

Development of New Power Train for Honda FCX Fuel Cell Vehicle

Takayuki OGAWA*
Sachito FUJIMOTO*

Kenichiro KIMURA*
Kiyoshi SHIMIZU*

Kenji UCHIBORI*

ABSTRACT

In response to increasing environmental concerns and demands for clean energy, Honda has developed an emission-free clean power train employing fuel cells. This power train has been fitted in the FCX fuel cell vehicle, which is being simultaneously marketed in Japan and the US in a world first. The new power train is made up of a combined pure hydrogen fuel cell stack and Ultra capacitor system, and a reluctance torque traction motor. In addition to achieving a zero level of emissions of CO₂ and other pollutants, the new power train has raised the energy efficiency of the FCX to 45%, almost 1.5 times that of an electric-gasoline hybrid vehicle (HEV) of equivalent size. The FCX also has higher fuel economy than an HEV, and better acceleration from a standstill compared to a gasoline internal combustion engine vehicle (ICEV).

1. Introduction

In response to environmental issues such as global warming and air pollution, Honda has worked to improve gasoline engine combustion technology through the use of VTEC⁽¹⁾ and to develop high-efficiency clean power trains for the Honda EV PLUS electric vehicle⁽²⁾, the Honda Civic GX natural gas vehicle⁽³⁾, and the Honda Civic Hybrid⁽⁴⁾, a gasoline/electric hybrid vehicle. Now, with the goals of achieving zero emissions, including CO₂, and of utilizing alternative energy sources instead of depending on fossil fuels, the focus has turned to fuel cells using pure hydrogen as their fuel. In combination with a traction motor that utilizes reluctance torque and Honda's proprietary ultra-capacitor, Honda has introduced their independently cultivated electric drive technology, high-pressure gas storage technology, and high-precision hybrid energy management technology, creating a highly efficient, high response clean power train that is installed in the FCX fuel cell vehicle. The FCX is the world's first commercial fuel cell vehicle being delivered simultaneously to Japan and the USA.

This paper explains the power train installed in the FCX.

2. Development Concepts

The goals of this development project were not limited to the environmental performance demanded by society of an automobile, but also included those areas which are often sacrificed for environmental performance — acceleration performance and high response, as well as smooth drivability — but are demanded by the customer in terms of marketability. A new, pioneering, next generation power train was realized, achieving all the goals at a high level. The practical development concepts are as follows.

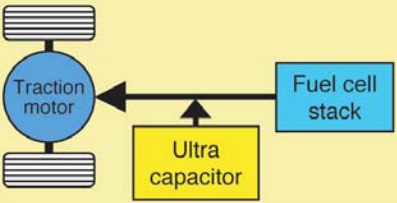
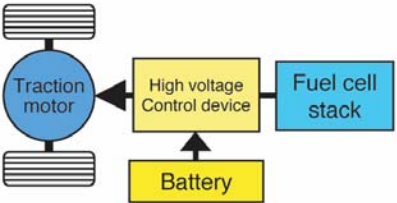
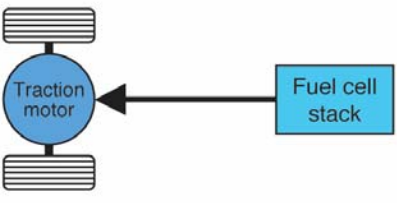
- (1) Zero Emissions, CO₂-free
- (2) Vehicle energy efficiency which exceeds that of a hybrid vehicle (Tank to wheel)
- (3) Standing start acceleration performance that is better than that of a gasoline vehicle.
- (4) A compact design that efficiently utilizes space.

3. Power Train System

In actualizing the development concepts, a basic system study was carried out.

