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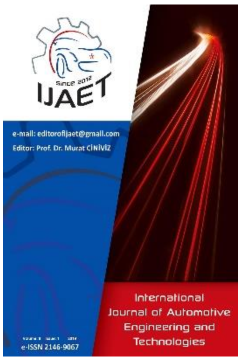

Original Research Article

Development of a Prototype Hydrogen Vehicle

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ABSTRACT

Developing technology, new technologies, and changing world standards have led researchers to search for new energy sources. In addition to countries such as America, Germany, and Japan, most automobile manufacturers have been able to adapt to changing standards, have done major researches on alternative energy vehicles, and have started to market their products. In this study, a prototype hydrogen vehicle was developed for TÜBİTAK Efficiency Challenge Electric Vehicle Organization. Design criteria were determined within the limits of the competition rule book. A computer-aided design (CAD) program was used in the vehicle shell and mechanical part designs. Vehicle flow analysis was carried out with the help of computational fluid dynamics (CFD) program. Laboratory condition long-term performance test of the fuel cell has been carried out and whether the fuel cell power was sufficient for the vehicle.

Keywords: Prototype, Hydrogen, Fuel cell vehicle, Proton Exchange Membrane fuel cell

1. Introduction

Most of the energy requirements of the world have been met by fossil fuels such as petroleum, coal, etc. Although their frequent usage all over the world, they have lots of undesirable effects as releasing pollutants locally and greenhouse gas effect globally [1].

On the other hand, fossil fuel depletion depending on excessive usage has appeared as a critical concern to be overcome by scientists recently. Researchers intensely work to find alternative energy sources to replace the conventional fuels for the solutions of both economic and environmental issues. On this way, there are various alternative energy sources which are possible candidates for the replacement of petroleum-based fuels such as biodiesel, various alcohols (methanol, ethanol, butanol, dimethyl ether, etc.), SNG (synthetic natural gas), and hydrogen [2].

Hydrogen is outshining alternative resource among of all with its excellent properties. Wider range of flammability levels, high laminar flame speed, and its molecular structure make it proper for direct usage with a dual-fuel mode in internal combustion engine applications. It is a carbonfree fuel source which means that there is no hydrocarbon, carbon monoxide, and carbon dioxide emission release towards nature as a result of the combustion process [3].

Besides direct usage of hydrogen in internal combustion engines as fuel, another possible way to reduce the dependency of fossil fuels is passing through fuel cell technology which consumes hydrogen to produce electricity. Fuel cells can be defined as devices which conduce to static energy conversion between chemical reaction of fuels and electrical energy by emitting only water as a product [4]. Literature survey showed that there has been a huge effort on the study of fuel cell technology recently [5–9].

The main classification of fuel cells with respect to their electrolyte and fuel types can be accomplished as the following: Proton exchange membrane, alkaline, phosphoric acid, molten carbonate, solid oxide, and direct methanol fuel cell [4]. Especially, proton exchange membrane (PEM) fuel cells bring notable advantages like fast start-up, increased efficiency, higher power density, reduced operation temperature, ease, and safe handling [10].

Electric vehicles (EVs) and hydrogen fuel cell electric vehicles (HFCVs) which have no tailpipe exhaust emissions have been prominent lastly. Although some problems are being faced with by searchers with the use of EVs such as high cost, battery charging times, ranges of driving, extra weights generated by battery packages, and infrastructural deficiencies (limited charging stations), HFCVs offer remarkable superiorities over EVs as less time for refueling and more driving distances [11].

Its contribution to the literature is undeniable to the studies conducted in student-centered organizations around the world such as the Shell Eco-Marathon, Formula Student, and TÜBİTAK Efficiency Challenge. Gencer et al. [12] investigated experimentally and numerically analysis of the aerodynamic performance of an electric vehicle. They obtained a drag coefficient of 0.227882 which is smaller than a general passenger vehicle with improved aerodynamics of 0.25. This is a very useful value, especially for an efficiency competition. Acer et al. [13] conducted a study about the design and optimization of a wheel hub for TÜBİTAK Efficiency Challenge electric vehicles. At the end of the study, they presented a lighter and safer product with Al 7075 material for the wheel hub. With a lighter wheel hub, they have achieved less energy consumption in the efficiency challenge.

