RUNNING EXPERIMENTS AND ENERGY SAVING RUNNING SIMULATIONS OF SINGLE PERSON OPERATED FUEL CELL VEHICLE WITH 1 KW 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 the use of fossil fuels. This paper presents the running experiments and the optimum running mode simulations of the developed small fuel cell vehicle.

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 an internal combustion engine must be replaced with a more ecological system in order to reduce greenhouse gas (i.e., carbon dioxide) emissions. As a result, fuel cell electrical vehicles (FCV) are becoming very promising technologies for reducing carbon dioxide emissions. Several large automobile enterprises or research institutes are developing fuel cell electrical vehicles [1-6]. As they are researching high powered fuel cells of 100 kW class, the cost of these vehicles is prohibitive. 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 lower powered fuel cell. Taiwan University developed a small fuel cell scooter with two wheels [7]. The developed fuel cell scooter could run on a public road despite using a small fuel cell of 2 kW class.

Our aim is to develop a small fuel cell vehicle using four wheels which can run 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 powers of 200 W [8] and 20 W [9, 10]. We have also been developing a hybrid wheelchair with a photovoltaic and a fuel cell [11-13]. Now, we have started to develop a micro car class fuel cell vehicle using 1 kW fuel cell, which we have named the micro FCV. The micro FCV is a single person ride vehicle which can run on a public road. The micro FCV uses a fuel cell while running on a flat road at a constant speed, however uses a battery when it accelerates or it climbs a slope. We have improved a purchased micro car class electrical vehicle to develop our micro FCV.

This paper will explain the experimental results of the running tests. An optimum energy saving running scheme will be proposed, and the simulation results will be explained.

2. System Configuration of the Developed micro FCV

Fig.1 is the photographs of the developed micro FCV. A Milieu R produced by the Takeoka Jidosha Kogei Corporation was purchased, and converted into a fuel cell electric vehicle. The Milieu R is a micro car class electric vehicle driven by a motor using below 0.6 kW. Fig.2 outlines the system configuration of the micro FCV. The micro FCV has a hybrid energy system using a battery and a fuel cell. The battery system is used when large power is required, for example during acceleration or climbing a slope. The fuel cell system is used when the required power is below 1 kW. Sensors I and II measure the voltage, current, temperature, and humidity of the fuel cell. These values are then indicated on an LCD display, for the driver to monitor them. Table 1 displays the main specifications of the developed micro FCV. The dimensions are 2150x1240x1325 mm, and weighs approximately 233 kg. The front and rear treads are 1085 mm and 1060 mm, and the wheelbase is 1480 mm. A 48 V 24 Ah lead acid battery system along with a 500 W DC brush motor is used. A 1 kW fuel cell and a 3 L 19.6 MPa hydrogen tank are also used.

Fig. 1 Photographs of developed micro FCV

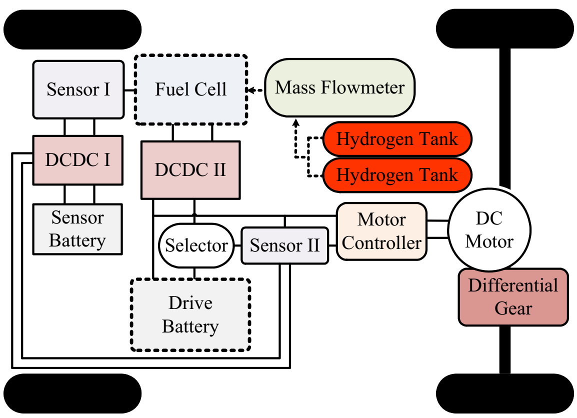

Fig. 2 System configuration of developed micro FCV

Table 1 Main specifications

Length×Width×Height [mm]		2150×1240×1325
Tread [mm] Front/Rear		1085/1060
Wheelbase [mm]		1480
Net weight [kg]		233
Fuel cell	Type	PEM
	Rated output [W]	1000
Drive battery	Type	Lead acid battery
	Voltage [V]	48
	Capacity [Ah]	24
Sensor battery	Type	Lead acid battery
	Voltage [V]	12
	Capacity [Ah]	3
Motor	Type	DC brush moter
	Rated output [W]	500
Max. Speed [km/h]		30
body		GFRP
Hydrigen tank	Max. Pressure [MPa]	19.6
	Capacity [L]	3
Tire	Outer deameter [mm]	352
Brake	Front	Hydraylic disc break
	Rear	Hydraulic drum break

3. Outline of Running Tests

We conducted six running tests to observe the performances of the micro FCV; (1) during the ecological running competition of JISFC (Japan Inter-College Solar & Fuel Cells Car Championship) in Akita, (2) electricity consumption at wheel idling, (3) flat road, (4) maximum velocity, (5) uphill, and (6) observing the relationship between velocity and motor voltage. This paper will describe the two experimental results of (3) flat road and (5) uphill.

