MECHANICAL DESIGNS AND FUEL CELL TEMPERATURE CHARACTERISTICS OF SINGLE PERSON OPERATED FUEL CELL VEHICLE WITH 1kW FUEL CELLS (micro FCV)

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1. Introduction

We have developed a single person operated small fuel cell vehicle which uses a 1 kW fuel cell. The hydrogen used for the fuel cell is produced by a water electrolysis hydrogen generator using a solar powered energy source. The advantage of using a solar powered energy source is that it produces power without requiring use of fossil fuels.

Most of the observed increases in global average temperatures are very likely correlated with the rise in anthropogenic greenhouse gas concentrations in the Earth's atmosphere. One of the primary contributors to the emission of these gases is fossil fuel combustion. Thereafter, a vehicle using the internal combustion engine must be replaced with more ecological system in order to reduce greenhouse gas (e.g., carbon dioxide) emissions. As a result, fuel cell electrical vehicles (FCV) are becoming one promising technologies for reducing the carbon dioxide emissions. Several large automobile enterprises and research institutes are developing fuel cell electrical vehicles [1-6]. As they are researching high powered fuel cells in the 100 kW class, the cost of these vehicles may be prohibitive for some consumers. It is essential, thereafter, to reduce the cost of fuel cell vehicles. The purpose of our research is to develop a low cost fuel cell vehicle using a low powered fuel cell. Taiwan University developed a small fuel cell scooter with two wheels [7]. The developed fuel cell scooter is permitted to run on a public roads despite its use of a small fuel cell in the 2 kW class.

Our aim is to develop a small fuel cell vehicle using four wheels which will be permitted to operate on a public road. We have already developed fuel cell vehicles for Japanese light weight electrical vehicle competitions. The designed systems were single person operated vehicles with fuel cells of rated power 200 W [8] and 20 W [9, 10]. We have been also developing a hybrid wheelchair which utilizes a photovoltaic and a fuel cell [11-13]. We have now started to develop a micro car class fuel cell vehicle which will use a 1 kW fuel cell (named the micro FCV). The micro FCV is a single person ride vehicle which will be permitted to operate on a public road. The micro FCV uses a fuel cell when operating a flat road at constant speed, however uses a battery when it accelerates or climbs a steep slope. We have improved a purchased micro car braking system and the hydrogenous piping system as well as experiments conducted on electricity generation by the fuel cell. Structural analysis was conducted, and showed the design to be safe. Electricity generation characteristics of the fuel cell dependent on ambient temperature was observed.

2. Developed micro FCV

Fig.1 shows the photograph of the developed micro FCV. The Milieu R of the Takeoka Jidosha Kogei Corporation was purchased, and converted to a fuel cell electric vehicle. The Milieu R is a micro car class electric vehicle driven by a motor using below 0.6kW. Fig. 2 shows the mechanical configuration of the micro FCV. The battery was set under the seat. The fuel cell, the hydrogen tanks, and the control systems were set at the back of the seat. The micro FCV has a hybrid energy system which uses a battery and a fuel cell. The battery system is used when a large amount of power is required, e.g. situations of acceleration or steep slope climbing. The fuel cell system is used when the required power is below 1 kW.

Fig. 1: Photograph of developed micro FCV

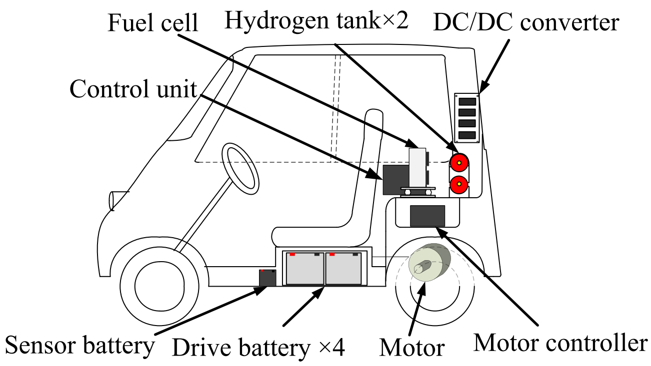


Fig. 2: Mechanical configuration of developed micro FCV

3. Hydrogen Piping System Designs

Fig.3 shows the hydrogen piping system of the micro FCV. A regulator reduces hydrogen pressure in the hydrogen tanks to between 0.05 to 0.065MPa. The hydrogen is then supplied into the fuel cell. A mass flow meter measures the hydrogen consumption rate in the fuel cell which is displayed on the segment. Fig.4 is a photograph of the hydrogen piping system. The regulator, the mass flow meter, and the valve were fixed on a wall inside the vehicle body.