* Wako Research Center

Table 1 Comparison of system configurations

	Basic configuration	System configuration	Efficiency	Power performance
Capacitor-assisted system FCX		High-voltage distribution system not required	Electric transmission efficiency : HIGH Braking regeneration : YES	Instantaneous high power assist possible
Battery-assisted system		High-voltage distribution system required for fuel cell stack / battery	Electric transmission Efficiency : MED (Losses of high voltage controllers) Braking regeneration : YES	Power assist possible
Fuel cell direct-supply system		Simple high-voltage system Startup device required	Electric transmission Efficiency : HIGH Braking regeneration : NO	Power and responsiveness depend on fuel cell stack

First of all, the hydrogen supply was considered, and in order to satisfy the requirements of zero emissions and being CO₂-free, a method was adopted that stored pure hydrogen on the vehicle, rather than using a reforming system. High-pressure hydrogen tanks were adopted as the hydrogen storage method after considering the current infrastructure and equipment situation, vehicle energy efficiency, hydrogen charging time, and the ease of the refueling operation.

The motor drive system utilizes the power from the fuel cell stacks as its drive force. It may be combined with energy storage, such as a battery or capacitor, to provide a regeneration of deceleration energy and power assistance. The results of a drive system comparison, shown in Table 1, led to the adoption of an ultra-capacitor assistance system having the following advanced features.

- Making it possible to efficiently utilize deceleration energy to have good energy transfer efficiency, and therefore to achieve high vehicle energy efficiency.
- Making large power assistance possible instantaneously gives advanced dynamic performance.

- It is not necessary to have an energy distribution system using a high voltage control device, so the system can be made smaller and lighter weight.

3.1. System Configuration

The power train system's configuration is shown in Fig. 1. The power train is comprised of high pressure hydrogen tanks that have a physical volume of 156.6 L and store hydrogen at a maximum pressure of 34.4 MPa, a fuel cell system that generates the electrical power necessary to drive the vehicle, an ultra-capacitor that recovers deceleration energy and assists with maximum power during standing start acceleration, a power control device, and a traction motor that drives the vehicle. Figure 2 shows the power train layout.

3.2. Fuel Cell System

The fuel cell system has many component elements and requires space for installation. However, because it is

