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Fuel Cell System for Two-Wheeled Vehicles

Yasuyuki MURAMATSU, Masatsugu OHISHI and Shuhei ADACHI

Yamaha Motor Co., Ltd.

Direct methanol fuel cell (DMFC) system is a compact lightweight system as it eliminates the need of a complex reformer unit. Moreover, since the methanol-water-solution used as fuel does not correspond to a flammable substance, it is thought that convenience is high.

We have developed the hybrid scooter integrated with the DMFC system and the Li-ion rechargeable batteries, and optimized various parameters related to the performance and the efficiency. The power output of the DMFC system was adjusted to the value necessary for a constant ground run in 30 km/h of a commercial small electric scooter. All the system components had to be constituted in the limited space and under the restricted weight conditions.

The net-power-output of the system was examined under various air flow rate, fuel flow rate and methanol concentration conditions. We confirmed that the maximum net-output of the system was obtained at a condition different from one at the maximum gross-output conditions, because the increase of the gross-output had been accompanied by the increase of the auxiliary power consumptions. It was clearly found that the trade-off relation of the gross-output increase and the auxiliary power consumption increases must be considered to set up the optimized operating condition of the system.

Keywords: Direct methanol fuel cell, small electric scooter

1. INTRODUCTION

Fuel cells are the focus of much attention today as next-generation energy conversion devices. We have been involved in research into the performance of fuel cell systems based on the idea of powering a small electric vehicle with a 500W class fuel cell. The fuel cell we used in our research was a direct methanol type fuel cell (DMFC). This is a fuel cell capable of generating electricity by supplying a fuel solution of methanol and water directly into the cell stack, and because the fuel supply system of the DMFC can be more compact than that of a fuel cell that runs directly on hydrogen as its fuel, the DMFC can be made into a more compact system overall. (1*)(2*)

It is known that a number of operating parameters like fuel concentration and air flow influence the performance and efficiency of a fuel cell. (3*)

For this study, we created a fuel cell system with the stacks necessary to generate enough electricity to power a small electric vehicle and the auxiliary equipment that could be mounted on such a vehicle. Then, by optimizing the various main parameters we brought it to a generating condition that produced the highest net output.

This is a report of our lab test results in obtaining the conditions of maximum output from a system made up of components that could be mounted on a small electric vehicle. We also discuss the energy efficiency of a fuel cell system for mounting on a vehicle.

2. EXPERIMENT

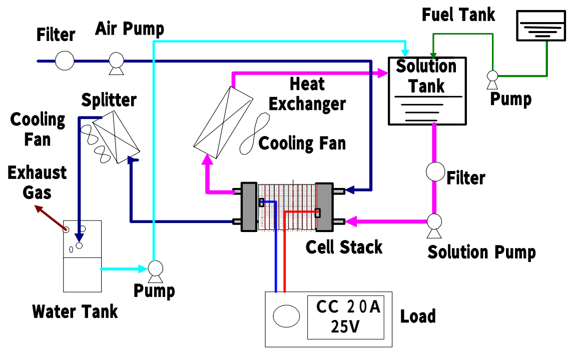

Fig.1 Configuration of the test set-up

We know that the performance of a fuel cell stack depends on a number of parameters. In order to be able to freely control the generating conditions of the fuel cell stack we created a test system for evaluation in the lab. Fig. 1 shows the test device system.

In this study we investigated the effect of concentration of the fuel-water solution and air flow rate on the performance of the system and determined the conditions that produced the largest net output for the system.

3. EXPERIMENTAL RESULTS

3-1. DEFINITIONS

NET output for the fuel cell system is defined as follows.
Qnet = Qa - Qb
where Qnet is fuel cell NET output (W).
Qa is output at the fuel cell stack's terminal (W).
Qb is electric consumption of the system's auxiliary equipment (W).

The energy efficiency of the system is defined as follows.
η sys = Qnet ・ t / Qm
where η sys is system energy efficiency.
t is time (s).
Qm is the higher heating value (HHV) of the methanol consumed (J).

