

Development of New FC Stack for CLARITY FUEL CELL

Hideaki KIKUCHI*
Daisuke OKONOGI*

Hayato KAJI*
Hitoshi HARATA**

Takayuki NISHIYAMA*

ABSTRACT

In order to make the fuel cell stack lighter weight and more compact, the cell thickness and the number of cell stacks were reduced. This achieved the world's highest level of volume power density at 3.1 kW/L. The reduction in cell thickness was achieved by the uniform distribution of water in the membrane electrode assembly, a reduction in the gas flow channel depth, and reduction in the membrane electrode assembly thickness. The reduction in the number of cell stacks was achieved by narrowing the gas flow channel pitch so as to enhance the power output performance per cell. Structuring the FC stack so that the gas flow channels are oriented laterally allowed the height of the fuel cell stack to be reduced while the connection bar was used as a cell retention structure, increasing the impact resistance. This enabled mounting of the fuel cell stack under the front hood. Making the fuel cell lighter weight and more compact reduced its heat mass so that the time taken to reach 50% of rated capacity when the fuel cell is at a low temperature could be shortened to one-half of the time required by a previous fuel cell. The membrane electrode assemblies that make up the cell were given a resin frame around their periphery, and squaring off their shape reduced the amount of material needed in the electrolyte membranes and diffusion layers while also increasing their continuous manufacturing productivity.

1. Introduction

Fuel cells are anticipated to provide a renewable, clean power train that does not discharge any CO₂ or environmentally harmful substances.

In 1999, an fuel cell stack developed by Honda was installed in an FC test vehicle, and in 2003, a Honda FC stack that allowed for higher power density and starting in cold climates was announced⁽¹⁾. In 2006, Honda announced the V Flow FC stack with 50% greater volume power density and 67% greater weight output density⁽²⁾. An FC stack development initiative was undertaken with the CLARITY FUEL CELL, and the objectives were expanded to further reduction in weight, greater compactness, and installation⁽³⁾ under the front hood. The cell thickness was reduced, the number of cell stacks was reduced, and the impact resistance was increased. This effort raised the volume power density by 60% and the weight output density by 35% compared to the V Flow FC stack. The new FC stack, which also yielded enhanced low-temperature

starting performance and increased MEA⁽⁴⁾ manufacturing productivity, was announced in 2016. Figure 1(a) shows the external appearance of the V Flow FC stack and Fig. 1(b) that of the new FC Stack. This paper will introduce the new FC Stack, which has achieved lighter weight and greater compactness, enabling installation of an FC power train under the front hood.



Fig. 1 Appearance of fuel cell stack

* Automobile R&D Center

** Honda Engineering Co., Ltd.

2. About Fuel Cells

As shown by the proton exchange membrane fuel cell in Fig. 2⁽⁵⁾, an FC directly converts chemical energy into electrical energy by using a polymer electrolyte membrane (PEM) to cause electrochemical reactions between hydrogen and the oxygen in the air.

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

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

A PEM that conducts hydrogen ions is sandwiched between two electrode layers that are composed of a hydrogen electrode and an oxygen electrode (an air electrode) and diffusion layers to form an MEA. This MEA is then sandwiched on both sides by two separators to form one cell. One cell cannot obtain a theoretical voltage of more than 1.23 V even when the circuit is open. Therefore, as shown in Fig. 3, cells are stacked so that they can produce a high voltage. In order to bring out the performance of the MEA, it is also important to humidify and hydrate the PEM and electrode layer to lower the conduction resistance of the hydrogen ions⁽⁵⁾⁻⁽⁷⁾.