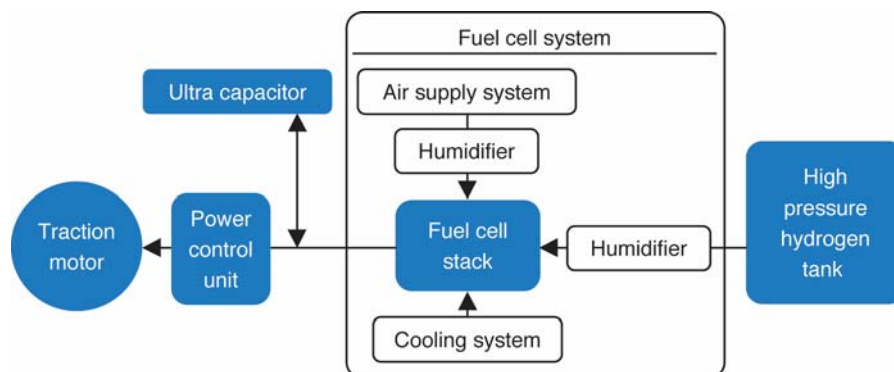


Fig. 1 Power train system configuration

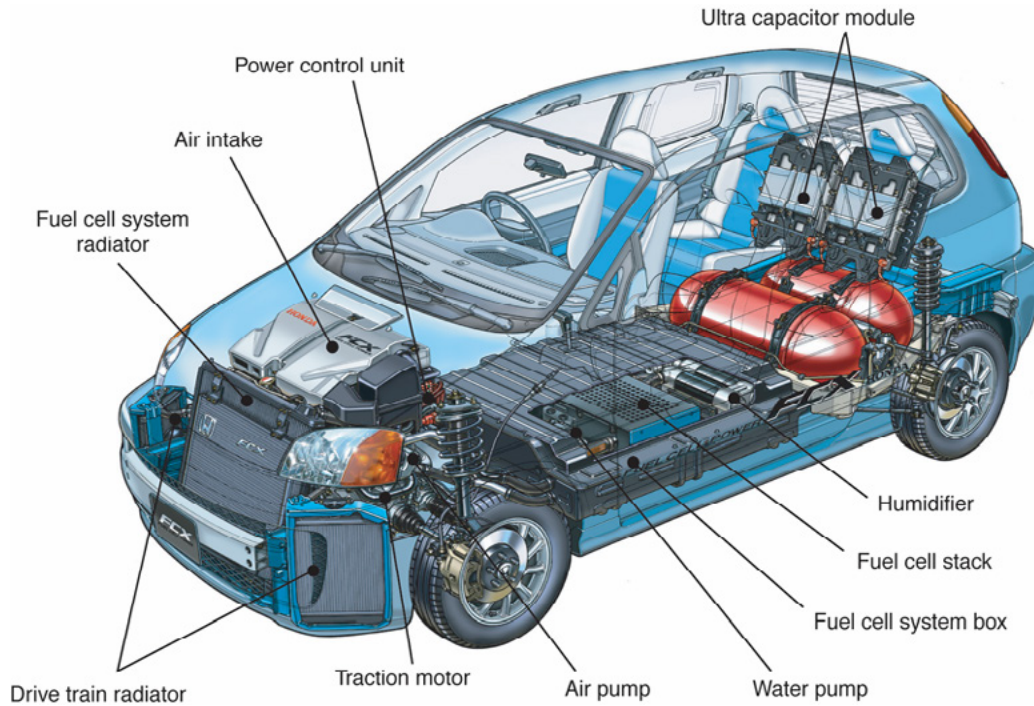


Fig. 2 Power train layout

possible to connect the gas and coolant supplied to the fuel cell stacks using pipes, and the power from the stack using cables, there is a high level of freedom in determining installation locations. Utilizing this freedom, the fuel cell system electrical generating parts are concentrated in a fuel cell system box under the floor. This gives an ideal weight distribution with low center of gravity, and allows the vehicle to have a spacious interior.

3.2.1. Fuel cell stacks

The fuel cell stacks are solid polymer PEMFC (proton exchange membrane fuel cell) type fuel cells, model MK902 made by Ballard Power Systems, Inc., generating a maximum power of 78 kW.

3.2.2. Air supply system

Air is supplied to the fuel cell stacks at the appropriate pressure and flow, through the use of a Lysholm-type air pump driven by a high voltage motor.

Furthermore, the following actions were taken in order to keep air intake noise and air pump vibration noise to a minimum, providing a quiet performance.

- Development of a compact integrated intake module with a muffled resonator chamber.
- Adoption of a double floating mount method that uses rubber mounts to affix the air pump and air pump drive motor onto the traction motor and transmission, which are, in turn, mounted on the vehicle body.

3.2.3. Hydrogen supply system

The hydrogen, stored at a maximum pressure of 34.4 MPa in the high-pressure hydrogen tanks, is supplied to the fuel cell stacks through a regulator, which adjusts it to the appropriate pressure.

3.2.4. Humidification system

It is necessary to humidify the hydrogen and air supplied to a PEMFC fuel cell stack. In order to respond to this requirement, a (completely independent) recycled-water-recovery-type of

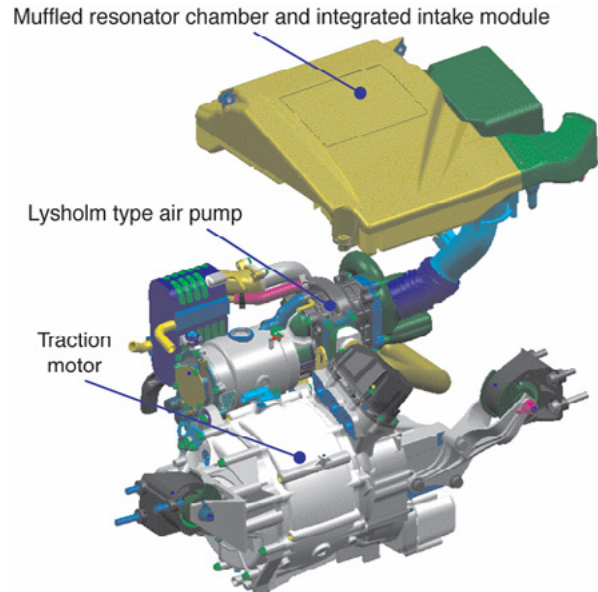


Fig. 3 Power train noise reduction measures

humidification system was developed whereby the water vapor generated as a byproduct of electricity generation by the fuel cell stack is directly re-used to humidify hydrogen and air. This means that neither a condenser nor system to supply water for humidification is necessary, and that the overall system is simple.