In this study, a prototype hydrogen vehicle was developed by undergraduate students directed by supervisors for the competition organized by TÜBİTAK. A PEM fuel cell was used as a propulsion system according to the advantages supplied by them. The design of the vehicle, shell-frame drawings, and many tests were conducted by the students and academicians withal.

2. Materials and Methods

2.1. Materials

2.1.1. Motor

The electric motor that provided the movement of the vehicle was obtained from a local company. The electric motor used to move the vehicle is shown in figure 1.

Figure 1. Electric Motor (Mitsuba)

The technical specifications of the electric motor are listed in Table 1.

Table 1. Technical specifications of electric motor

Motor Code	M0548-II
System Outline	1000W 48V
Dimensions	φ262mm×L47mm
Weight	7.4 kg
Maximum Power	2000 W
Maximum Efficiency	96% (Only Motor)
Nominal Rotating Speed	675 Rpm
Rotating Direction	Forward: Left Turn

2.1.2. PEM fuel cell

A PEM fuel cell that converts the chemical energy of hydrogen into electrical energy is used to produce the electrical energy required for the motor. The PEM fuel cell used to power the electric motor is shown in figure 2.

Figure 2. H-1000 XP PEM fuel cell

The technical specification of the PEM fuel cell is given in Table 2.

Table 2. Technical specification of H-1000 XP

Number of cells	50
Dimensions	264mm x 203mm x 104mm
Weight	Stack less than 4.9 kg System less than 6.8 kg
Peak power	1100 kW
Rated current	0 – 33.5A @ 30V
DC voltage	25V-48V
Reactants	Hydrogen and Oxygen
Composition	99.99 % dry H_2
Humidification	Self-humidified
Cooling	Air
Start-up battery	12V

2.1.3. Material selection for vehicle other parts

It should be noted that the weight of the vehicle is very important in order to minimize energy consumption since TÜBİTAK competition is not a speed race but an efficiency challenge. Therefore, the materials to be used in the vehicle parts must be light and at the same time strong in terms of safety. In Table 3 selected materials for different vehicle parts are listed.

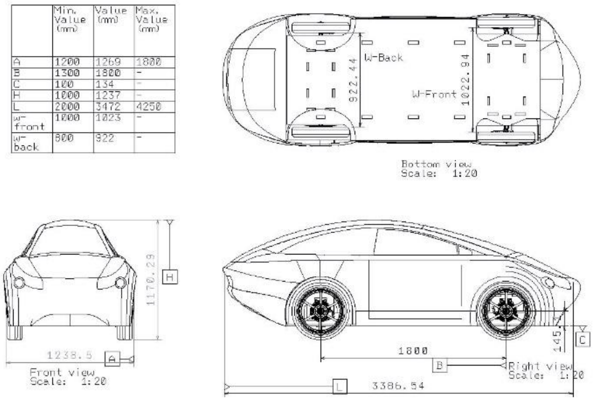
Table 3. Selected materials

Vehicle part	Material
Chassis	Carbon Fiber
Shell	Carbon Fiber
Rim	Aluminum 6061 T6
Wheel hub	Aluminum 7075 T6
Axle	Steel 4140
Spindle	Aluminum 7075 T6
Lower and upper swing	Aluminum 7075 T6

2.2. Methods

2.2.1. Design of the vehicle

All parts of the vehicle were designed with a computer-aided design (CAD) program according to TÜBİTAK competition rules and technical drawings of the full vehicle are shown in Figure 3.



	Min. Value (mm)	Value (mm)	Max. Value (mm)
A	1200	1269	1800
B	1300	1800	-
C	100	134	-
H	1000	1237	-
L	2000	3472	4250
w-front	1000	1023	-
w-back	800	922	-

Figure 3. Technical drawings and views of the vehicle

Additionally, roll bars are the critical elements of the design of the vehicle, and drawing of the roll bars was also done with the CAD program, and its representation on the vehicle chassis is given in Figure 4.