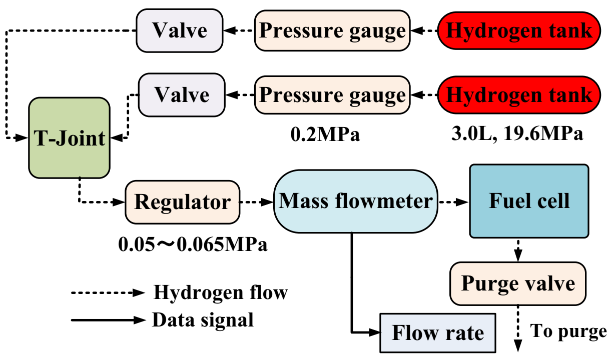


Fig. 3: Hydrogen piping system of micro FCV

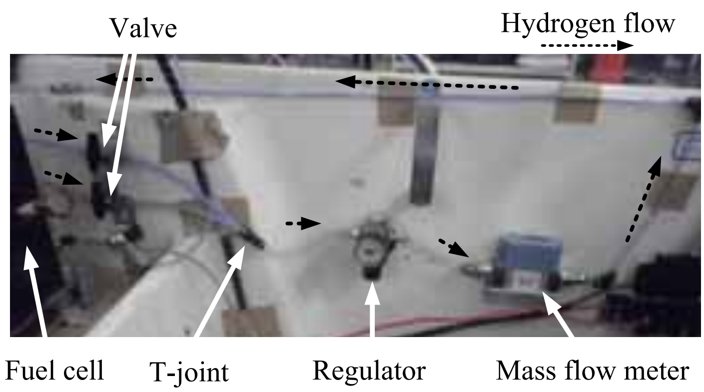


Fig. 4: Photograph of hydrogen piping system

4. Braking System Designs

In order to reduce the running resistance, it is very essential to reduce the weight of the overall vehicle. Therefore, we redesigned the rotating parts and suspension system with lightweight components. The tire and wheel systems were replaced with smaller wheels and tires as well as lightweight components. The front braking systems was converted from a drum brake to a disk brake. An adapter was designed to attach the new wheels and the drum brake. Fig.5 shows the braking systems and the actuator system of the micro FCV. A three dimensional CAD was used to design the front braking systems after measuring the existing braking components. Next, the designed model was assembled based on the CAD design. Figs.6 and 7 show the modeling diagram of the front and rear braking systems respectively. Al5056 was used to produce the components of the hub, handle-arm, knuckle, caliper-jig, and adapter as it is corrosion resistant. SUS440C was used to produce the disk as it is abrasive. Finally, SCM440 was used to produce the shaft in order to provide the necessary strength required. The designed components were produced using a lathe and a milling machine. The knuckle and the hub were fabricated using an NC machine tool to create their curved surfaces.

Figs.8 and 9 are the before and after images of the replacements to the braking system. The weight of the overall suspension system was decreased 31%.

