

Next-generation Fuel Cell Stack for Honda FCX

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ABSTRACT

The next generation fuel cell stack employs an aromatic electrolyte membrane, which offers outstanding proton conductivity, a stamped metal separator formed with a unitized seal for superb electrical and thermal conductivity, and a simple stack structure which is obtained using the springiness of the stamped metal separators. The combination of these innovative new technologies enables the new fuel cell stack to achieve output density that ranks among the best in the world, to be half the size of its predecessor, and to operate in temperatures from -20 to $+95$ °C, leading to its enhanced environmental adaptability.

In order to maximize space efficiency in the fuel cell system box, the FCX uses two compact FC stacks. The resulting integrated module structure, with the humidifier unit, enables a more compact fuel cell system box to be achieved. Energy efficiency of the new fuel cell system has also increased over the previous model, due to the enhanced power generation efficiency of the fuel cell stack.

1. Introduction

To address energy and air pollution issues, Honda has been carrying out research and development on a clean power plant that discharges practically no CO₂ or toxic substances.

Since equipping a test vehicle with self-developed fuel cell stacks in September 1999, Honda has aimed to promote fuel cell-powered vehicles, and has worked on developing more compact fuel cell stacks with higher output so as to make them adaptable to wider areas^{(1), (2)}. The new-generation fuel cell stack was announced in October 2003, and a Honda FCX, the first electric car equipped with this fuel cell stack, was delivered to State of New York in November 2004.

This report introduces the lightweight and compact next-generation fuel cell stack which drastically reduces the number of parts used, produces high output that ranks among the best in the world, and starts even below freezing temperature.

2. Development Goals

Currently, the competition to develop proton exchange membrane fuel cells for transport vehicles, including automobiles, and for general household use has become fierce.

This type of fuel cell can be used at comparatively low temperatures in the vicinity of 80 °C, and is relatively compact. However, issues for automobile use such as the starting of the vehicle below freezing temperature, effective utilization of space, and energy efficiency still need to be addressed. The two main goals for the development of the next-generation fuel cell stack were identified as below.

- (1) Compact with high output (output density)
- (2) Environmental adaptability (performance at high temperatures/low temperatures)

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3. Fuel Cell Stack

As shown in Fig. 1, a proton exchange membrane fuel cell makes use of a polymer electrolyte membrane and directly converts chemical energy to electric energy using the electrochemical reactions between hydrogen and oxygen.

Hydrogen electrode (-) : $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$

Oxygen electrode (+) : $1/2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$

The polymer electrolyte membrane that conducts the protons is sandwiched between two electrode layers (hydrogen electrode/oxygen electrode), and this assembly in turn is sandwiched between two gas diffusion layers to form the Membrane and Electrode Assembly (MEA)⁽³⁾. The MEA is held between two separators on both sides to form a single cell. Since a voltage of only 1.23 V can be obtained from one cell theoretically, the cells are stacked as shown in Fig. 2, so that the stacking of cells one by one generates progressively higher voltages. The voltage is determined by the number of cells stacked, and the current is determined by the surface area of the electrodes. Accordingly, either the number of stacked cells has to be increased, or the surface area of the electrode has to be increased, to increase the power output.

Conventionally, fluorine electrolyte membranes were used for the stack. Because this type of membrane becomes soft at high temperatures, its use has been restricted to the range of 0 °C to 80 °C. Carbon separators have also been used in the past, which with their high electrical resistance and poor heat conduction became an obstacle in attaining high performance. A quick rise in temperature, from low temperatures, was also suppressed. Furthermore, carbon separators do not have very high strength. To use the separator as a structural member that firmly holds multiple cells within a stack from both sides, its thickness needed to be

increased. Thus, compactness of the stack could not be achieved easily.

High output of the stack was achieved by developing an aromatic electrolyte membrane with high proton conductivity, and both compactness and high output were achieved by developing a stamped metal separators having high electrical and thermal conductivity formed with a unitized seal. A simple stack structure was obtained using the springiness of the stamped metal separator formed with a unitized seal. This arrangement helped to achieve approximately a two-fold increase in compactness and high output compared to the conventional stack, as shown in Fig. 3, and enabled starts below freezing temperature. The evolution of the high power output, compactness, and lightness of the stack are shown in Fig. 4, Fig. 5 and Fig. 6, respectively.

