

New Fuel Cell Stack for FCX Clarity

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ABSTRACT

In order to achieve weight savings, increased compactness, and higher power output from the fuel cell stack that functions as the core technology for a fuel cell vehicle, Honda has employed a unique configuration in the development of its new V Flow FC stack. The development of the new FC stack has enabled the realization of a V Flow FC platform in which the FC stack is positioned in the center tunnel. This has in turn enabled the use of a full sedan layout.

Based on a V Flow cell structure and wave flow channel separators, and employing a one-box stack configuration, the V Flow FC stack achieves a 50% increase in volume output density and 67% increase in weight output density against the previous FC stack. In addition, the new configuration has increased water drainage capacity, which has reduced heat mass and resulted in enhanced low-temperature startability. Continuous production and automated layering of the MEA and separators that comprise the cells, in addition to a reduction in the number of parts, have enabled the achievement of increased productivity.

1. Introduction

Emitting no CO₂ or environmentally-harmful substances, fuel cells are viewed as a clean, resource-recycling powerplant, able to assist in responding to global warming and energy issues. Fuel cell vehicles employ a system in which electricity generated by fuel cells is used to drive a motor, and Honda has pushed ahead with R&D on fuel cells in the belief that a vehicle embodying a new sense of value could be created by means of the design of the powerplant layout and adjustment of its power characteristic.

Honda first fitted a fuel cell stack developed in-house in an experimental fuel cell vehicle in September 1999. In October 2003, the company announced the development of the Honda FC stack, employing stamped metal separators with unitized seals and aromatic electrolytic membranes. The Honda FC stack achieved a high power density, and was able to start in cold climates⁽¹⁾.

As a result of continuous efforts to introduce further innovations to the configuration of its fuel cell stacks, Honda has been able to develop a one-box stack, using a proprietary V Flow cell structure and wave flow channel separators, that achieves a 50% increase in volume output density and 67% increase in weight output density. In September 2006, the company announced an FCX concept based on its proprietary V Flow FC stack and a V Flow

FC platform in which the V Flow FC stack was fitted in the center tunnel. In November 2007, the FCX Clarity, a vehicle embodying the FCX concept, was announced. Production of the FCX Clarity commenced in June 2008.

This paper will provide an overview of the V Flow FC stack configuration, which has enabled the realization of weight savings and increased compactness, higher power, enhanced low-temperature startability, and increased productivity. Figure 1 shows a cut-away view of the V Flow FC stack. In this image, hydrogen and its flow path is shown in red, and air and its flow path is shown in blue.



Fig. 1 Cut-away model of V Flow FC stack

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2. What is a Fuel Cell?

As Fig. 2 shows, a proton exchange membrane fuel cell is a cell that utilizes a polymer electrolytic membrane to directly convert chemical energy into electrical energy via an electrochemical reaction between hydrogen and oxygen.

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

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

The polymer electrolytic membrane that allows the passage of hydrogen ions is sandwiched between two electrode layers (a hydrogen electrode and an oxygen electrode) and two diffusion layers, which together form a Membrane Electrode Assembly (MEA)⁽²⁾. This MEA is sandwiched between two separators, forming a single cell. Because the voltage of a single cell cannot exceed a theoretical voltage of 1.23 V even when the circuit is open, the cells are stacked as shown in Fig. 3, and a high voltage is produced by the generation of electricity by