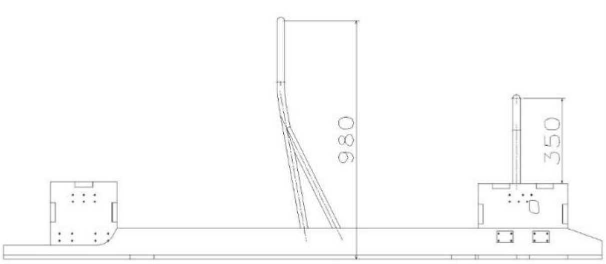


Figure 4. Dimensions of roll bars

2.2.2. Calculation of drag coefficient

CFD method was used to calculate the drag coefficient of the vehicle. The following variables were used for analysis and in order to achieve faster analysis results, the vehicle was divided into 2 symmetric parts. The vehicle geometry before starting the analysis is shown in figure 5.

Velocity: The vehicle needs to move approximately 55 km/h on the track, therefore the velocity is defined as 15.27 m/s.

Front Area: A = 0.66 m^2

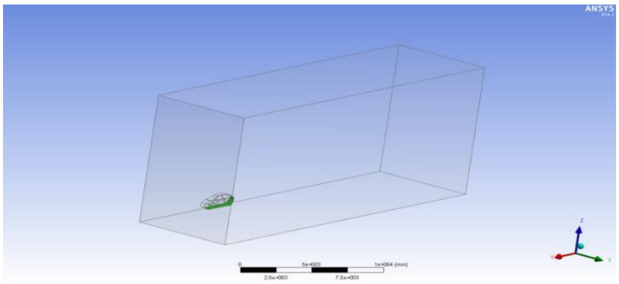


Figure 5. Vehicle geometry before analysis

3. Results and Discussions

3.1. The shell of the vehicle

The shell is made of carbon fiber material, which makes the vehicle lighter. The production process was handled by a local company in Adana Metal Industry Site. A male mold was produced to get female molds that are required to produce the shell (Figure 6).

Figure 6. Production of shell

3.2. Structural analysis of mechanical parts of the vehicle

3.2.1. Roll bars

The required analysis was done with the aid of the static structural module of ANSYS. 1 kN point load was applied between the upper point and lowest point of roll bars according to competition rules.

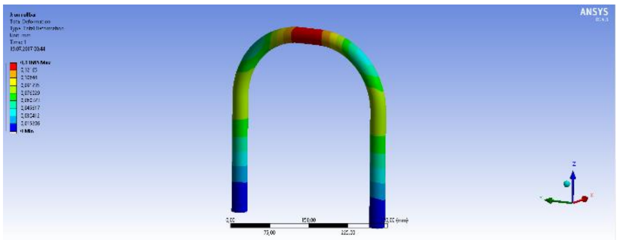


Figure 7. Deformation analysis of front roll bar

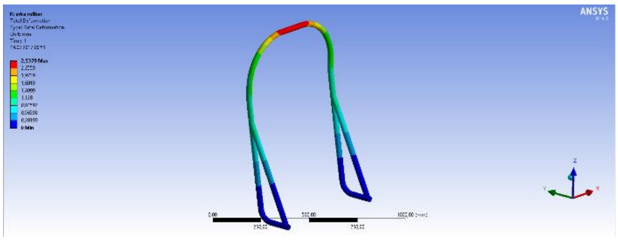


Figure 8. Deformation analysis of rear roll bar

Figure 7 and 8 show that the calculated maximum deformation of front and rear roll bars are 0.13685 mm and 2.5379 mm, respectively. It was conducted that the displacement level did not exceed the defined limits.

3.2.2. Other parts

Table 4 shows the results of the analyses made on the parts of the vehicle exposed to the highest load due to vehicle and driver weights.

The results obtained showed the strength of the produced parts within the desired limits.

