Specifications and schedule of a fuel cell test railway vehicle

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1. Abstract

This paper describes both the schedule of development and the specifications for the fuel cell test railway vehicle.

We aim at the development of a railway vehicle to which fuel cells are applied. In 2004, we already tested induction motor operation with a VVVF inverter by 30kW class fuel cells. Based on the experiments and research, we made a 100kW class fuel cell test railway vehicle. Therefore, this paper focuses on the following.

- Specifications for the fuel cell test railway vehicle
- Outline of test railway vehicle and equipment layout
- Motor characteristics of the test vehicle
- Train performance curve of the test vehicle in test track
- Test schedule of the test vehicle

Through this paper, we expect to promote the environment-friendly railway transportation system.

2. Introduction

In recent years, it is necessary to save energy and reduce CO2 emissions. Railway is essentially energy saving and low CO2 emission transport. However, railway is still demanded to preserve the environment. To achieve this, the use of fuel cells is expected as a key technology in environmental protection. Fuel cells utilize hydrogen and oxygen from the air to create electricity by a chemical process. The only emissions are water and exhausted air which did not react in fuel cells. Therefore, the fuel cells are environment-friendly. Thus, we aim at the development of a railway vehicle to which fuel cells are applied.

In 2004, we already tested induction motor operation with a VVVF inverter by 30kW class fuel cells. Consequently, we verified the compatibility between the railway vehicle traction system and fuel cells[1]. Based on experiments and research, we made the 100kW class fuel cell test railway vehicle.

3. Operation principle of fuel cell

We chose proton exchange membrane type fuel cells (PEMFCs) for on board power source of railway vehicle traction, due to their lighter weight, shorter start-up time and lower operating temperature. Therefore, this section discusses briefly the operation principle of PEMFCs.

1. In the fuel cell, a high polymer membrane coated with a platinum catalyst is sandwiched between two electrodes (see Fig.1).
2. Hydrogen is fed to the anode (negative electrode). And, oxygen is fed to to the cathode (positive electrode).
3. The hydrogen comes into contact with the platinum catalyst. Then, the hydrogen releases electron ($e^-$) and changes into hydrogen ion (proton $H^+$).
4. Due to the membrane can transmit the hydrogen ion but cannot transmit the electron, the electron is lead to external loads through the anode.
5. The hydrogen ion passes trough the membrane to the cathode. Then, hydrogen ion, electron from the external loads and oxygen unite together and form water.
6. Consequently, current flows from the cathode to the anode through the external loads. And, heat and water are emitted at the same time.
This action is reverse operation of dissociation of water. As hydrogen and oxygen can be combined to produce electrical energy and water without contamination, the fuel cells are clean power source.

The fuel cell powered railway vehicles reduce both carbon dioxide emission and energy consumption due to high-efficiency of fuel cells, idling-stop and regenerative brake in exchange of diesel vehicles. The latter implies that energy storage (for example battery) is installed on board. Further, unlike diesel vehicles, fuel cells generate electricity by a chemical process without explosion, noise and vibration.

![Fuel cell operating Principle](image1.png)

**Proton exchange high polymer membrane**  **Separator and Electrode**

4. Specifications of the devices for the fuel cell test railway vehicle

(1) Fuel cell

We made 100kW class fuel cells experimentally. Pure hydrogen is supplied from hydrogen cylinder to the fuel cells. And, oxygen is supplied as the air by compressor. As all electrical auxiliaries are powered by the fuel cells, the fuel cells can operate stand-alone. Fig.2 shows an exterior of the fuel cells. Table 1 shows a specification of the fuel cells. And, Fig.3 shows a characteristic curve about fuel cells’ voltage and power – load current. Fig.3 shows that the bigger the output power is, the lower the output voltage is.