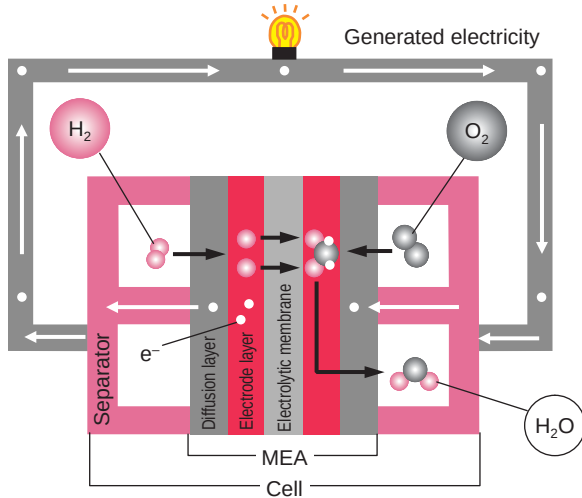


Fig. 2 Mechanism of electricity generation in fuel cell stack

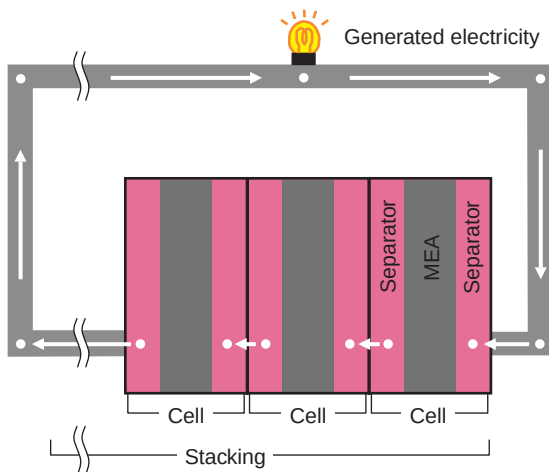


Fig. 3 Fuel cell stack configuration

each individual cell. Voltage is therefore determined by the number of cells in the stack, and current is determined by the area of the electrodes. Because of this, it is necessary to increase either the number of cells in the stack or the area of the electrodes in order to increase power.

3. Development Goals

The following goals were set for the development of a fuel cell vehicle:

- (1) Contribution to combating global warming and addressing energy issues.
- (2) Embodiment of new values that change the future of the automobile.
- (3) Development of mass production technologies looking towards widespread diffusion.

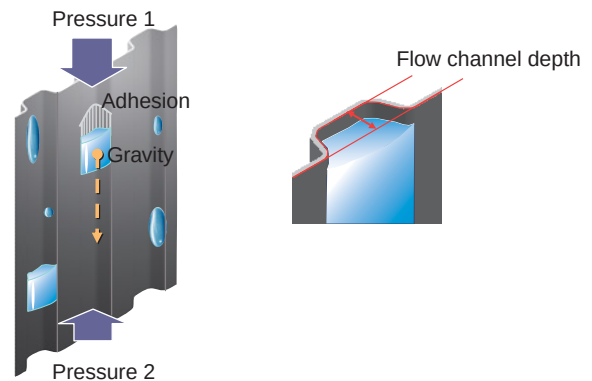
The following four points were therefore established as the main targets in the development of the new fuel cell stack:

- (a) Achievement of weight savings and increased compactness
- (b) Increased power and stability of electrical generation
- (c) Enhanced low-temperature startability
- (d) Increased productivity

4. V Flow Cell Structure

In order to generate electricity by the fuel cells, it is necessary to provide hydrogen and air continuously over the generating surfaces. However, if the water produced from the reaction between the hydrogen and oxygen accumulates in the gas channels, it can impede the flow of gas, preventing hydrogen and air from being supplied uniformly to the generating surfaces and making generation unstable.

In order to make the fuel cell stack more compact, it



$$\text{Water drainage capacity} = \text{Pressure 1} - \text{Pressure 2} + \text{Gravity}$$

$$\text{Flow channel depth} = \frac{\text{Water adhesion force}}{\text{Water drainage capacity}}$$