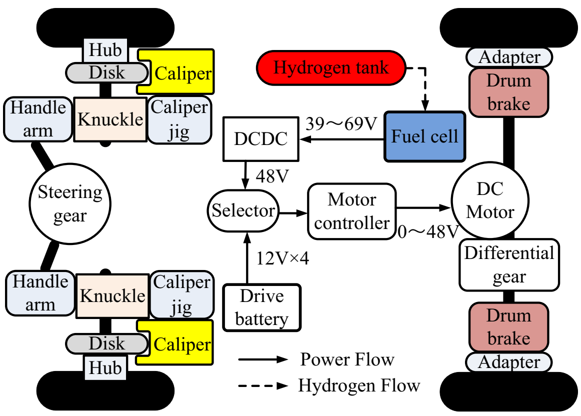


Fig. 5: System configuration of developed micro FCV

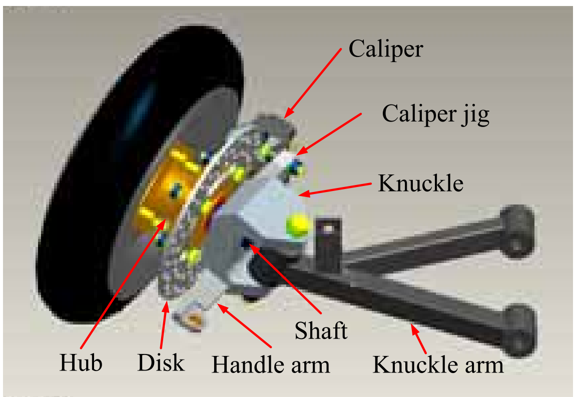


Fig. 6: Modeling diagram of front braking system

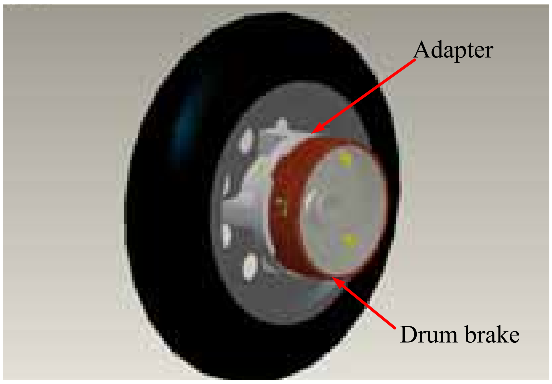
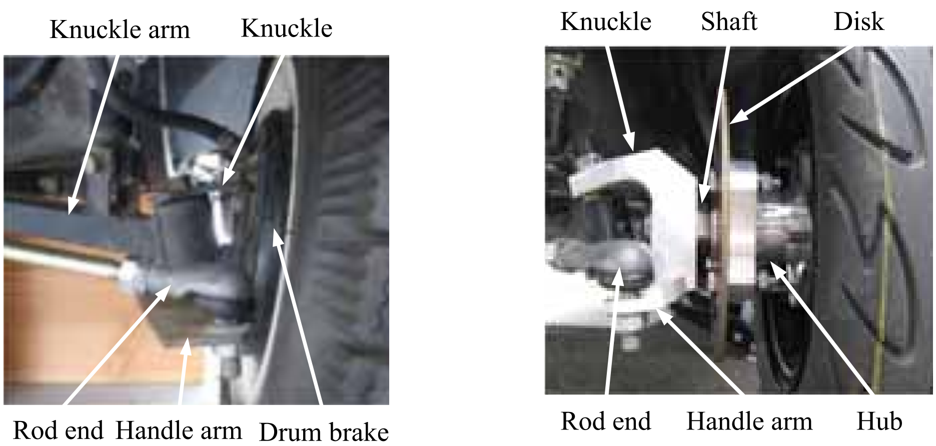
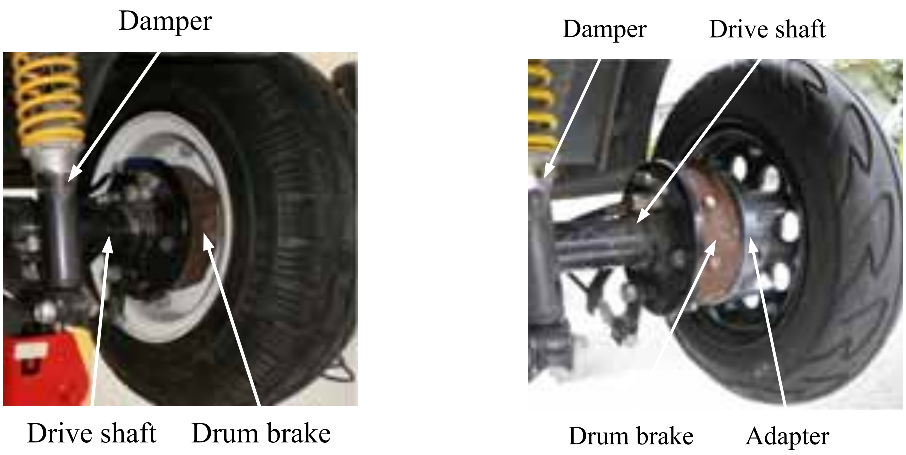


