

Development of New TOYOTA FCHV-adv Fuel Cell System

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ABSTRACT

Since 1992, Toyota Motor Corporation (TMC) has been working on the development of fuel cell system technology. TMC is designing principal components in-house, including fuel cell stacks, high-pressure hydrogen storage tank systems, and hybrid systems. TMC developed the '02 model TOYOTA FCHV, the world-first market-ready fuel cell vehicle, and started limited lease of the vehicles in December 2002. In June 2008, TMC developed a new TOYOTA FCHV-adv which obtained vehicle type certification in Japan, and is currently available for leasing in Japan and the United States. In the development of the TOYOTA FCHV-adv, TMC has improved the cruising range and cold start/drive capability from the previous TOYOTA FCHV. The TOYOTA FCHV-adv has achieved an actual cruising range of over 500 km, which is equivalent to that of current gasoline vehicles. In addition, the TOYOTA FCHV-adv has proven starting/driving capability at -30°C temperature. This paper introduces the TOYOTA FCHV-adv fuel cell system that has demonstrated practical cruising range and cold start/drive capability.

INTRODUCTION

In recent years, amid expectations for the creation of effective measures to combat global warming, the world is looking forward to the arrival of the "hydrogen age". Many automakers are developing environmentally friendly, highly energy efficient fuel cell vehicles to meet these expectations. In 2002, TMC started leasing the

TOYOTA FCHV. In June 2005, the TOYOTA FCHV became the first FCHV in Japan to acquire vehicle-type certification, and in July 1, 2005, the lease of '05 model TOYOTA FCHV, equipped with TMC-developed high-pressure hydrogen storage tanks, has started. The total number of leased vehicles has reached 39 in Japan and the United States; and 62 units, including test vehicles, have been running on public roads. Table 1 shows a leasing status and vehicle placement of the TOYOTA FCHVs until now.

	Japan	USA	Total
 02 model Since Dec/02	11	7	18
 05 model Since July/05	12	9	21
Sub total	23	16	39
Test Vehicle ('02-'06)	14	9	23
Total (incl. test vehicle)	37	25	62

Table1. Leasing Status of TOYOTA FCHV

As mentioned above, TMC has developed world-leading fuel cell vehicles. However, the following major issues were still unresolved toward sales and commercialization of fuel cell vehicles to the public:

- cold start capability
- cruising range
- FC stack durability
- cost reduction

The performance of the new fuel cell hybrid vehicle “TOYOTA FCHV-adv” has enhanced significantly by improving three of the above issues: cold start capability, cruising range and FC stack durability.

NEW TOYOTA FCHV-ADV SPECIFICATIONS

TMC has developed a new fuel cell hybrid vehicle “TOYOTA FCHV-adv” toward achieving a world of sustainable mobility, in which methods of travel coexist in harmony with people and the environment. The lease of TOYOTA FCHV-adv that acquired vehicle-type certification from Japan's Ministry of Land, Infrastructure and Transport in June 2008 has started in the United States this year. Fig. 1 and Table 2 show its appearance and specifications.



Fig.1. FCHV-adv

Vehicle		TOYOTA FCHV-adv	TOYOTA FCHV
Overall length/width/height		4,735/1,815/1,685	4,735/1,815/1,685
Weight (kg)		1880	1880
Seating capacity		5	5
Maximum cruising range (km)* 10-15 test cycle/JC08 test cycle		Approx. 830/Approx. 760	Approx. 330/-
Maximum speed (km/h)		155	155
Fuel Cell	Name	Toyota FC Stack	Toyota FC Stack
	Type	Polymer electrolyte	Polymer electrolyte
	Output (kW)	90	90
Motor	Type	Permanent magnet	Permanent magnet
	Maximum output in kW (ps)	90 (122)	90 (122)
	Maximum Torque in N-m (kg-m)	260 (26.5)	260 (26.5)
Fuel		Hydrogen	Hydrogen
Storage system		High-pressure storage tanks	High-pressure storage tanks
Maximum storage pressure (MPa)		70	35
Tank capacity (L)		156	148
Battery		Nickel-metal hydride	Nickel-metal hydride

*As based on TMC calculations

Table2. FCHV-adv Specifications

In December 2006, a prototype of the TOYOTA FCHV-adv was approved by the Minister of Land, Infrastructure and Transport during its development. TMC has conducted vehicle performance evaluations on public roads in both Japan and the United States to validate

the design improvements, including cruising range and cold start capability. The TOYOTA FCHV-adv has driven for a total of over 360,000 km for public road tests in Japan, the United States and Canada. As a part of the tests, it successfully completed an approximately 560km long-distance road test by traveling from Osaka to Tokyo on a single fueling of hydrogen. In addition, cold tests carried out in Hokkaido, Japan, the United States and Canada have verified its cold start/driving capability at sub-freezing temperatures including -37°C.

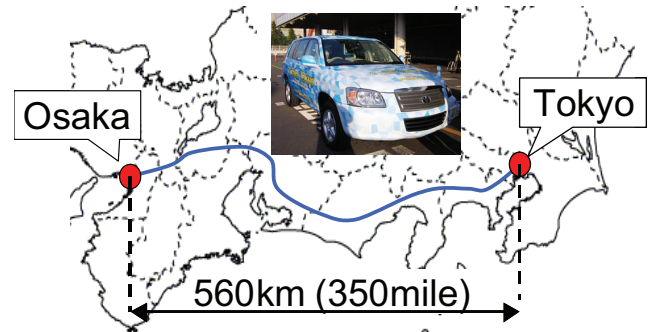


Fig.2. Public Road Testing (Osaka-Tokyo single fueling test and Canada cold test)

Fig. 3 shows the TOYOTA FCHV-adv system diagram. The system consists of the FC stack, hydrogen-supply system, air-supply system and cooling system. Hydrogen stored in the 70MPa high-pressure hydrogen storage tanks are supplied to the FC stack after its pressure is regulated to an appropriate level by the regulator and injector. Unused hydrogen from the FC stack is recirculated by the hydrogen compressor. Those components used in the hydrogen recirculation system are packaged in the FC stack case.