Fig. 4 V Flow cell structure

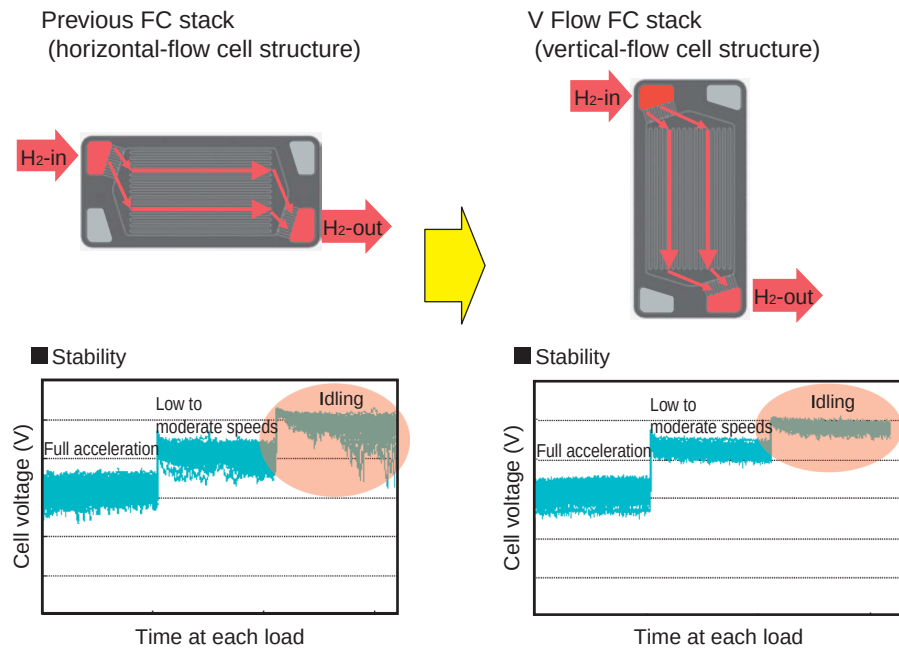


Fig. 5 Comparison of cell structure

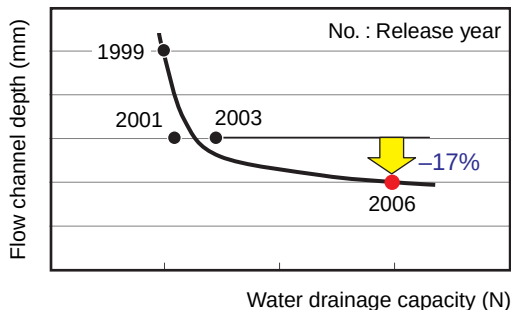


Fig. 6 Comparison of flow channel depth

is necessary to reduce the thickness of the cells by reducing the depth of the gas flow channels for hydrogen and air. However, reducing the depth of the gas channels would increase the force producing adhesion of the water to the walls of the channels, thereby promoting water accumulation. The relationship between the depth of the channels, the water adhesion force and the water drainage capacity can be expressed as follows (Fig. 4):

Flow channel depth = Water adhesion force / Water drainage capacity

In order to reconcile the achievement of stable generation performance with reduction of the depth of the gas channels, it is therefore necessary to increase the water drainage capacity to the same degree that the water adhesion force increases as a result of the reduction of the depth of the channels. This led to the development of a V Flow cell structure, in which hydrogen and air flow vertically, rather than horizontally, as in the previous FC stack. In the previous horizontal-flow cell structure, the

difference in pressure between the inlet and the outlet of the cells functioned as the only force promoting drainage of the water in the flow channels. The new vertical-flow cell structure adds gravity to this pressure difference, thus increasing the water drainage capacity. This has enabled stable generation to be maintained despite the reduction in depth of the flow channels (Fig. 5). As a result, the depth of the flow channels has been reduced by 17% against that of the previous cells (Fig. 6).

5. Wave Flow Channel Separators

Generation performance can be maximized by achieving a uniform flow of hydrogen, air, and coolant to the generating surfaces. If the coolant in particular does not flow uniformly, localized areas of high temperature will form in the MEA, and changes will occur in the MEA in those areas.

The use of stamped metal separators and straight flow channels creates a configuration in which hydrogen, air, and coolant all flow in the same direction. This necessitated the use of three manifolds positioned in a row in each cell to introduce the substances, reducing the width of their supply path to the generating surfaces and impeding uniform supply.

It was judged that positioning the gas manifolds vertically and widening the gas supply paths, in addition to bifurcating the short sides of the generating surfaces, would be an effective means of achieving a uniform supply of hydrogen and air to the generating surfaces. Wave flow channel separators were therefore used to achieve a horizontal flow of coolant (Fig. 7). The development of wave flow channel separators that turn the