3.2.5. Cooling system

Two cooling systems were adopted – a fuel cell cooling system and a drive train cooling system.

The fuel cell cooling system circulates a special fuel cell coolant from the fuel cell through a large radiator developed specially for fuel cell vehicles, making it possible to efficiently release heat from the coolant at a lower control temperature than with a gasoline engine.

3.3. Traction Motor

The new traction motor, which is the major source of driving power, was developed with the aim of greatly improving power performance over that of the EV PLUS.

Power and torque characteristics for the FCX motor and the EV PLUS motor are shown in Fig. 4.

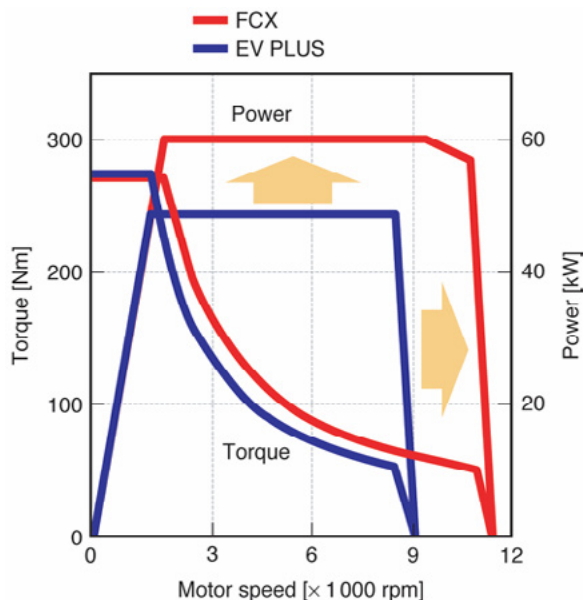


Fig. 4 Power / torque characteristic

First, looking to improve power across the whole range, reluctance torque was also utilized in addition to the magnetic force generated by conventional magnets. Reluctance torque is obtained by letting the magnetic field generated by the stator attract the protruding portion of the magnetic rotor's yoke. In addition, full range full digital controls were adopted.

For the motor to reach maximum speed, it is necessary to have motor heat generation suppression or to make the rotors very heat resistant. At the same time as using highly heat resistant magnets to minimize eddy current loss, which is a cause of magnetic heat generation, the magnets are separated in the rotor shaft direction, and electromagnetic insulation is placed between magnets.

Thanks to these and other measures, such as an efficient mechanism to cool the stator coil heat, the new motor is, as shown in Table 2, smaller than the EV PLUS, and yet achieves a rated power of 60 kW and a CITY mode efficiency of 93% or more.

Table 2 FCX and EV PLUS motor specifications

	EV PLUS	FCX
Max. output (kW)	49	60
Max. torque (Nm)	275	272
Max. revs (rpm)	8750	11000
Avg. efficiency in CITY mode (%)	90	93 or greater

4. Fuel Cell + Ultra-Capacitor System Driving Performance

4.1. Power Characteristics

Figure 5 shows an example of fuel cell and ultra-capacitor power characteristics during driving. At a standing start or when accelerating, the ultra-capacitor swiftly assists the fuel cell, giving good responsiveness to the driver's acceleration operation. During deceleration, energy is regenerated, and the ultra-capacitor is charged.

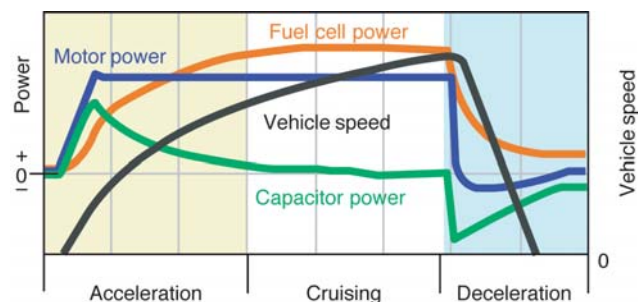


Fig. 5 Fuel cell and capacitor power characteristics

4.2. Acceleration Performance

Figure 6 shows the acceleration rise characteristics during a standing start. Utilizing the power assistance from the capacitor and the traction motor characteristics that generate maximum torque instantly from a standing start, the acceleration rise response time for the FCX is greatly reduced in comparison to that of the ICEV or the HEV. Furthermore, since there is no gear shifting, it is possible to continue that acceleration, and this gives a very smooth superior acceleration feeling.