Air compressed by the air compressor is supplied to the FC stack through the humidifier. The humidifier extracts water vapor (generated water) from the air discharged from the FC stack, and humidifies the air supplied to the FC stack to the optimum level. The TOYOTA FCHV-adv is equipped with a humidifier bypass valve through which dry air that is not humidified according to the FC Stack condition can be supplied to the FC stack. The back pressure regulator, which is installed at the FC stack

outlet, is electronically controlled to keep the supplied air pressure at the proper level according to the operating condition. The TOYOTA FCHV-adv is equipped with air-shutoff valves which close the cathode side after the FC system is shutdown.

The cooling system has been simplified from the '05 model TOYOTA FCHV, combining the air cooling system and FC stack cooling system into one system.

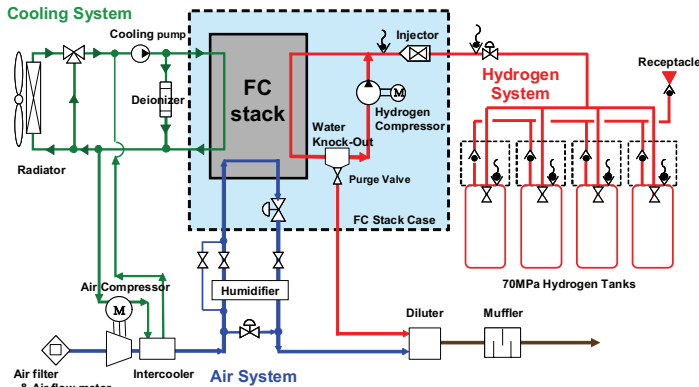


Fig.3. FC System Diagram of TOYOTA FCHV-adv

IMPROVEMENT OF COLD START/DRIVING CAPABILITY

It is well known that improvement of cold start/driving performance in fuel cell vehicles is one of the major technical issues. This is because generated water accumulated in the fuel cell Membrane Electrode & Gas Diffusion Layer Assembly (MEGA) and gas channel is frozen under sub-freezing temperatures, deteriorating gas diffusion performance. The moving parts of the FC system are also frozen solid by the generated water.

To start a fuel cell vehicle at sub-freezing temperatures and continuously generate power, technical development is needed that prevents generated water from freezing inside the fuel cell, which impedes gas diffusion, and also quickly raises the fuel cell temperature above sub-zero temperatures. TMC observed the phenomenon with a microscope and infrared imagery, and completed detailed analysis of the mechanism of water generation. Based on the results, TMC optimized the separator and GDL design that ensures high gas diffusion performance under cold conditions. As a result, we have improved power generation performance at sub-freezing temperatures. Fig. 4 compares power generation performance immediately after vehicle start under -10°C with the integrated sweep current. The improvement of gas diffusion performance made it possible to sweep larger current immediately after FC system startup.

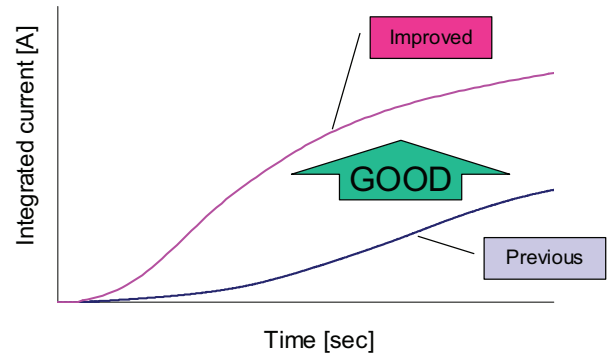


Fig.4. Integrated Sweep Current under -10°C Conditions

Reducing heat capacity of the fuel cell stack itself is also important to increase the fuel cell temperature effectively in a short time. By using a new metal fuel cell separator instead of carbon material, TMC has reduced heat capacity by 50% (Fig. 5), and as a result, substantially reduced warm-up time by more than 50%.

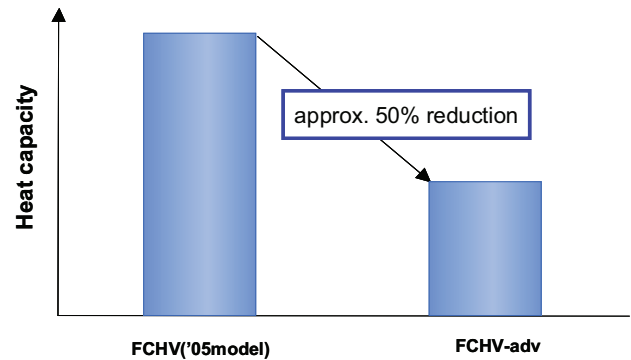


Fig.5. Comparison of Stack Heat Capacity

In addition, it is also critical to prevent the system components from being frozen in order to maintain power generated from sub-freezing conditions. A design improvement of the TOYOTA FCHV-adv co-locates components that might be frozen by generated water, such as the hydrogen recirculation system, inside the FC stack case (Fig. 6). This made it possible to maintain component temperatures above sub-zero temperatures while driving in ambient conditions less than -30°C .