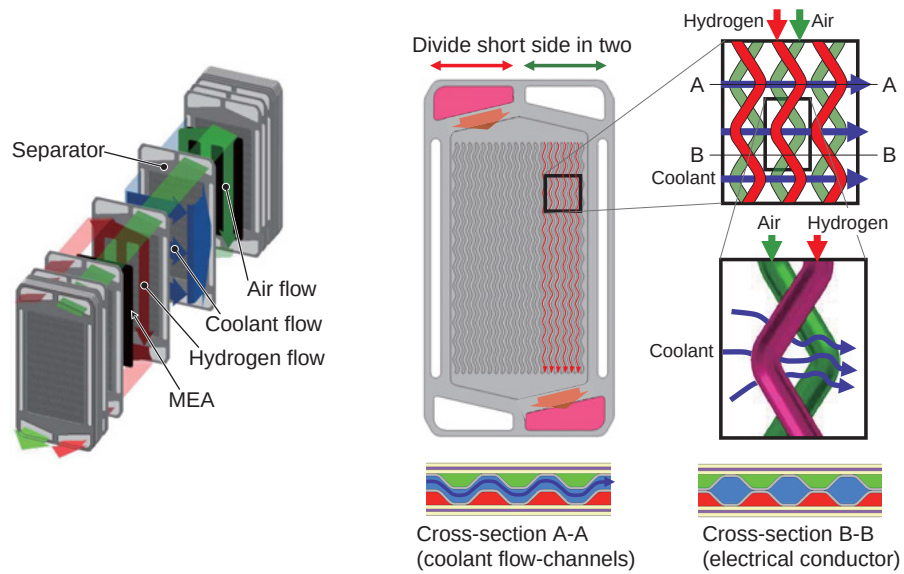


Fig. 7 Wave flow channel separator structure

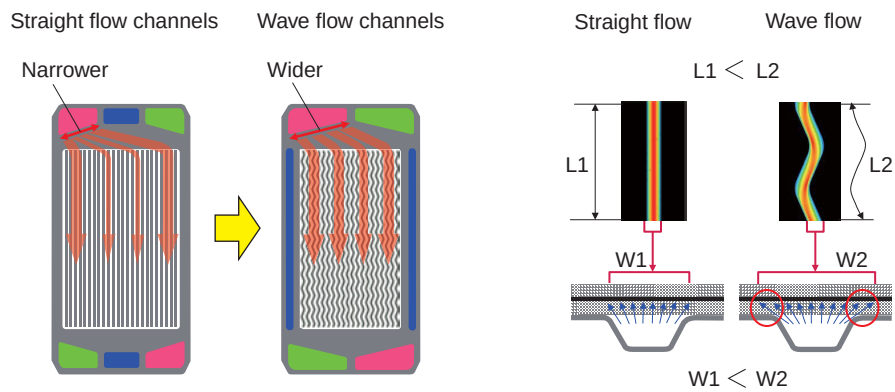


Fig. 8 Enhanced hydrogen-air distribution

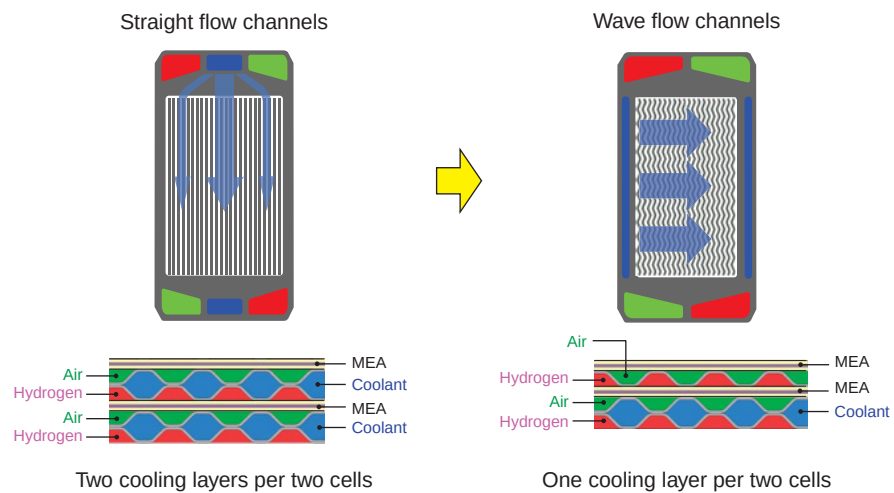


Fig. 9 Enhanced coolant distribution

coolant flow in a horizontal direction, across the flow of hydrogen and air, enabled the width of the supply paths for both gases and coolant to be increased, enabling the achievement of uniform supply to the generating surfaces. In addition, because each wave flow channel is longer than a corresponding linear flow channel, and varies the flow, the use of the wave flow channel separators has increased the dispersion of hydrogen and air (Fig. 8).