Fig.3 shows the measured points used in the experiments where the voltage, current, and hydrogen flow rate are measured.

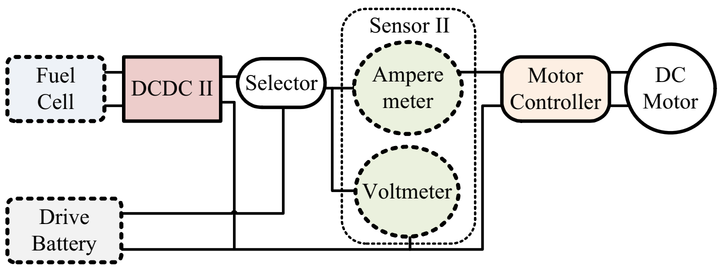

Fig. 3 Measured points

4. Experimental Results of Flat Road Tests

Experiments on the flat road tests were conducted. The relationships between electricity consumption and hydrogen flow rate at each velocity were obtained. The vehicle velocity was calculated by the measured running time. Fig.4 is a photo of the running test course used in our experiments, where the total distance from start point to goal point is 390 m. The running experiments were conducted twice.

The experiments were carried out based on the on-board speedometer. Velocities of 5, 10, 15, 20, 25 and 30 km/h were examined. The vehicle ran at constant speed from the starting point to the goal point. The fuel cell was used at the speeds up to 25 km/h, however the battery was used at 30 km/h due to the higher power requirement. Each data was measured at 1 second samples. A data logger recorded the experimental results. Electricity consumption is calculated using P=IV, where P is the electricity consumption [W], I is the current [A], and V is the voltage [V].

Fig.5 gives an example of the relationship between electricity consumption and the hydrogen flow rate at 21 km/h. Table 2 shows the practical velocity which was obtained using the running distance and time. Figs. 6 and 7 show the relationships between time, electricity consumption and hydrogen flow rate at each velocity. Electricity consumption at velocities 5 km/h and 7 km/h was at approximately the same value of 250 W. Hydrogen flow rate increased when vehicle velocity increased. The hydrogen flow rate at 21 km/h was 12 L/min. Fig.8 shows the relationship between the electricity consumption and the hydrogen flow rate comparing the catalogue values and the electrical load tests. The hydrogen flow rate is proportional to the square of electricity consumption. The measured hydrogen flow rate is higher than the catalogue values. The inclinations are approximately the same. Fig.9 shows the averaged electrical consumption and Fig.10 shows the averaged hydrogen flow rate during the experimental run (see Figs. 6 and 7).

Electricity consumption is above the desired amount at each velocity. Lower electricity consumption is necessary in order to decrease the hydrogen flow rate. Adaptations of a direct drive motor and low rolling resistance tires will be addressed in future designs. A lighter weight vehicle design is also expected to decrease the electricity consumption.

The inconsistency between the practical velocity and the on-board speedometer ranged 10-30 %. We believe this deviation is due to the difference in the outer diameters of the tires used in this experiment and the original tires of the purchased Milieu R.

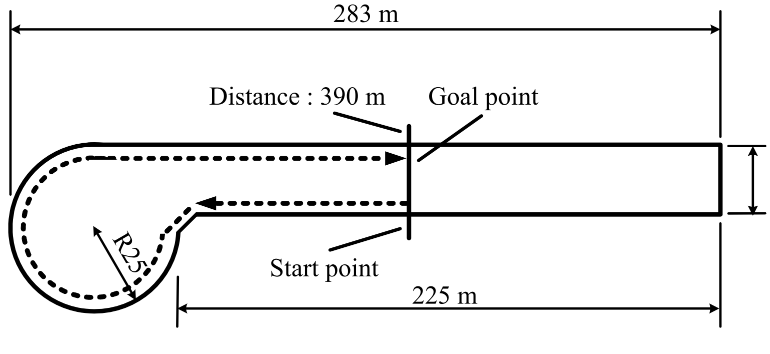

Fig. 4 Running test course

Table 2 Practical velocity

On board velocity [km/h]	5	10	15	20	25	30
1st LAP [sec]	268	188	110	75	64	56
2nd Lap [sec]	248	188	112	85	69	57
Average [sec]	258	188	111	80	67	57
Practical velocity [km/h]	5	7	13	18	21	25