3.1. Aromatic Electrolyte Membrane

An electrolyte membrane with a new molecular structure was developed, as shown in Fig. 7, by combining an ion exchange

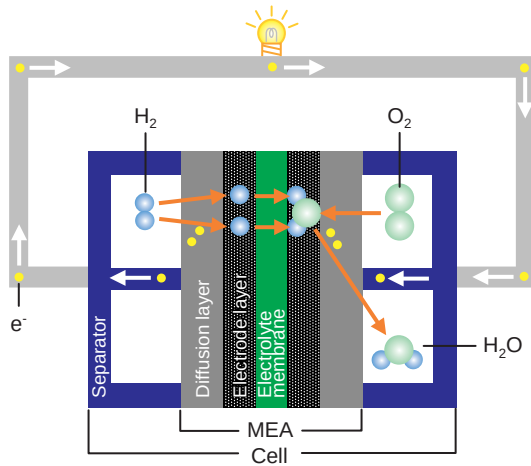


Fig. 1 Electrical generation in fuel cell

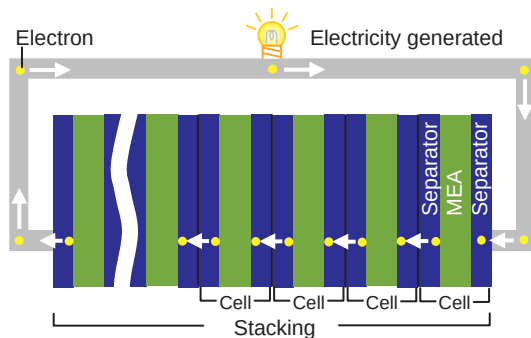


Fig. 2 Structure of fuel cell stack

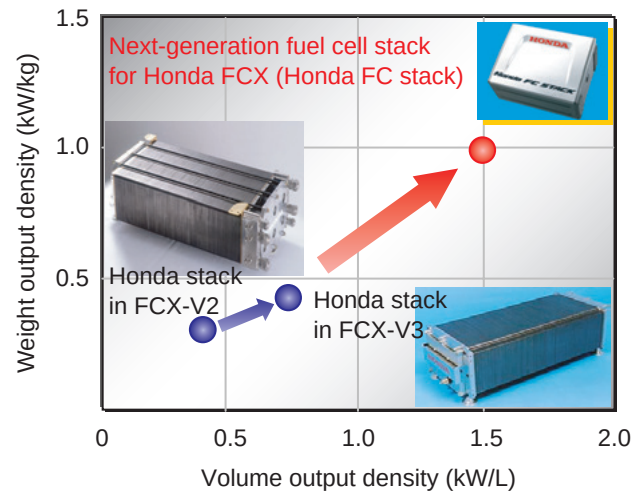


Fig. 3 Honda stack evolution

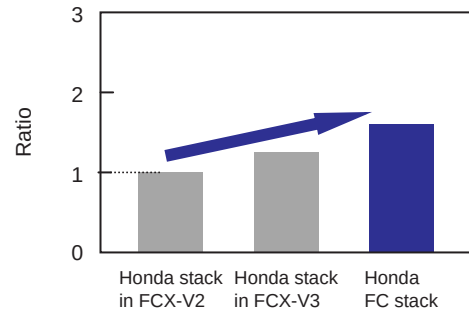


Fig. 4 Power output evolution

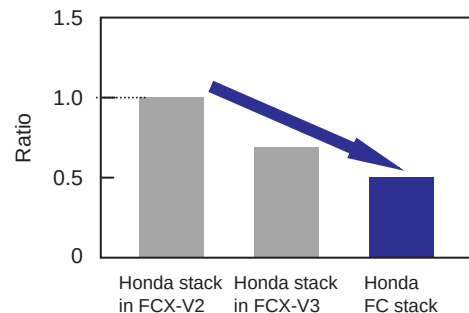


Fig. 5 Compactness evolution

substrate (sulfone substrate) with the main chains of an aromatic structure having high thermal stability. The ion exchange substrate concentration governing ion conductivity was increased, more than a comparable conventional fluorine electrolyte membrane. The results were that the membrane resistance was halved as shown in Fig. 8, and high proton conductivity was attained, even below freezing temperature. A fuel cell stack that could generate power at -20°C was therefore achieved.