3-2. STACK CHARACTERISTICS

The following is an example of the specifications of a DMFC stack mounted on a vehicle.
Max. output: 500W
Rated Voltage: 25V
Fuel: 3% methanol-water solution
Oxidant: Air
Dimensions: W208 x L260 x H134 (mm)
The output of the stack varies with parameters including the concentration of the fuel and the amount of air flow.

3-3. AUXILIARY EQUIPMENT CHARACTERISTICS

Of the auxiliary equipment in the DMFC system, the one that consumes the largest amount of electricity is the air pump. Fig.2 shows and example of the relationship between the amount of electricity consumed by the air pump and the air flow rate

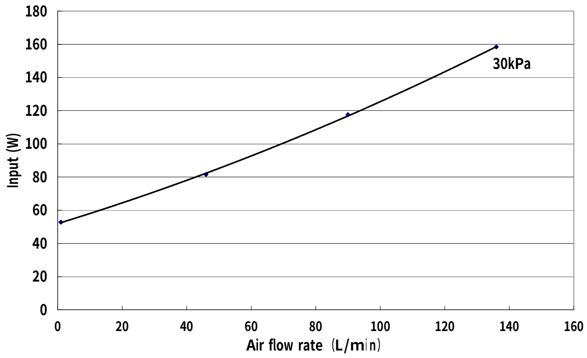

Fig. 2 Air pump electricity consumption

It is seen that there is roughly a linear increase in air pump electricity consumption as the rate of air flow is increased.

Fig. 3 shows the characteristics of the methanol-water solution pump used.

It is seen that there is very little change in the electricity consumption within the range of circulation rate for the methanol-water solution necessary to cause the generating reaction.

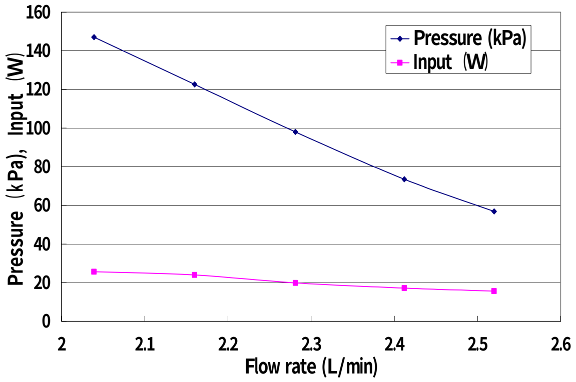

Fig. 3 Characteristics of the solution pump

The other auxiliary equipment (cooling fan, gas-liquid separation fan, fuel pump, etc.) only run intermittently and the average electricity consumption is determined to be about 30W.
From the above measurements, the following simplified equation can be made:
Electricity consumption for all the auxiliary equipment (W) = Air pump electricity consumption (W) + 50W

4. OPTIMIZATION OF RUNNINNG CONDITIONS

4-1. EFFECT OF FUEL-WATER SOLUTION CONCENTORATION ON THE GROSS OUTPUT OF A CELL STACK

The stack performance (gross output) and stack efficiency for a cell stack of the specifications shown in 3-2 were measured while varying the fuel-water solution concentration over a range from 1 ~ 3.2 wt%. The running conditions were a fuel-water solution flow (methanol feed) of 2.4 l/min., and air (normal atmospheric air) flow of 100 l/min. and a stack temperature of 65 degrees C. The ambient temperature was 23 ~ 41 degrees C., the atmospheric pressure was 1000 ~ 1023 hPa and the relative humidity was within a range of 30 ~ 73%.
Fig. 4 shows gross output and stack efficiency in relation to generating amperage. When the generating amperage was below 15A, very little change in stack performance was observed at different fuel-water solution concentrations. When the generating amperage was 15A or higher the output was the highest at a fuel-water solution concentration of 2 wt%. In the high amperage range concentration over voltage increased and performance decreased when the fuel-water concentration got down to 1 wt%.
Regarding stack efficiency, it was found that stack efficiency

increased as the amperage increased at all concentration levels. However, the rate of stack efficiency increase grew smaller at the generating amperage of 15A or over. Within the rated amperage range, the stack efficiency was highest at a fuel-water solution concentration of 1 wt%.