Table 4. Structural analysis results of other parts of the vehicle

Part Name	Deformation (mm)	Equivalent (Von-misses) Stress (MPa)
Rim	2	139
Wheel hub	0.03	23
Axle	0.16	233
Spindle	0.02	64
Lower swing	0.03	37
Upper swing	0.4	75
Lower bracket	0.003	15
Upper bracket	0.11	211

3.3. Performance tests of PEM fuel cell

Performance tests were carried out in a laboratory condition due to the long duration of the tests. An electronic load was used to load the PEM fuel cell. It was observed that the fuel cell operates stably in each load range and the graph of hydrogen consumption values is given below.

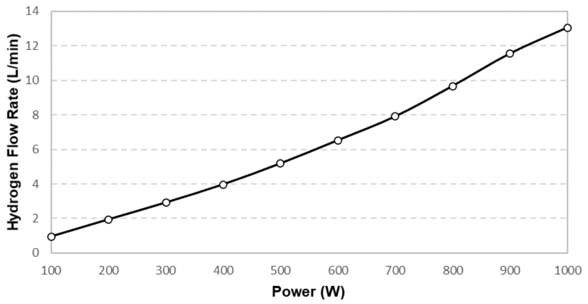


Figure 9. Hydrogen Consumption

In Figure 9, it can be easily seen that the need for hydrogen has also increased with the increase in power at room temperature (25 °C). The fuel consumption can be varied with ambient temperature since high ambient temperature will require higher fan power consumption in order to cool fuel cell and also it will affect the fuel cell stack performance.

Figure 10 shows the consumption of both air and oxygen versus power. Oxygen usage was lower than air usage.

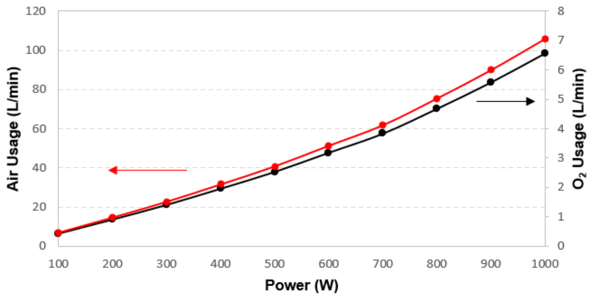


Figure 10. Air and Oxygen Usage

Because PEM fuel cell uses oxygen from the air to compound with hydrogen in order to generate electricity. Then remaining air is used to cool the fuel cell stack.

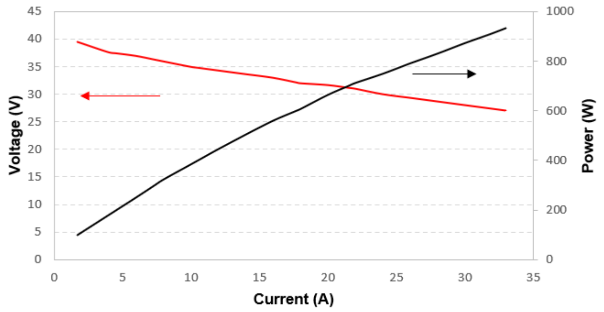


Figure 11. Polarization curve of fuel cell

Figure 11 shows the polarization curve of the fuel cell system operating at the nominal conditions of the fuel cell at normal room temperature. At low power densities, the cell potential decreases as a result of activation losses and at moderate current, the cell potential drops with current due to ohmic losses, and finally, at high current levels, the cell potential drops as a result of concentration losses. Due to all these losses, when the fuel cell is operated in high power bands, this will result in decreases in cell potentials.

4. Conclusion

At the end of this project, a two-seater automobile with a weight of about 165 kg was introduced. The prototype vehicle, created with the help of three-dimensional design and static analysis, and CFD analysis, has been successfully installed in TÜBİTAK efficiency challenge. Targeted studies and outputs were also provided at the beginning of the project and a prototype hydrogen vehicle was manufactured.

As a result of CFD analysis, the C_d coefficient was calculated as 0.21 and this value was observed to be at an acceptable level for today's standards. The design with a 0.21 drag coefficient reveals the novelty of the study.

For lightweight vehicle, the material selection is the key factor, and it was concluded that light materials such as carbon fiber and aluminum used in this project respond to this low weight requirement.

It was accomplished that the performance results of the fuel cell were sufficient for the vehicle after the tests were completed.

Acknowledgement

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