As a result, hydrogen and air pass over the entire surface of the electrode layer. More effective use is made

of the generating surfaces, resulting in a 10% increase in generating performance against that of the linear flow channels. In addition, the horizontal coolant flow has helped to achieve uniform cooling of the generating surfaces, enabling the cooling layers that were previously required for each cell to be halved in number, and the number of separators required for every two MEA to be reduced from four to three (Fig. 9). As a result, the thickness of the stacks has been reduced by 20%, and their mass by 30% (Fig. 10).

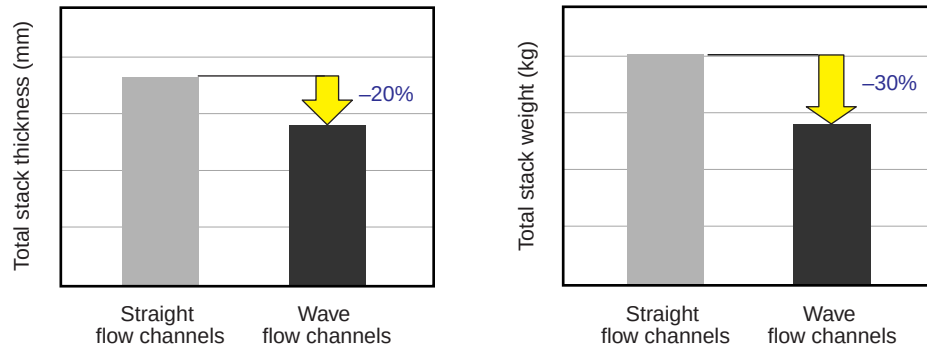


Fig. 10 Reduction of stack thickness and weight

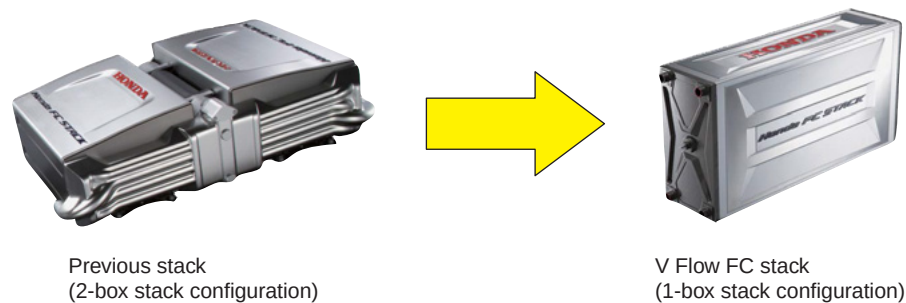


Fig. 11 Evolution of stack configuration

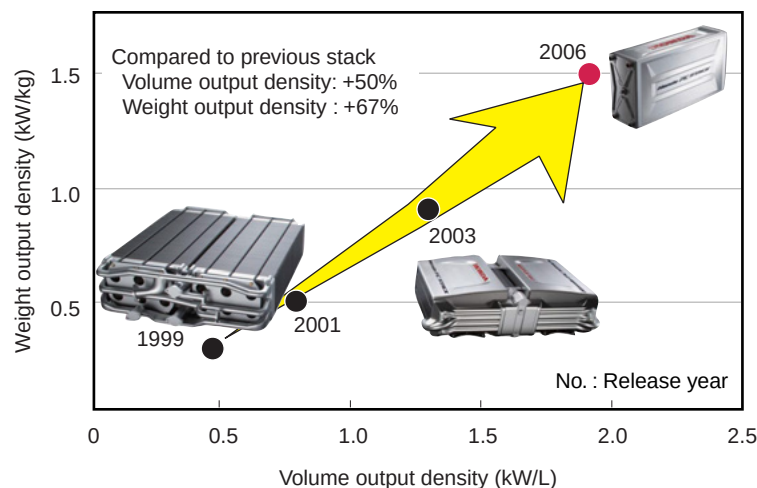


Fig. 12 Comparison of stack output density

Table 1 Evolution of Honda fuel cell stack

Release year	1999	2003	2006
Appearance			
Output	60 kW	86 kW	100 kW
Volume	134 L	66 L	52 L
Weight	202 kg	96 kg	67 kg
Electrolytic membrane	Fluorine electrolytic membrane Operating temperature: 0 °C - 80 °C	Aromatic electrolytic membrane Operating temperature: – 20 °C - 95 °C	Aromatic electrolytic membrane Operating temperature: – 30 °C - 95 °C
Stack configuration	Bolt-fastened configuration	Panel box configuration	1-box stack configuration
Cell structure	Machined carbon separators Separate seals	Stamped metal separators with unitized seals	V Flow cell structure Wave flow channel separators