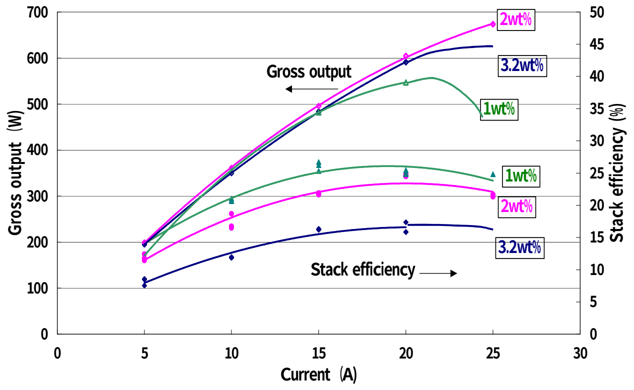

Fig. 4 The relationship between cell stack gross output and efficiency and amperage at the different fuel-water solution concentration levels.

4-2. EFFECT OF AIR FLOW RATE ON CELL STACK NET OUTPUT

Generally speaking, with a proton-exchange membrane fuel cell, when the membrane has an appropriate moisture, the more you increase the air flow rate the higher the output will be. However, raising the air flow rate also increases the electricity consumption by the air pump. Fig. 5 shows the relationship between gross output, auxiliary equipment input and net output per amount of air flow when run at an amperage of 20A, a fuel-water solution concentration of 3.2 wt% and a solution flow of 2.4 l/min. at a stack temperature of 65 degrees C. Although the gross output increases as the air flow rate is increased, so does the electricity consumption of the auxiliary equipment. As a result, the highest net output is achieved at an air flow rate of 70 ~ 90 l/min.

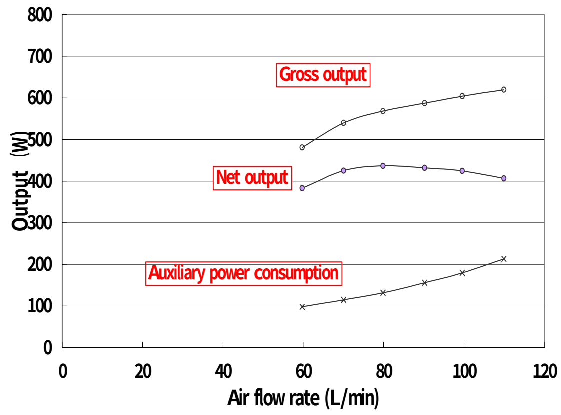

Fig. 5 The dependency on air flow for DMFC output @ 20ACC operation

We sought the optimum air flow conditions when the concentration of the fuel-water solution was lowered from 3.2 wt% to 2 wt%. Fig. 6 shows the variance in net output in relationship to air flow rate in an amperage range from 5 ~ 20 A. From Fig. 6 we can see that when the solution concentration is set lower, a shift occurs toward a lower rate of air flow to produce the highest output. Fig. 7 shows the relationship to net output when generating at the conditions shown in 4-1. with a solution concentration of 2 wt% when expressed in terms of air stochiomtric flow rate.