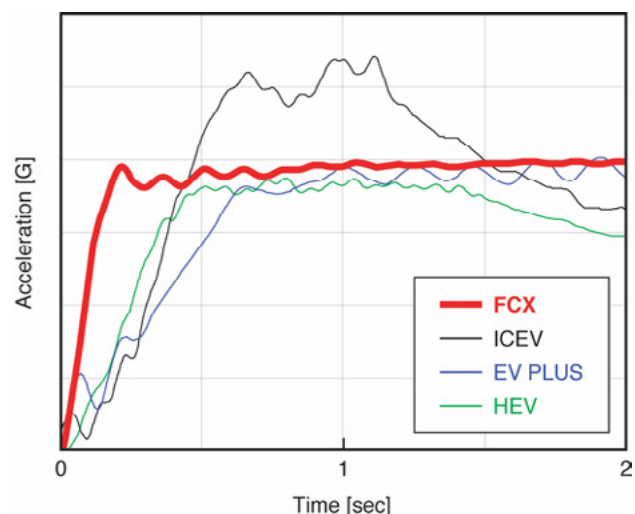


Fig. 6 Standing start performance

4.3. Efficiency and Fuel Consumption Performance

Figure 7 shows fuel cell power, capacitor power and voltage when driving in CITY mode, as used in US fuel consumption certification testing. When the vehicle is stopped, the air supply system and the fuel cell stack electricity generation are stopped by the auto idle-stop system, and the amount of electricity consumed by auxiliary devices is reduced. Thanks to this feature, the amount of hydrogen consumed is minimized. In addition, at the end of driving the ultra capacitor voltage is equal to that of at the beginning, and highly accurate energy give-and-take is feasible, even in CITY mode where assistance and regeneration are repeated.