Fig. 7: Modeling diagram of rear braking system



(a) Before improvement (b) After improvement

Fig. 8: Photographs of front braking system



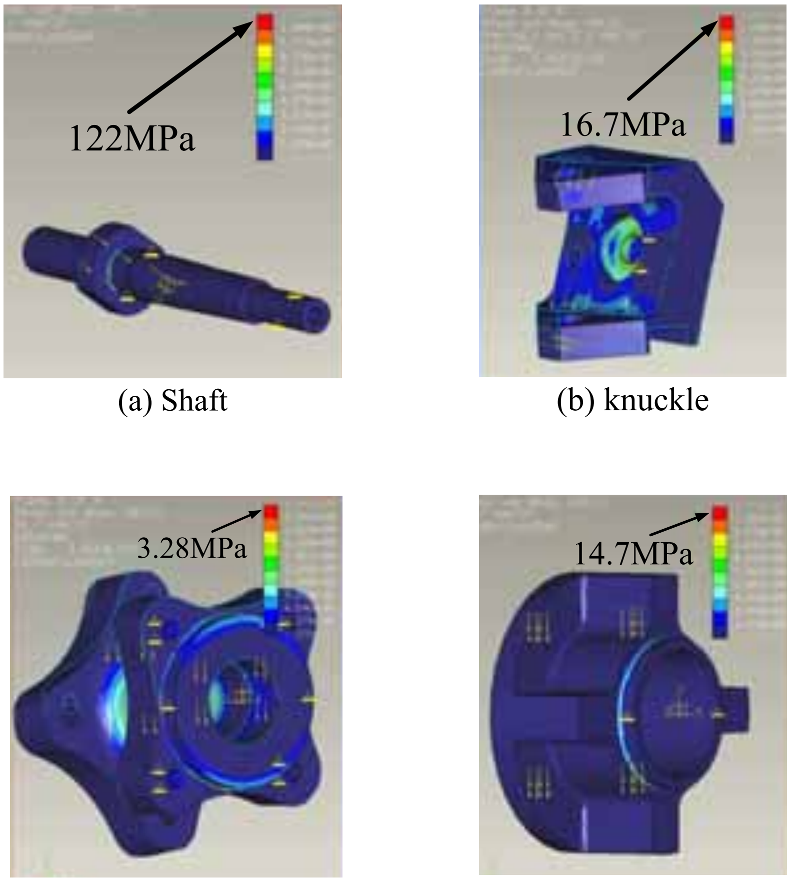
(a) Before improvement (b) After improvement

Fig. 9: Photographs of rear braking system

5. Strength Analysis of Lightweight Design Components

Strength analysis of the braking system components was conducted in order to confirm their safety. Static and dynamic analyses were conducted. The shaft, knuckle, hub, and adapter were tested using static analysis, and the hub, caliper-jig, and adapter tested using dynamic analysis. Both models were formulated utilizing static and braking wheel loads. The braking load was determined by the deceleration force, which is calculated by assuming a braking distance of 5m from a velocity of 30km/h.