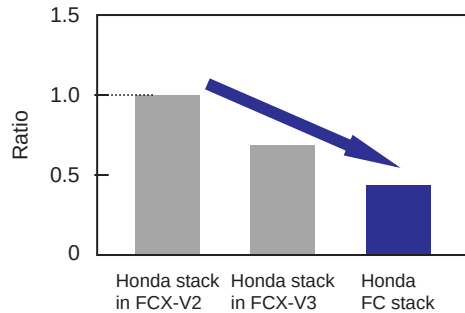


Fig. 6 Lightness evolution

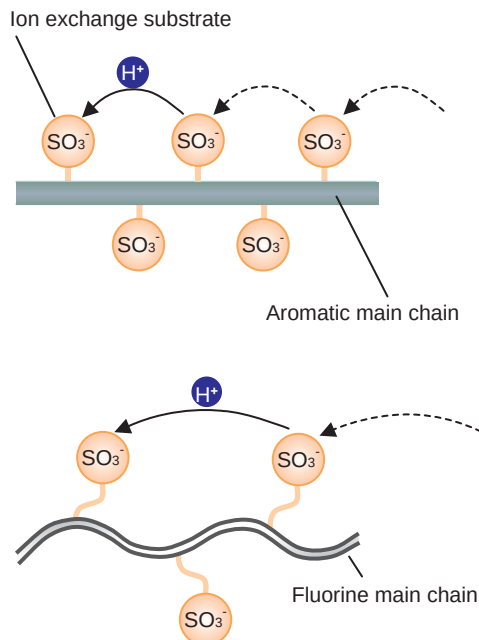


Fig. 7 Comparison of polymer structures

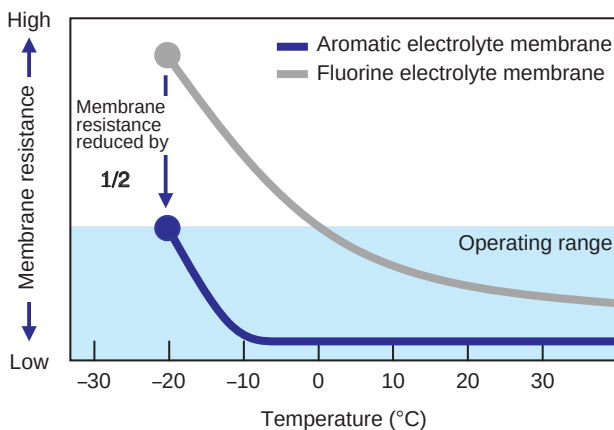


Fig. 8 Enhanced proton conductivity electrolyte membrane

The conventional fluorine electrolyte membrane becomes soft and deforms abruptly when the temperature rises above 80°C , therefore, it could not be used at temperatures above this level. The newly developed aromatic electrolyte membrane does not become soft or deform at high temperatures, due to its aromatic main chains having high strength and high thermal resistance. As shown in Fig. 9, the new membrane enabled high temperature use at 95°C , in addition to exhibiting high durability (Fig. 10). However, chinks occur between the electrode layer and the membrane in conventional membrane/electrode layer manufacturing, as shown in Fig. 11, even though the aromatic main chain shows good anti-deformity characteristics at high temperatures. An original manufacturing method was developed to address this issue, and superior adhesion has been realized between the electrolyte membrane and electrode layer.