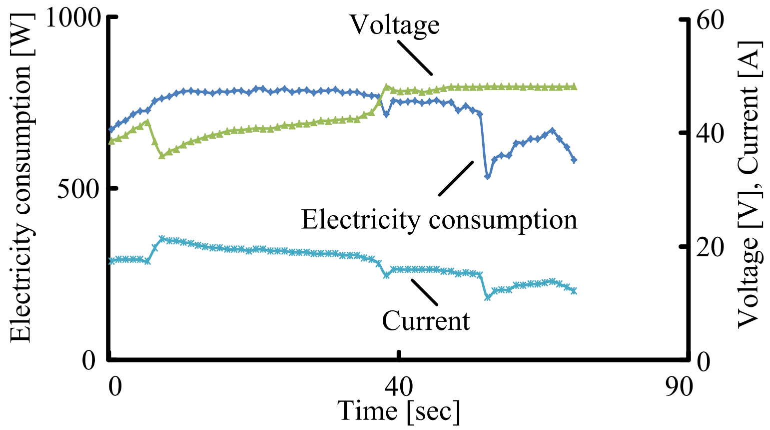

Fig. 5 Relations between electricity consumption, voltage and current at 21 km/h

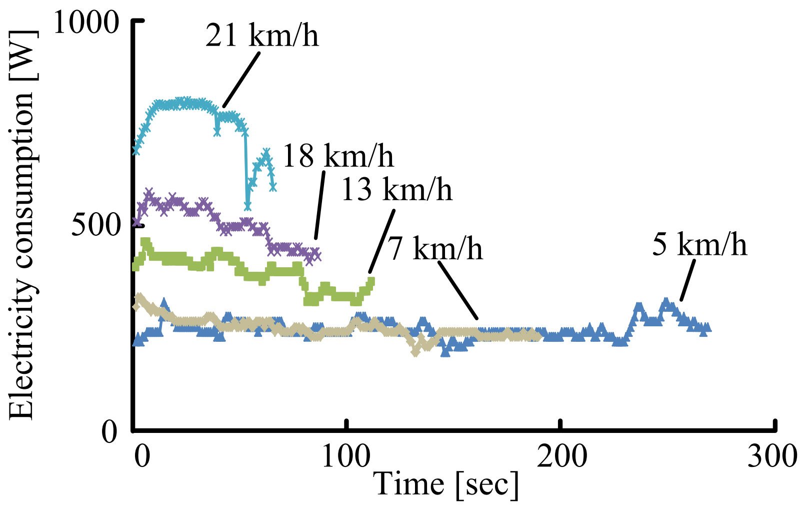

Fig. 6 Experimental results of electricity consumption

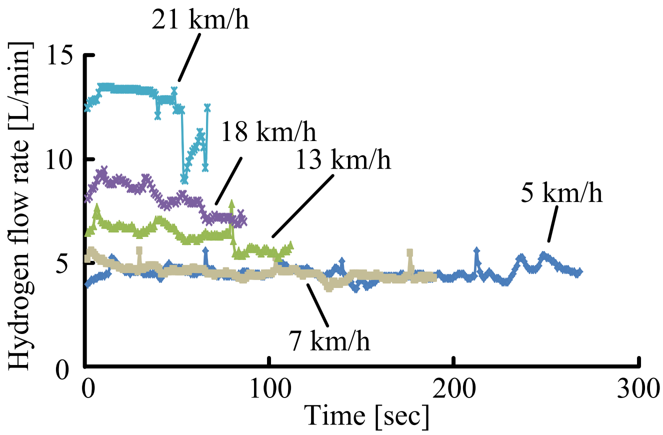

Fig. 7 Experimental results of hydrogen flow rate

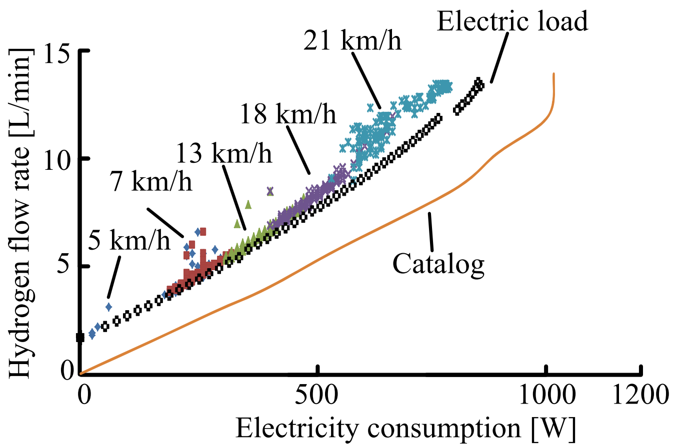

Fig. 8 Relations between electricity consumption and hydrogen flow rate

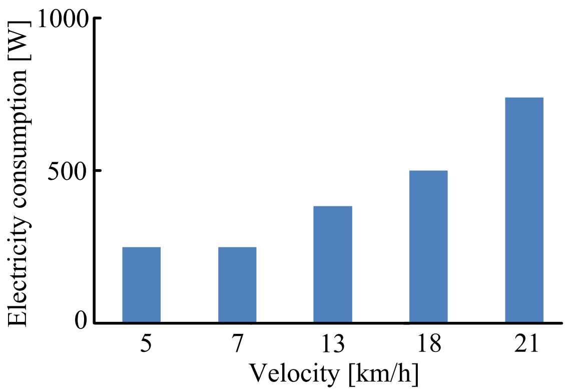

Fig. 9 Averaged electricity consumption

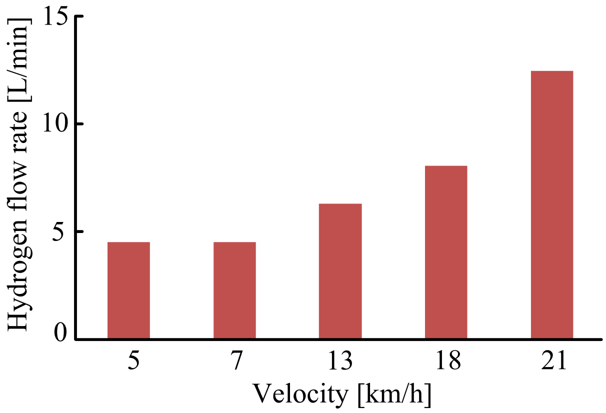

Fig. 10 Averaged hydrogen flow rate

5. Experimental Results of Uphill Running Tests

Uphill running tests were conducted. The performance during slope climbing is essential to determining vehicle performance. The relationship between electricity consumption and hydrogen flow rate at uphill was obtained.

Fig.11 provides the specifications of the experimental uphill course. The slope gradient and the slope angle are obtained using the height [m] and the base distance of the sloping road [m]. The calculated gradients were 5% and 6%. The experiments were conducted 3 times at the 5% gradient slope at the velocities of 10, 15, and 20 km/h according to the on board speedometer. The experiments on the 6% gradient slope were conducted once. Both tests were conducted using the battery system.