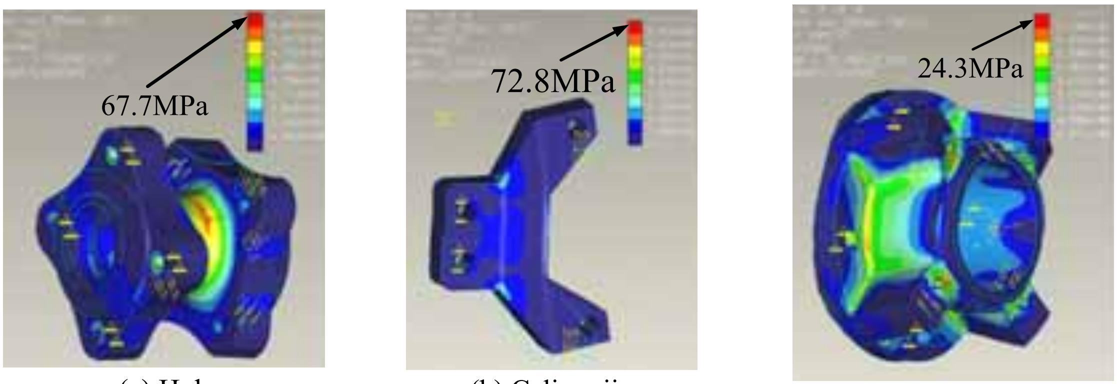
Figs.10 and 11 show the stress simulation results of the static and the braking loads. The safety factors were determined using the stress simulation results. The safety factors of the shaft, knuckle, hub, and adapter were respectively 6.84, 14.7, 74.9, and 16.7 with respect to the static load. The safety factors of the hub, caliper, and adapter were respectively 3.62, 3.37, and 10.1 with respect to the braking load. We confirmed that the designed braking components met their safety factor requirements. However, the safety factors of the hub, the knuckle, and the adapter exceeded their limits, and therefore must be redesigned.



(a) Shaft (b) knuckle

(c) Hub (d) Adapter

Fig. 10: Simulation results of static load



(a) Hub (b) Caliper jig (c) Adapter

Fig. 11: Simulation results of braking load

6. Braking tests

Braking test experiments were conducted to confirm the performance of the newly designed braking system. Fig.12 shows the experimental method of the braking test. When the vehicle passes the starting line, it begins to stop using the braking system. The stopping distance is measured as the distance from the starting line to the stopping position. Braking tests were conducted at a velocity of 30km/h on a dry test road.

Fig.13 shows the experimental results of the braking test. The braking distance before the improvements was 4.5m. The braking distance after the improvement was 2.3m. We confirmed that the new braking system improved performance by nearly a factor of 2.

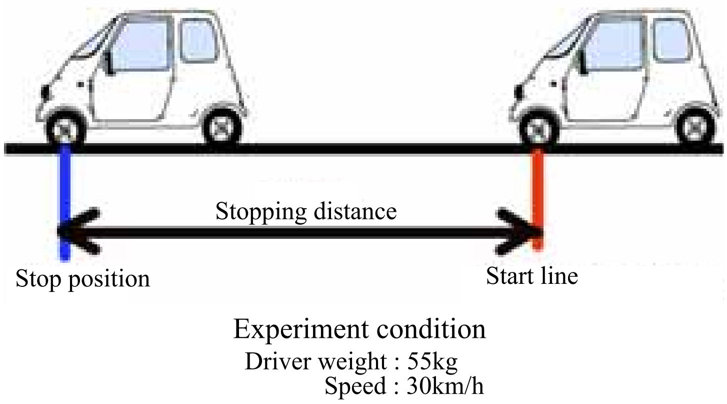


Fig. 12: Experimental method of braking test

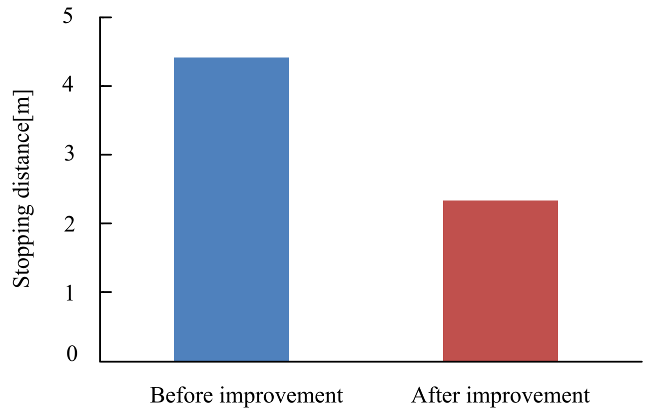


Fig. 13: Experimental results of braking test

7. Participation to JISFC2010

(Japan Inter-College Solar & Fuel Cells Car championship)

The micro FCV participated in the JISFC2010 (Japan Inter-College Solar & Fuel Cells Car Championship) to evaluate its long distance running performance. The JISFC is held at the solar sports line in Ogata village, Akita prefecture every year. The course is mostly flat, and one lap is 25 km. Participant vehicles run twenty five hours over three days. The micro FCV was able to run two laps (50 km) of the course over a running time of five hours in total. The temperature at the course was approximately 35º C.

