount of hydrogen contained in the tank, it was possible to conclude that the driving time of the model with the given amount of hydrogen is approximately 39 minutes. During experimental rides, the average driving time with the tank, in which hydrogen was under the pressure of approximately 3.15 MPa, was approximately 30 minutes.

Following the subsequent comparison of the theoretical driving time and the real measured time during which the fuel cell was able to supply electrical energy to the electric motor, it was possible to conclude that the real operation time of the fuel cell, as compared to the theoretical one, is 77 %. Such decrease could be potentially avoided by recuperation of hydrogen that was used for blowing through.

During the experimental measurements, the fuel cell temperature was rising. The maximum temperature of the fuel cell is 50 °C; however, as a result of cold weather, in none of the measurements the fuel cell temperature exceeded 50 °C, representing the maximum as well as the operating temperature. If the temperature exceeded 50 °C, it would result in triggering the fan that would substantially disturb the measurements because the consumption of the fuel cell would rise from the average value of 20 W up to the value of 100 W; this would significantly reduce the period during which it is possible to obtain energy from the fuel cell from the given amount of hydrogen.

3. Conclusion

The designed model of the vehicle provides an appropriate base for subsequent tests of hydrogen fuel cells, or, after small adjustments, also methyl alcohol fuel cells that might facilitate applications in smaller robotic devices in which the use of hydrogen is excluded for various reasons.

The structure of the chassis facilitates not only testing various fuel cell modules that may differ in fuel, arrangement or power but also testing various tanks, either high-pressure or low pressure – metal hydride tanks.

Due to the concept of the drive, it is possible to choose from different operating modes. The vehicle may be operated as a mere electric vehicle (operated using the set of lithium batteries with the capacity of 16 Ah). Another option is the use of a fuel cell as the primary source of electric power for the electric motor. Fuel cells are suitable for mobile applications working at low operating temperatures. One of their benefits is achieving higher thermodynamic efficiency of the electrochemical reaction, as compared to the efficiency of the transformation of energy from a chemical bond into electrical energy using heat engines.

The dimensions of the model in the scale of 1 : 6 facilitate easier performance of tests of various systems of fuel cells and metal hydride alloys because the measurement of relevant data does not require the use of larger amounts of costly metal hydride materials for the purpose of hydrogen accumulation in tanks.

4. Acknowledgement

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