6. One-box Configuration

The reduction in the thickness of the cells achieved through the use of a V Flow cell structure and wave flow channel separators has helped to enable a one-box FC stack configuration to be employed in place of the previous two-box configuration (Fig. 11). As a result, volume output density has been increased by 50% and weight output density by 67% against the previous stack, and packageability has been enhanced (Fig. 12).

Table 1 shows the evolution of the Honda FC stack. The new one-box stack, achieving a volume output density of 1.92 kW/L, has helped to enable the realization of the full sedan layout used in the FCX Clarity, a V Flow FC platform in which the fuel cell stacks are fitted in the center tunnel.

7. Enhanced Low-temperature Startability

The previous Honda FC stack employed aromatic electrolytic membranes in which membrane resistance had been reduced by half and stamped metal separators with high heat conduction, enabling generation to be commenced at -20°C.

One of the goals established for the present FC stack was to enable its use in a wider range of areas. The use of the V Flow cell structure has increased water drainage

capacity and reduced heat mass by 40% (Fig. 13), resulting in increased output at start-up. Heat mass was reduced as a result of the reduction of the volume of coolant and the number of separators employed, enabled by the use of the wave flow channel separators, and by the reduction of the number of box components resulting from the use of a one-box stack configuration. The lower heat mass has enabled the time required to reach 50% output at start-up at -20°C to be reduced by three-quarters against that in the previous stack (Fig. 14), and has also enabled start-up at -30°C.

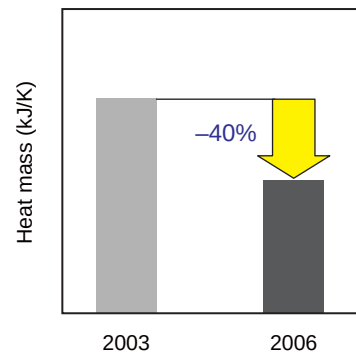


Fig. 13 Comparison of heat mass

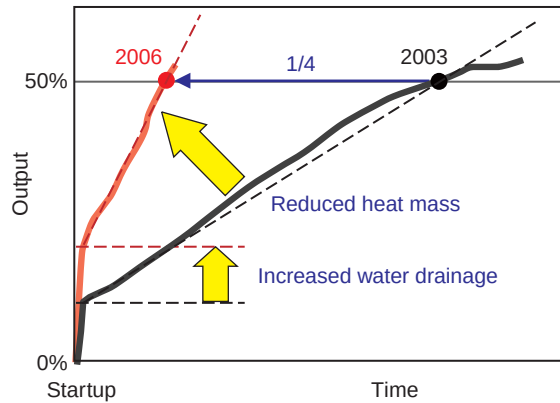


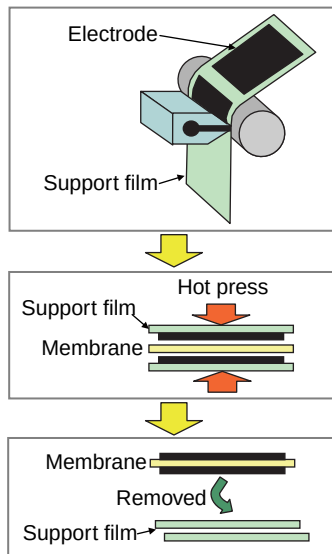
Fig. 14 Comparison of low-temperature performance (-20°C operation)

8. Increased Productivity

Fuel cell stacks are made up of some hundreds of layered cells, making the achievement of increased productivity for the cell components an issue. Production technologies that increased productivity for the MEA and separators that make up the cells and cell layers, in addition to specifications that were appropriate for these production technologies, were therefore developed.