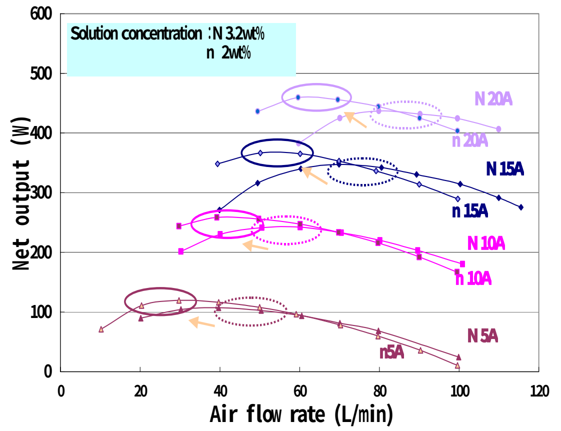

Fig. 6 The relationship between air flow rate and net output

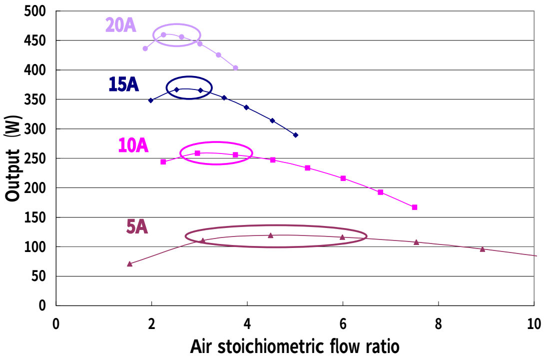

Fig. 7 The relationship between air stoichiometric rate and net output

4-3. ENERGY EFFICIENCY

Fig. 8 shows system efficiency and net output in relation to air flow rate. System efficiency is defined as the net output minus the higher heating value (HHV) of the energy of the fuel (methanol) consumed.

The running conditions are a fuel-water concentration of 2 wt% and a fuel-water flow of 2.4 l/min. at a stack temperature of 65 degrees C. using normal atmospheric air. At all amperage levels tested, the lower the air flow rate, the higher the system efficiency became.

From this Fig. we can also see that, while the conditions for achieving maximum system efficiency and achieving maximum net output are different, it is still possible to achieve high levels of both efficiency and output by choosing the right air flow conditions. Running at a generating amperage of 20A, we achieved net output of 460W and an efficiency of 20%.

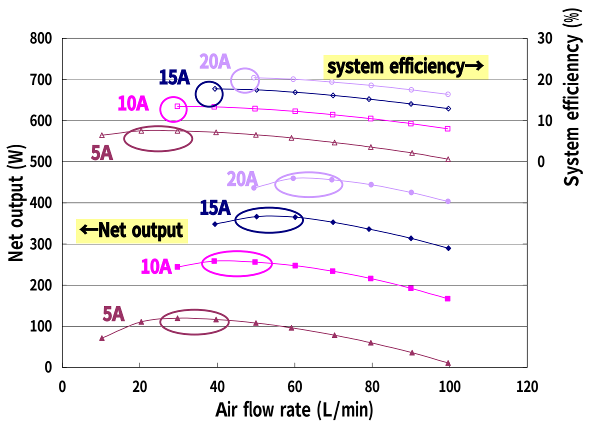

Fig. 8 Air flow in relation to net output and system efficiency

5. CONCLUSION

1) Lab (table-top) tests were conducted to determine the conditions for maximum net output of a DMFC type fuel cell system for mounting on a vehicle

Because increasing air flow rate is accompanied by a sharp increase in electric power consumption by the air pump, there is a maximum value to be found in net output in relation to air flow rate.

2) In representative running conditions the efficiency of the DMFC system was 20%.

The above results represent data obtained from a table-top (not vehicle mounted) system tested in the lab.

With an actual vehicle-mounted system, there are numerous other control parameters such as water composition, consumption balance conditions, temperature control conditions, solution concentration control conditions and conditions involved in maintaining a balance between the vehicle's running load and the system's output. The vehicle is able to run because of measures to optimizing these parameters.

Fig. 9 shows the vehicle mounting the DMFC system that began public road testing in September of 2004. In order to accommodate for changes in load when starting up, accelerating, climbing hills and waiting at traffic lights, this vehicle adopts a secondary battery in a type of hybrid system. At present, the various types of data are being collected from actual road tests for use in further system development aimed eventually at practical use of this vehicle.

Fig. 9 A vehicle mounting the DMFC system

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