3.2. Stamped Metal Separator Formed with Unitized Seal

The separator should have high electrical conductivity since it forms a pathway for the electrons. At the same time, thermal conductivity (temperature rise property) is also important,

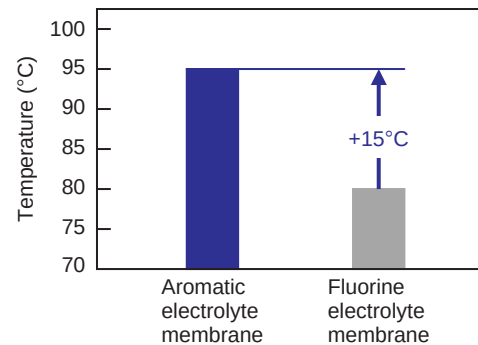


Fig. 9 Enhanced max operating temperature

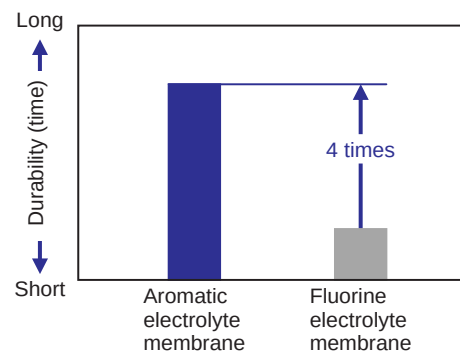


Fig. 10 Enhanced high-temperature durability (80i)

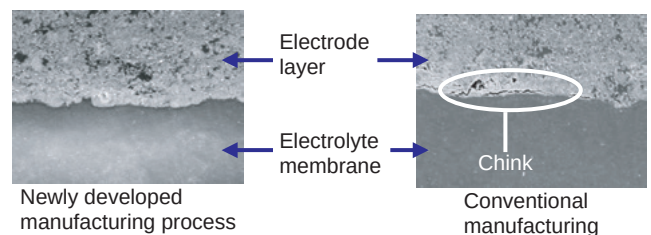


Fig. 11 Comparison of adhesion between aromatic electrolyte membrane and electrode layer

considering that the water produced, when power is generated below freezing temperature, should not freeze. Making use of the high electric and thermal conductivity of stainless steel, a stainless steel plate containing electrically conductive metallic inclusions was developed reducing the contact resistance to one-fourth the resistance of conventional carbon separators at -20°C (Fig. 12).

By using stainless steel, which has higher strength than carbon, a design with half the thickness of that of a carbon separator was possible. As a result, the thermal conductivity was enhanced five-fold (Fig. 13), enabling the entire stack to be warmed quickly and equally, curtailing the time required from the start of power generation to warm-up of the unit.

Metallic materials have been considered in techniques for enhancing both electrical and thermal conductivity. There are issues involved, however, mainly oxidation and corrosion because of the electric current. For instance, if passive treatment is used to prevent oxidation and corrosion, the resistance of the metallic surface increases and adequate performance cannot be obtained, which is why carbon separators were normally used in the past. To resolve this issue, conductive particles (electrically conductive metallic