In the case of the previous MEA, in order to produce a Catalyst Coated Membrane (CCM) prior to sandwiching between the diffusion layers, the electrode was hot-pressed onto the membrane after the electrode had been coated on a support film. For the new cells, a technique of shape-controlled electrode coating on the membrane has been

Conventional process



New process

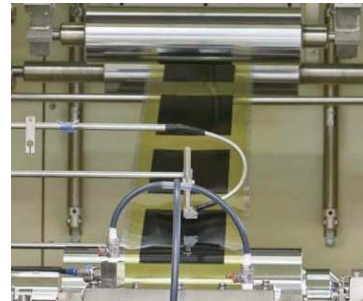
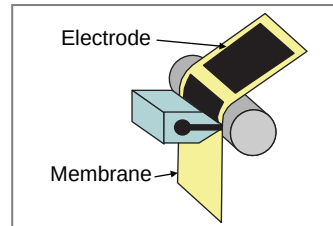
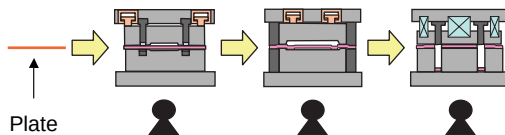


Fig. 15 Electrode coating process

Conventional process



New process

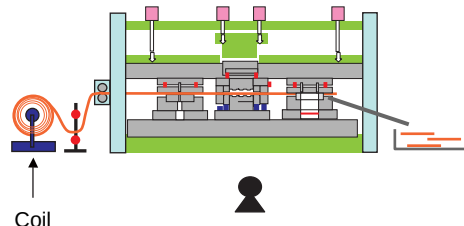


Fig. 16 Separator stamping process

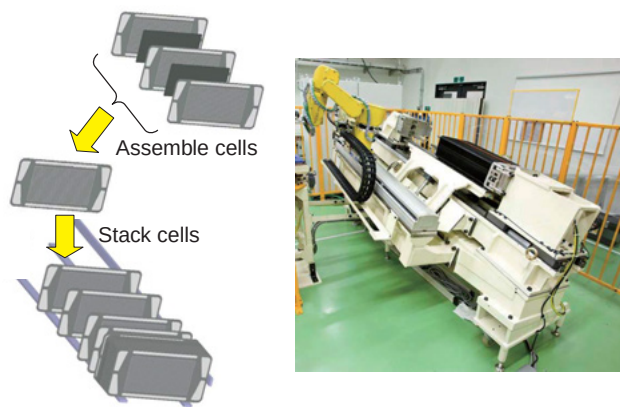


Fig. 17 Cell stacking process

developed to enable direct formation of the electrodes in a predetermined shape on the roll-shaped electrolytic membrane (Fig. 15). In addition, progressive stamping using metal in coils has been employed to produce the stamped metal separators, in place of the previous method of stamping individual plates in successive batches, in order to enable continuous production (Fig. 16).

The previous MEA were easily broken, making their handling during layering a considerable challenge. In the new configuration, two cells formed from two MEA and three separators are treated as a unit, enabling layering to be carried out automatically by robots as if stacking books on a bookshelf (Fig. 17).

In addition, the reduction of the number of cooling layers and use of a one-box configuration has enabled the number of components to be reduced.

The development of these production technologies and appropriate specifications has enabled the achievement of continuous production, resulting in increased productivity.

9. Conclusion

The V Flow FC stack forms the core of the V Flow FC platform employed in the FCX Clarity, a fuel cell vehicle that embodies an advanced design. The following major technologies were applied to the V Flow FC stack:

- (1) The development of a V Flow cell structure enabling vertical flow of hydrogen and air has increased water drainage capacity. This has enabled compactness to be increased without compromising the stability of electricity generation and has enhanced low-temperature startability.
- (2) The development of wave flow channel separators that produce a uniform supply of hydrogen, air, and coolant to the generating surfaces and enable the number of cooling layers to be reduced has resulted in the achievement of weight savings, increased compactness, higher power, and enhanced low-temperature startability.
- (3) The reduction of the thickness of the cells and the achievement of weight savings and increased

compactness have enabled the use of a one-box stack configuration in place of the previous two-box stack configuration, enabling the FC stack to be positioned in the center tunnel of the vehicle.

- (4) Continuous production of the MEA and separators that make up the cells, automated layering, and the reduced number of cell components has resulted in increased productivity.

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