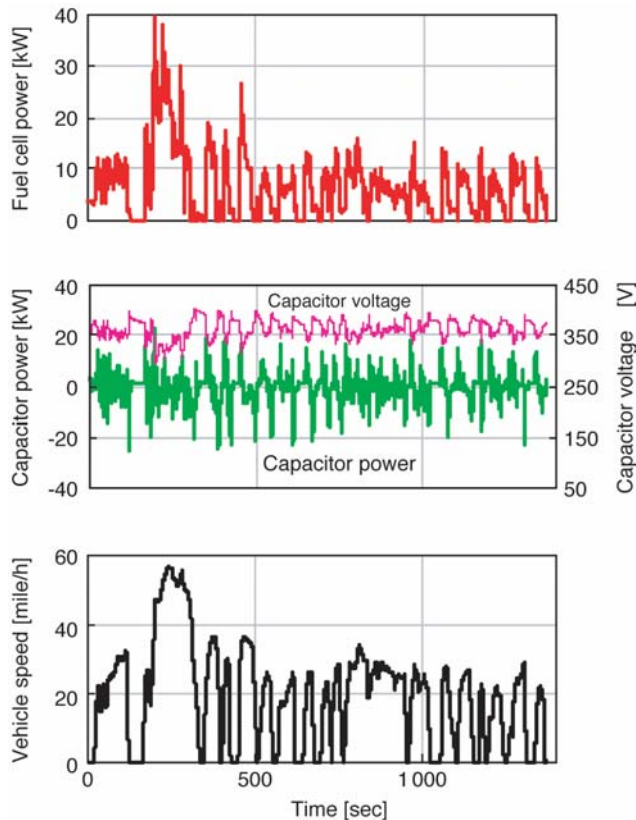


Fig. 7 Speed and power profile in CITY mode

Through the above energy management control, as shown in Fig. 9, the FCX achieves an energy efficiency of 45%, which is twice that of an ICEV, and approximately 1.5 times that of an HEV of equivalent size. The FCX is the world's first fuel cell vehicle to obtain EPA (US Environmental Protection Agency) and CARB (California Air Resources Board) fuel economy certifications⁽⁵⁾. In CITY mode, the certified value is 56.8 miles/kg Hydrogen and the label value is 51 miles/kg Hydrogen, while in highway mode, the certified value is 61.7 miles/kg Hydrogen and the label value is 48 miles/kg Hydrogen. Figure 8 shows the fuel economy label. In interpreting this label, the energy of 1 kg of hydrogen is roughly equivalent to the energy of 1 gallon of gasoline. Figure 10 compares fuel economy in CITY mode, between the ICEV, the HEV, and the CNG (natural gas) vehicles of roughly the same size. The FCX fuel economy is 1.7 times that of the ICEV and the CNG vehicles, and surpasses even the HEV.

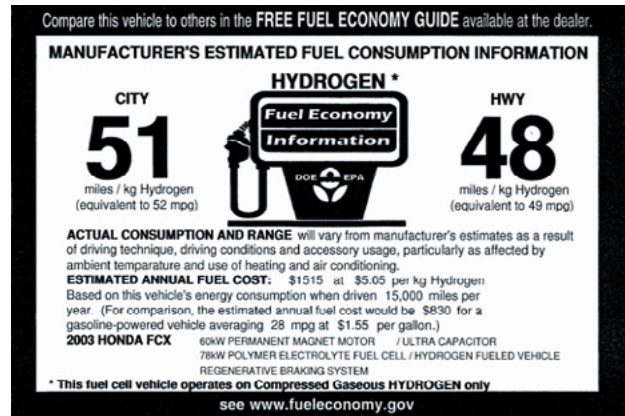


Fig. 8 FCX fuel economy label

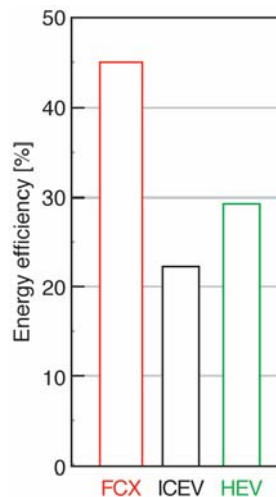


Fig. 9 Efficiency in CITY mode

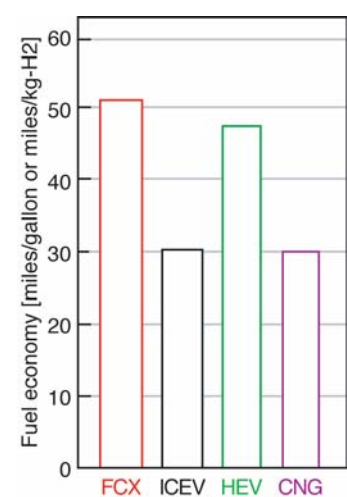


Fig. 10 Fuel economy in CITY mode

5. Summary

A power train system was developed that combines a pure hydrogen fuel cell with an ultra-capacitor, achieving a vehicle energy efficiency of 45%, which is 1.5 times better than that of an HEV of equivalent size, in addition to zero emissions, including CO₂. Moreover, it was possible to reach a fuel economy of 51 miles/kg hydrogen (label value), which surpasses an HEV, and to have a standing start acceleration performance that surpasses an ICEV. As a result, the FCX power plant is truly the next generation power plant that achieves, at a high level, the “drivability, fuel economy, and marketability” demanded of a vehicle by the customer, providing the ultimate in clean driving performance.

However, in looking towards widespread use of fuel cell vehicles, many issues remain, including low temperature start, cost reduction, and cruising range.

Now, with the world's first fuel cell vehicle being on the market and delivered, Honda continues to work on further technological development, in order to address these issues.

6. Acknowledgements

Finally, the authors would like to express their deepest gratitude to the many people, both at Honda and beyond, that generously cooperated in the development of the FCX, its launch, and sales.

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■ Authors ■



Takayuki OGAWA



Kenichiro KIMURA



Kenji UCHIBORI



Sachito FUJIMOTO



Kiyoshi SHIMIZU