Fig.12 shows the experimental results of the electricity consumption where the experiments were tried three times. The slope gradient was 5% and the velocity was 7 km/h. Fig.13 displays the experimental results of the electricity consumption where the three velocities of 7 km/h, 13 km/h, and 18 km/h were tried. The slope gradient was 6% and the velocity was 7 km/h. Fig.14 displays the averaged electricity consumptions at the gradient of 5%. The experimental results of the electricity consumption values were 1200 W at 7 km/h, 1800 W at 13 km/h, and 2000 W at 18 km/h. Fig.15 displays the averaged electricity consumptions at the gradient of 6%. The experimental results of the electricity consumption values were 1900 W at 7 km/h, 2000W at 13 km/h, and 2200 W at 18 km/h. We confirmed that the developed micro FCV with a 500 W DC motor was able to climb a slope at the gradients of 5% and 6%.

Climbing resistance is considered when running on a sloped road. Climbing resistance is calculated using the total mass [kg], the acceleration of gravity [m/s^2], and the slope gradient. Electricity consumption of the climbing resistance was calculated at approximately 280 W using the calculated velocity [km/h]. The experimental conditions were V = 7 km/h, m = 285 kg, g = 9.81 m/s^2, and gradient = 5%. In addition to the electricity consumption of 250 W (the electricity consumption of the flat road at 7 km/h), calculated electricity consumption is 530 W. However, the experimental results of the practical electricity consumption were observed at 1200 W as shown in Fig. 13. We believe that the difference is the result of gear box inefficiency.