![An exterior of the 100kW class PEMFCs.](image2.png)
(2) Hydrogen cylinder

FC train requires on-board hydrogen storage for fuel. And, the hydrogen storage needs to be high-energy density state, strength and lightweight. Then, we chose composite cylinder made from an aluminum liner wrapped in carbon fiber. The composite cylinders can store 18kg of hydrogen at 35MPa(350bar/5100PSI) . The composite cylinders are lighter in weight and higher in pressure than conventional steel cylinder (14.7MPa). They have enough volume for one day test drive. And, as this storage system has decompression device, the hydrogen is automatically supplied to fuel cells less than 1MPa. And, for the safety, it has automatic relief valves for over pressure to diffuse and hydrogen leak sensor for shutdown hydrogen supply. Fig.4 shows exterior of the hydrogen cylinders. Table 2 shows a specification of the hydrogen cylinders.

<table>
<thead>
<tr>
<th>Output power (Net)</th>
<th>120 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Pure hydrogen</td>
</tr>
<tr>
<td>Oxidizer</td>
<td>Air</td>
</tr>
<tr>
<td>Output voltage</td>
<td>900–600 V</td>
</tr>
<tr>
<td>Start-up time</td>
<td>Within 5 min.</td>
</tr>
<tr>
<td>Weight</td>
<td>2000 kg</td>
</tr>
<tr>
<td>Outside dimension</td>
<td>1.65(L) × 1.25(W)</td>
</tr>
<tr>
<td>(Without Radiator)</td>
<td>× 1.50(H) m</td>
</tr>
</tbody>
</table>

Fig.4 An exterior of the hydrogen cylinders.
Table 2 A specification of the hydrogen cylinders.

<table>
<thead>
<tr>
<th>Storage volume of hydrogen</th>
<th>18 kg</th>
<th>Liner of cylinder</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage pressure</td>
<td>35MPa (5100PSI)</td>
<td>Reinforcement of cylinder</td>
<td>Carbon fibre</td>
</tr>
<tr>
<td>Supply pressure</td>
<td>Less than 1 MPa</td>
<td>Weight</td>
<td>800 kg</td>
</tr>
<tr>
<td>Hydrogen control</td>
<td>Constant pressure control</td>
<td>Outside dimension</td>
<td>1.61(L) x 2.65(W) x 0.78(H) m</td>
</tr>
</tbody>
</table>

(3) Inverter and motor
We chose two 95kW induction motors as traction motors. They are the same as the motor for actual commuter train. And, we chose a 680kVA inverter that is commonly applied to induction motor traction systems. Table 3 shows a specification of the motor and inverter.

They have too high output for 100kW class fuel cell as they are designed not for the FC train but for DC1500V fed ordinary Japanese electric railway vehicle.

Table 3 Specifications of the traction motor and inverter.

<table>
<thead>
<tr>
<th>Rating of traction induction motor</th>
<th>68A-1100V-95kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capability of traction inverter</td>
<td>1500V-680kVA</td>
</tr>
</tbody>
</table>

5. Outline of test railway vehicle and equipment layout

(1) Outline of test railway vehicle
Test railway vehicle type R291 is essentially modified existing rapid-service train’s body and commuter train’s bogies. Originally, the type R291 is 2-cars for 1-unit. However, as 100kW class fuel cells are not enough to drive 2-cars, we drive 1-car alone by the fuel cells. In this case, FC train has 2 bogies. One bogie is a motive bogie with 2 motors, and the other bogie is a trailing bogie without motors. Fig.5 shows a rough exterior of the test railway vehicle the type R291.

Fig.5 An exterior of exterior of the test railway vehicle type R291.