8. Experiments of Electricity Generation Characteristics of Fuel Cell Dependent on Ambient Temperature

The fuel cell generates heat when it generates electricity. The characteristics of the fuel cell vary dependent on ambient temperature. It is therefore important to examine these characteristics. A Horizon H-1000 fuel cell stack was used for these tests. Its specifications are shown in Table 1.

Fig.14 shows the experimental set up. The experiments were conducted in an experimental room. The room temperature was set at 6.5, 10, 15, 20, 25, and 30º C. The fan voltages of the fuel cell were set at 0, 3.5, 6, 9, and 12V. An electronic rated load of 1 kW was used. The electronic load was increased from 50 W to 900 W each minute. When the fuel cell was unable to generate electricity, the experiment was stopped. The values of the fuel cell voltage, current, hydrogen consumption rate, fuel cell stack temperature, humidity, fan voltage, and current were recorded using a data logger. Electricity generation performance decreased when the non-active gas is increased in the fuel cell. The non-active gas was purged, therefore when the electricity increased.

Table 2 shows the experimental results of the relationship between the air velocity and the fan voltage. This relationship was proportional. Fig.15 displays the experimental results of the fuel cell at the temperature of 20º C and the fan voltage of 12V. Figs.16 and 17 depicts the maximum power and temperature of the fuel cell which were related to the fan voltage and the ambient temperature. The fuel cell was able to generate 900W under the conditions: (a) the temperature was between 6.5 and 10º C, and the fan voltage over 9V, and (b) the temperature was between 15 and 20º C, and the fan voltage 12V. However, the fuel cell was not able to generate 900W at the temperature between 25 and 30º C.

We confirmed that the fan was able to cool down the fuel cell sufficiently at a temperature between 5 and 20º C, however it was not able to cool down at a temperature between 25 and 30º C. When the fan voltage is over 12 V, it is required to keep the fuel cell temperature below 38º C to obtain maximum electricity (see Figs.16, 17 (d)). When the fan voltage is at 0, 3.5, and 6V, however, the fuel cell is not able to generate maximum electricity regardless of the temperature being below 38º C (see, Fig.16, 17 (a), (b)). Therefore, it is necessary to use a fan, and to keep the fuel cell temperature below 38º C in order to obtain the maximum electricity.

Table 1: Specifications of fuel cell stack (Horizon H-1000)

Type of fuel cell	PEM
Number of cells	72
Rated power [kW]	1
Rated performance	43V@23.5A
Output voltage range [V]	39～69
Weight(with fan) [kg]	4.7
Size [mm]	256×220×122
Reactants	Hydrogen and Air
Rated H2 consumption [L/min]	14
Hydrogen pressure [MPa]	0.05～0.065
Ambient temperature [deg.C]	5～30
Max. stack temperature [deg.C]	65
Hydrogen purity [%]	99.999 dry H2
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Start up time	immediate
Efficiency of system [%]	40@43V