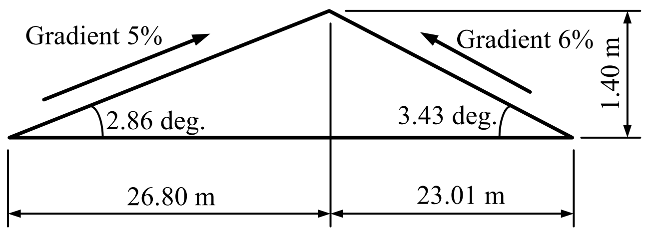

Fig. 11 Course of sloping road

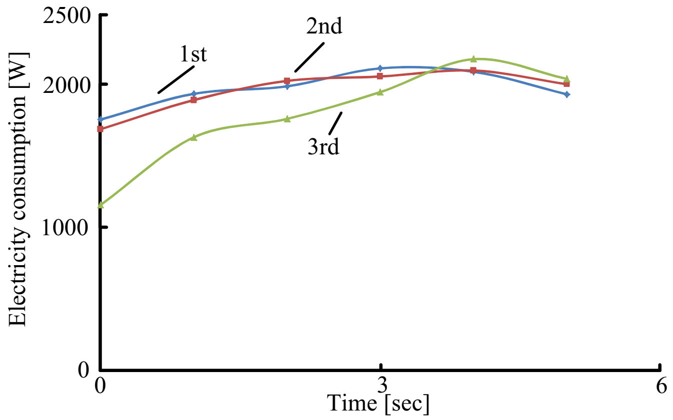

Fig. 12 Electricity consumption at gradient of 5% at 10 km/h

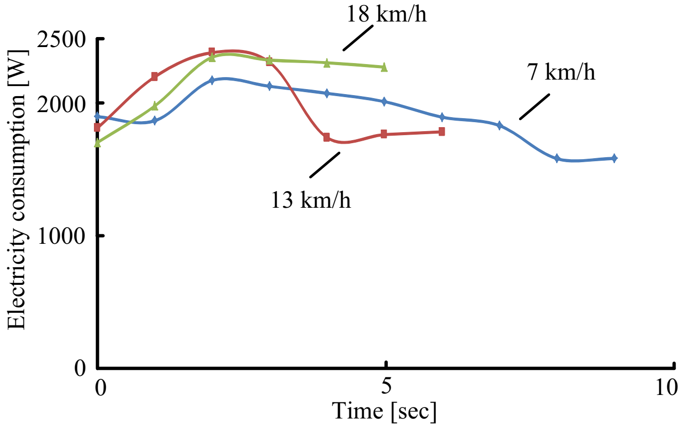

Fig. 13 Electricity consumption at gradient of 6%

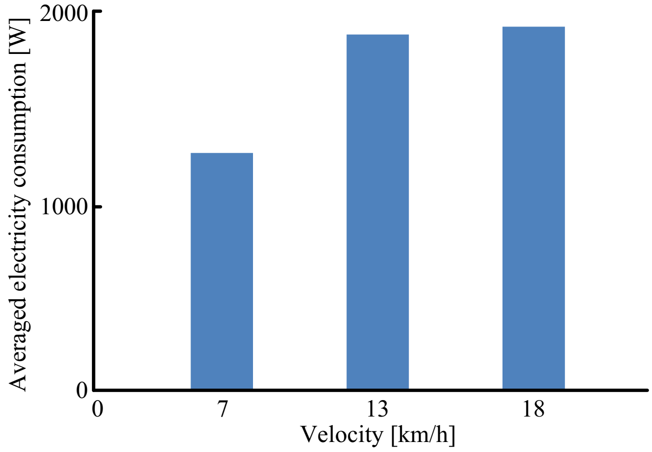

Fig. 14 Averaged electricity consumption at gradient 5%

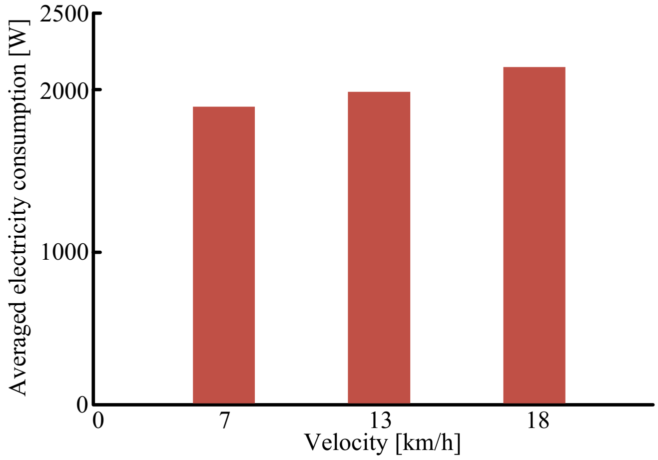

Fig. 15 Averaged electricity consumption at gradient of 6%

6. Optimum Energy Saving Running Scheme

Simulations of cruising distance based on results of the running tests on flat road were conducted. Two 3 L 19.6 MPa hydrogen tanks were used. First, the hydrogen capacity per one tank is calculated. Next, the hydrogen flow rate at each velocity is obtained. Fig.16 explains the relationship between the hydrogen flow rate and the velocity. The simulations are based on the experimental results of the averaged hydrogen flow rate on the flat road. The initial value with no load was 1.6 L/min. Running time and the cruising distance are calculated. The maximum cruising distance is the highest point on the cruising distance curve. Fig.17 explains the simulation