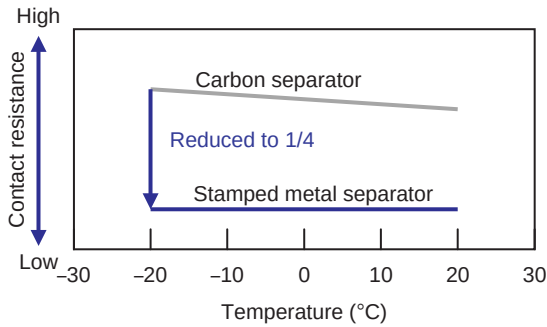


Fig. 12 Enhanced electrical conductivity of separator contact surface

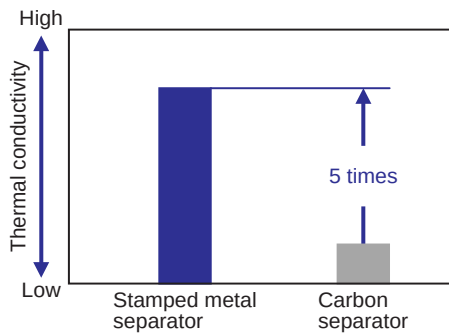


Fig. 13 Comparison of thermal conductivity

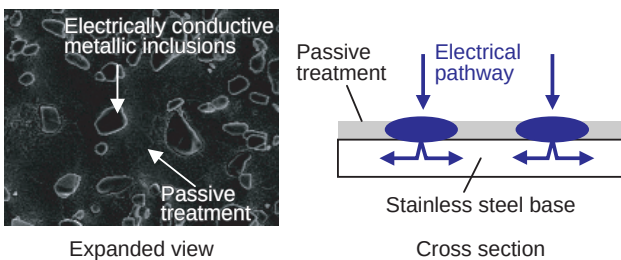


Fig. 14 Developed stainless steel

inclusions) that allow electricity to pass through easily were dispersed in the stainless steel base, as shown in Fig. 14, and the surface was subjected to passive treatment to achieve a good balance between high conductivity on the one hand, and durability and thermal conductivity on the other hand.

3.3. Stack Construction

As shown in Fig. 15, previous stack structures employed carbon separators and separate seals. A disk spring and backup plate were installed and connected by large size bolts to attain a high level of airtightness. In contrast, the fuel cell stack developed this time, as shown in Fig. 16, makes use of metallic separators with high strength and with 50% thickness of carbon separators. Moreover, the cell units have become thinner and the number of parts has been reduced, thanks to the use of unitized seals. Using the springiness of stamped metal separators, construction has been simplified effectively by merely encasing the stacked cells by panels, thereby reducing the number of parts of the entire stack to nearly half. In this way, the fuel cell stack has been made lighter and more compact, and the output density has been increased to more than two times the density of the conventional stack (Fig. 17 and Table 1).

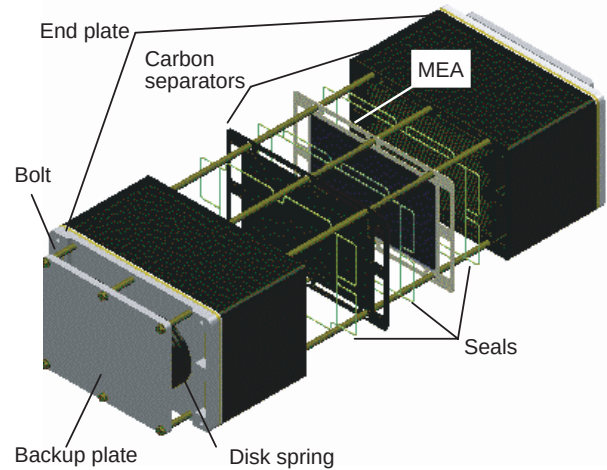


Fig. 15 Honda fuel cell stack in FCX-V3 (previous stack)

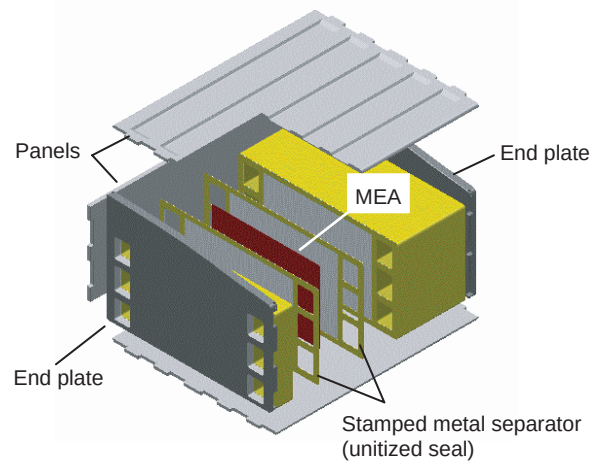


Fig. 16 Next-generation fuel cell stack for Honda FCX (Honda FC stack)

Table 1 Honda FC stack specifications

Output (kW)	50
Volume (L)	33
Weight (kg)	48
Max operating temperature (°C)	95
Cold start allowable temperature (°C)	-20