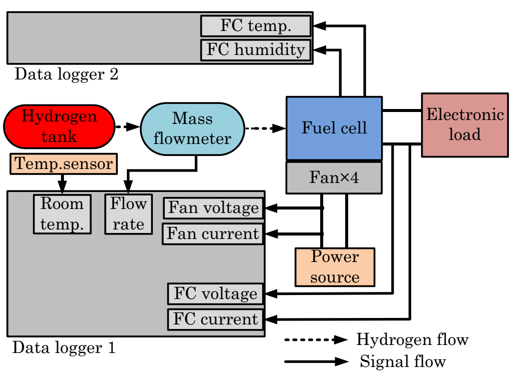


Fig. 14: Experimental set up

Table 2: Relations between air velocity and fan voltage

Fan voltage [V]	3.5	6	9	12
Air velocity [m/s]	1	2	3.7	4.8

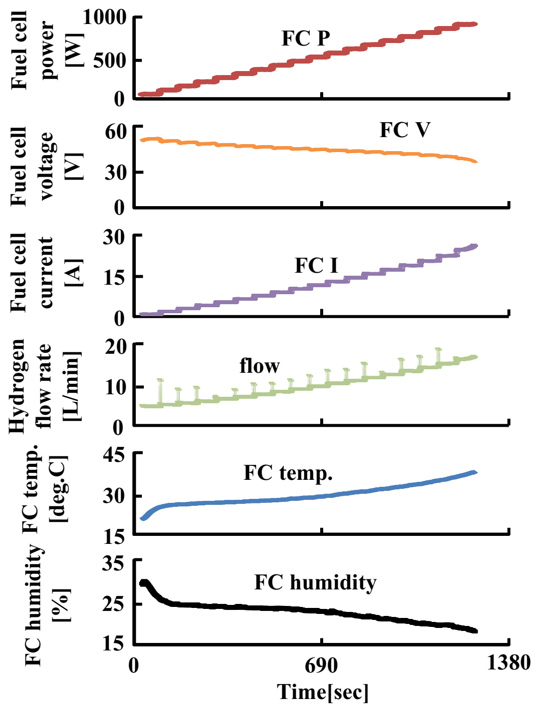


Fig. 15: Experimental results of fuel cell (room temp. 20deg.C, fan voltage 12V)