(2) Equipment layout
As this FC train runs 1-car alone, all equipments have to be installed in 1-car. Fig.6 shows an equipment layout of FC train. In the layout, batteries are not installed in the FC train in order to verify that fuel cell is valid for a power source of railway vehicle traction. Fig.7 shows traction circuit for the FC train. Hence, all energy for traction has to be drawn from only fuel cells not from current wire or batteries. Although the FC train has power collection equipment (pantograph), the pantograph draws electricity to auxiliary inverter. The auxiliary inverter supplies power to compressor for air brake equipments, lighting and so on. Therefore, it is not used for vehicle traction. The fuel cells and the traction inverter is installed inside of the car for the convenience of operations and measurements. The hydrogen cylinders are installed on under-floor to avoid inflow of leak hydrogen to the room. Furthermore, the fuel cells and the
hydrogen cylinders have hydrogen leak sensor to take the surest measurement for prevention of hydrogen leak.

![Diagram of FC train layout](image)

**Fig. 6** A rough equipment layout of FC train.

![Diagram of traction circuit](image)

**Fig. 7** Traction circuit for the FC train.

6. **Motor characteristic of the test vehicle**

At the fuel cells, the bigger the output power is, the lower the output voltage is (From 900V to 600V)(see Fig.3). Therefore, we designed a motor characteristic curve that is not affected by the voltage drop. At the characteristic, due to a well balance between variation of fuel cells voltage and that of motor current, the motor is operated at the limit of fuel cells’ power (120kW) at constant power region (Velocity 10~20km/h).
7. Train performance curve of the test vehicle in test track

Based on this motor characteristic, we draw train performance curve of the test vehicle in test track (see Fig.9). In the performance curve, maximum speed reaches about 40km/h. The maximum speed is not so high because the test track is short (600m).

Furthermore, we plan a high-speed drive test at rolling stock test plant in our site (see Fig.10). Here, we carry out high-speed driving test more than 40km/h. The plant is capable of simulating train driving situations. The train is parked on roller rig, and wheels of the bogie turns the roller like chassis dynamometer. This enables testing of conditions that cannot be tested on actual lines and the investigation of related effects and problems.
8. Test schedule of the test vehicle

This section discusses shortly test schedule of the fuel cell test vehicle.
We carry out the development of the FC train according to the development plan (see Table 4).
In the phase 1(2001-2003), we tested motive bogie operation with induction motors and a VVVF inverter by 30kW class fuel cells. Consequently, we verified the compatibility between the railway vehicle traction system and fuel cells.
In the phase 2(2004-2006), we designed 100kW class fuel cells and 35MPa hydrogen cylinders for FC train equipment. And, we made them and installed in the test vehicle. From now on, we intend driving test until the vehicle reaches a speed of 30-40 km/h. Furthermore, we carry out high-speed driving test at our rolling stock test plant from 0km/h to maximum speed.
In the phase 3(2007-2010), we propose to put FC train to practical use. We will develop practical scale fuel cells that have sufficient power for driving the railway vehicles. For practical use, the batteries and hybrid system will be installed in FC train to absorb regenerative energy. Moreover, we desire to make test run of FC train on commercial line of railway company.

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3 (proposed)</th>
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<tbody>
<tr>
<td>30kW class fuel cells</td>
<td>100kW class fuel cells</td>
<td>Practical scale fuel cells</td>
</tr>
<tr>
<td>Motive bogie operation test at test plant</td>
<td>35MPa hydrogen cylinders</td>
<td>Batteries and hybrid system</td>
</tr>
<tr>
<td></td>
<td>Equipments installation</td>
<td>Test-drive on commercial line of railway company</td>
</tr>
<tr>
<td></td>
<td>Test-drive at test track and test plant</td>
<td>Test-drive on commercial line of railway company</td>
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</table>

9. Conclusion

In this paper, we introduced 100kW class fuel cell test train. We discussed the specifications of fuel cells, hydrogen cylinders and traction circuit. And, we show all equipments for FC train are installed in 1-car. Next, we showed motor characteristic and train performance curve based on the specifications. Furthermore, we introduced the test schedule of the test vehicle and the course of the development.
Through this paper, we expect to promote the environment-friendly railway transportation system.

10. Acknowledgements

This development had been financially supported by a state subsidy of Japan.
11. References