Fig. 17 Honda FC stack

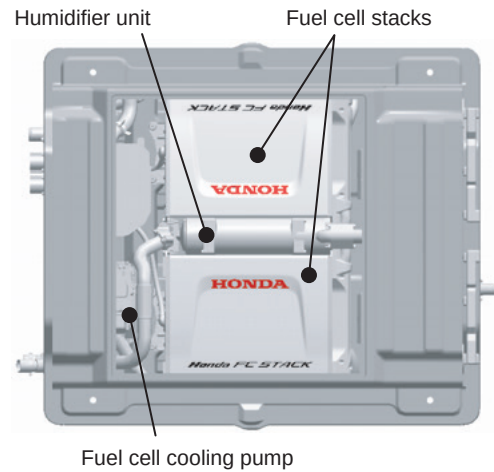


Fig. 18 Fuel cell system box configuration

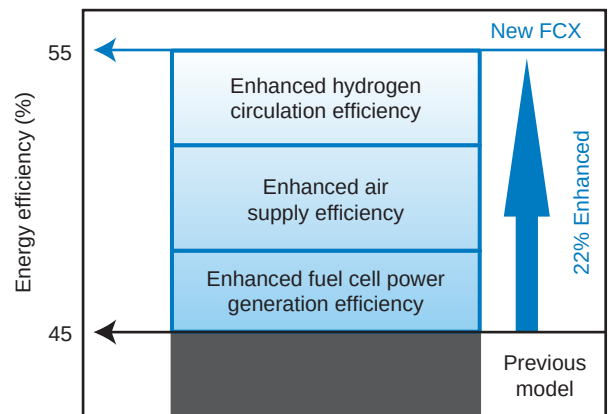


Fig. 19 Breakdown of enhanced energy efficiency (Honda data, LA-4 mode)

4. Fuel Cell Auxiliary System

The fuel cell stack was divided into two parts, with a humidifier module arranged between these two parts and integrated, which enabled the efficient layout of fuel cell auxiliaries, and attained compactness in the overall fuel cell system. The construction of the fuel cell system box fitted in the new model FCX is shown in Fig. 18.

Despite adding features to allow for low temperatures, the overall system has become lighter and more compact after rearranging the system. As a result, a fuel cell system that is about 5% smaller in volume and approximately 3% lighter in weight than that of the previous model⁽⁴⁾ was achieved.

The energy efficiency of the air supply system was enhanced by reducing the pressure losses of the air pathways, including the stack. The efficiency of the hydrogen circulation system was enhanced by reducing the power consumption through utilization of the low-pressure loss characteristics of the stack and reduction of pressure losses in the pathways, while also taking into account equal distribution of the hydrogen supply to the two fuel cell stacks.

With these changes, the energy efficiency of the entire fuel cell system, including stacks, was enhanced by 22% compared to that of the previous model (Fig. 19).

Furthermore, the start of power generation at temperatures as low as -20 °C was easily attained by optimally setting the air supply, hydrogen supply, humidification, and cooling.

5. Conclusion

The next-generation fuel cell stack fitted in the Honda FCX has achieved compactness and high output comparable to those of the highest levels worldwide, in addition to enabling starts below freezing temperature for the first time ever in fuel cell cars. Important technologies employed are summarized below.

- (1) Development of the aromatic electrolyte membrane enabled starting below freezing temperature, through increased proton conductivity, and enhanced durability at high temperatures.
- (2) Development of a stamped metal separator formed with a unitized seal, enabled the time from the start of power generation to warm-up to be reduced, because of enhanced electrical and thermal conductivity, while also enabling a significant reduction in the stack size.
- (3) The aromatic electrolyte membrane, stamped metal separator formed with a unitized seal, and simple stack structure enabled a compact design and high output to be achieved.
- (4) Utilizing two separate, compact fuel cell stacks enabled the appropriate arrangement and layout of auxiliaries, including humidifier modules to be achieved, thereby reducing the size of the fuel cell system. In addition, reviewing the operating conditions and reducing the pressure losses in the pathways enabled energy efficiency to be enhanced.

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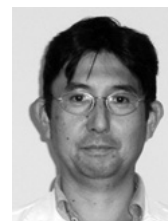
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