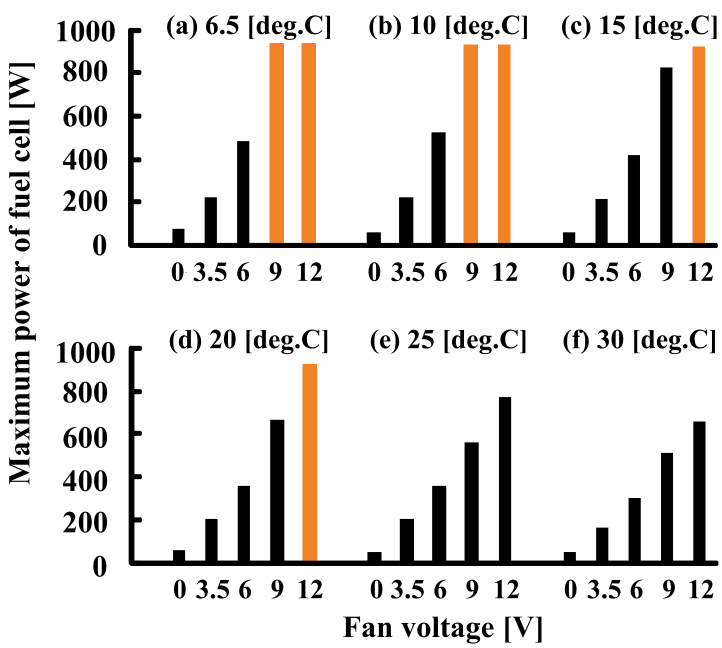


Fig. 16: Maximum power of fuel cell

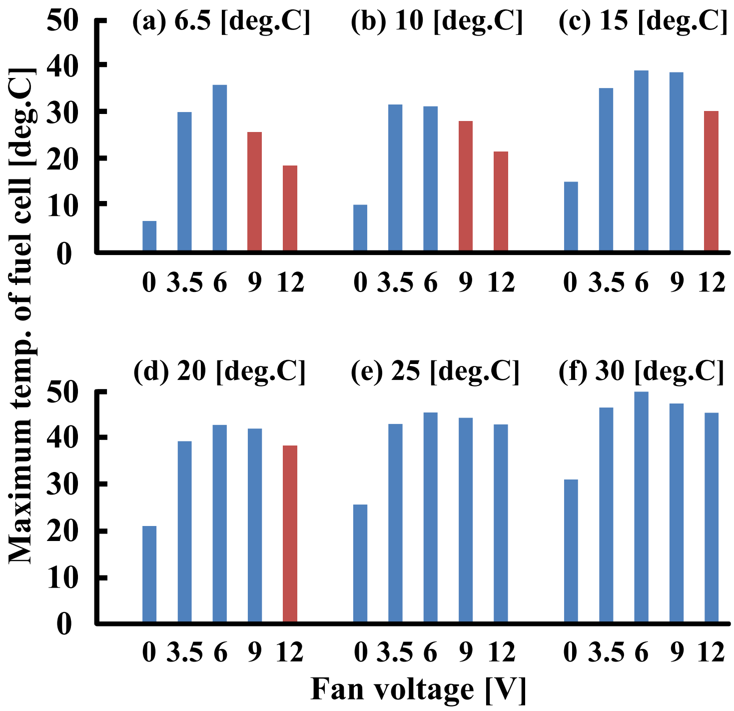


Fig. 17: Maximum temperature of fuel cell

9. Conclusions

An approximately 30 % reduction in weight as the result of redesigning the braking system with lighter components was achieved. The designed components met safety requirements. The performance of the braking system was improved by nearly double. The developed micro FCV participated in the competition of the JISFC2010, and was able to run 50 km. Characteristics of the fuel cell were examined. We confirmed that the characteristics of the fuel cell are strongly dependent on the ambient temperature and the cooling fan voltage. We are now considering a water cooling system to obtain enough electricity.

10. Acknowledgement

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REFERENCES

[1] Kotz, R., Muller, S., Bartschi, M., Schnyder, B., Dietrich, P., N.Buchi, F., Tsukada, A., G.Scherer, G., Rodatz, P., Garcia, O., Barrade, P., Hermann, V., Gallay, R., 2001. Supercapacitors for peak-power demand in fuel-cell-driven cars, Electrochemical Society Proceedings, Vol.2001-21, pp.564-575

[2] Rodatz, P., Garcia, O., Guzzella, L., Buchi, F., Bartschi, M., Tsukada, A., Dietrich, P., Kotz, R., Scherer, G., Wokaun, A., 2001. Performance and operation characteristics of a hybrid vehicle powered by fuel cells and supercapacitors, Soc. of Automotive Eng. 2003 Congress, SAE Paper 2003-01-0418, pp.1-12

[3] Tabo, E., kuzuoka, N., Takada, M., and Yoshida, H., 2004. Fuel cell vehicle technology trends and MMC initiatives, Mitsubishi Motors Technical Review, No.16, pp.51-55

[4] Okabe, M., Nakazawa, K., Taruya, K., Handa, K., 2008. Verification test of solar-powered hydrogen station (SHS) with photovoltaic modules, Honda R&D Technical Review, Vol.20, No.1, pp.67-73

[5] Emadi, A., Rajashekara, K., S.Williamson, S., and M.Lukic, S. 2005. Topological Overview of Hybrid Electric and Fuel Cell Vehicular Power System Architectures and Configurations, IEEE Trans. On Vehicular Technology, vol.54, no.3, pp.763-770

[6] C.Chan, C., 2007. The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles, Proc. of IEEE, pp.704-718

[7] H.Cheng, J., Y.Yu, C., and Hsu, V., 2009. Energy Management Algorithm for a Hybrid Fuel Cells Scooter, Int. IEEE Vehicle Power and Propulsion Conf., pp.370-375

[8] Takahashi,Y., 2009. Ultra Light Weight Fuel Cell Electrical Vehicle (UL-FCV), IEEE Int. Symposium on Industrial Electronics, pp.189-194

[9] Takahashi, Y., 2009. Environmental System Education using Small Fuel Cell Electrical Vehicle, J. of Fuel Cell Technology, vol.9, no.1, pp.128-131 (in Japanese)

[10] Takahashi, Y., and Nishimura, I., 2010. Economic Running Competition of Single Person Operated Ultra Small Fuel Cell Electrical Vehicle with 20 W Fuel Cell (Pico FCV), J. of Fuel Cell Technology, vol.10, no.2, pp.113-121 (in Japanese)

[11] Takahashi, Y., Matsuo, S., and Kawakami, K., 2008. Hybrid robotic wheelchair with photovoltaic solar cell and fuel cell, Int. Conf. on Control, Automation and Systems, pp.1636-1640

[12] Takahashi, Y., Matsuo, S., and Kawakami, K., 2010. Energy Control System of Solar Powered Wheelchair, Solar Energy, Intech, pp.134-144

[13] Takahashi, Y., and Matsuo, S. 2011. Running Experiments of Electric Wheelchair Powered by Natural Energies, IEEE Int. Symposium on Industrial Electronics, pp.945-950