results. The highest efficiency point of the developed micro FCV is 15 km/h, therefore the cruising distance is 37.0 km, the hydrogen flow rate is 7.8 L/min, and the running duration is

148 minutes. We have confirmed that the proposed scheme is able to approximate the optimum running pattern.

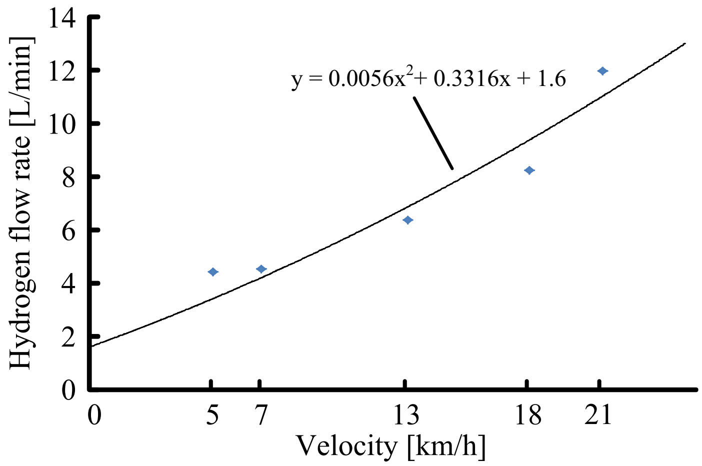

Fig. 16 Relations between hydrogen flow rate and velocity

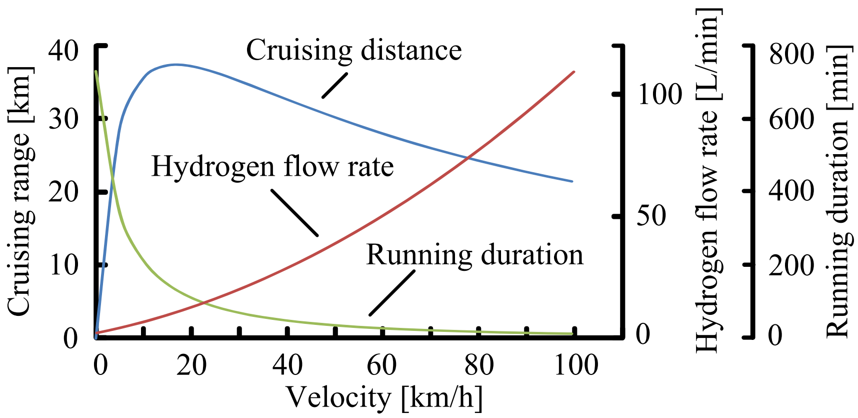

Fig. 17 Simulation results of cruising distance

7. Conclusions

The following were confirmed by the experimental results. Electricity consumption on the flat test course at 21 km/h was approximately 800 W. Electricity consumption is proportional to the square of hydrogen flow rate. Electricity consumption on a 6% slope was 2000 W at 18 km/h. The practical electricity consumption was larger than the calculated ideal electricity consumption. We believe that the difference is the result of gear box inefficiency. A simulation scheme of the cruising distance was proposed. Lower electricity consumption and higher cruising velocity must be addressed in future research.

9. Acknowledgement

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