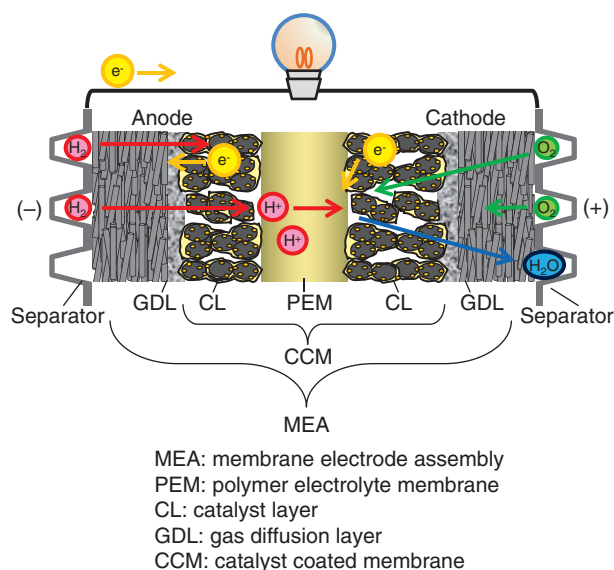


Fig. 2 Mechanism of electricity generation in FC stack

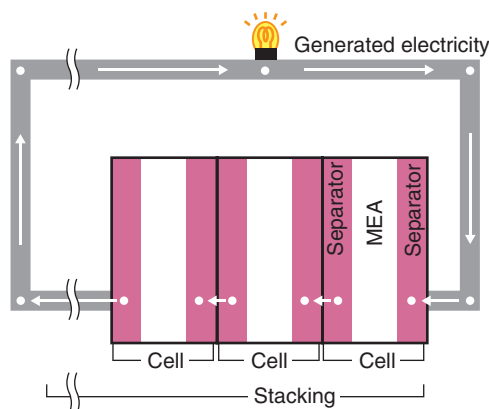


Fig. 3 FC stack configuration

3. Development Goals

The goals of CLARITY FUEL CELL development were to make an FC power train compact in size and install it under the front hood. This would realize the world's first fuel cell vehicle (FCV) to be available on the market in a five-passenger sedan package⁽³⁾.

In developing the new FC Stack, the following goals were adopted in light of the CLARITY FUEL CELL development goals and with a view to mass popularization in the future.

- (1) Make lighter weight and more compact
- (2) Heighten impact resistance
- (3) Enhance low-temperature starting performance
- (4) Enhance MEA manufacturing productivity

4. Achieving Lighter Weight and Greater Compactness

In order to make the FC stack lighter weight and more compact, it is necessary to reduce the cell thickness and reduce the number of cell stacks.

4.1. Reducing Cell Thickness

In order to reduce cell thickness, it is necessary to reduce the depth of the hydrogen and air flow channels and to reduce the MEA thickness. However, the following relationship is involved:

Gas flow channel depth = Adhesion force of generated water / Drainage force of generated water

When the hydrogen and air flow channels are made shallower, the proportion of force with which generated water adheres to the gas flow channel increases in size. This causes the generated water to be unable to drain and more likely to accumulate (Fig. 4). The supply of hydrogen and air is therefore hindered so that the cell becomes unable to generate a stable supply of electricity. Previous FC stacks were constructed so that air and hydrogen gases would flow in a downward direction in parallel flows. Gravity was used to heighten the drainage force and drain away the water produced by the generation of electricity. The cell thickness was reduced by reducing the depth of the gas flow channels while maintaining the stability of electricity generation by the FC stack. In the present development, further reduction of cell thickness has been sought by making the humidity in the MEA uniform and reducing the amount of

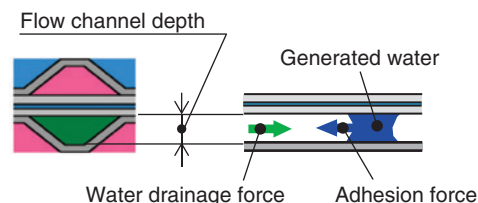


Fig. 4 Relationship between flow channel depth and adhesion force

humidification. This approach enabled the generated water to drain without condensing so that adhesion of generated water to the gas flow channel was eliminated even in the low-load range of operation where the drainage force was diminished. This maintained the stability of electricity generation while making it possible to further reduce cell thickness. First of all, the cells were changed from a structure in which air and hydrogen gases flowed in parallel to one in which the gases flowed in opposing directions (counter gas flow). As shown in Fig. 5, humidified air provides water to the MEA on the entrance side, and the generated water moves toward the exit side and is supplied to the MEA. Then water that has percolated through the MEA is back-diffused to the hydrogen electrode side, and water is supplied to the hydrogen entry side, making it possible to heighten the circulation of water within the electricity-generating surfaces and to make the water distribution uniform within the MEA. It is also important to have a uniform distribution of gas from the gas manifold to the gas flow channels, as shown in Fig. 6. As shown in Fig. 7, the two MEAs adopted from the previous FC stack version are held in place by three separators so that coolant can flow by on both sides. In this cell structure, the separator sandwiched between two MEAs will have hydrogen flowing past on one side and air flowing past on the other side. With stamped metal separators, the shape is indented on one side and protrudes on the other because of the press-forming process, so optimal distribution channels cannot be formed on each side. Consequently, as shown in Fig. 8, it was necessary to design the MEAs so that the

embossed forms would provide for a balance between the hydrogen electrode side and the air electrode side. Therefore a resin frame around the MEA periphery was devised (Fig. 9) and the press-formed surface of the separator was made flat. Grooves were then formed in the resin portions to provide for optimal distribution of the respective gases (Fig. 10) so that the distribution of both gases was enhanced and the water distribution in the MEA was also made uniform. Enhancements were also made to the MEA. The PEM was made thinner in order to enhance the water diffusion performance due to the difference in concentration in the

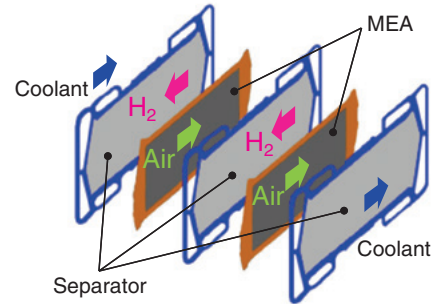


Fig. 7 One cooling layer per two cells

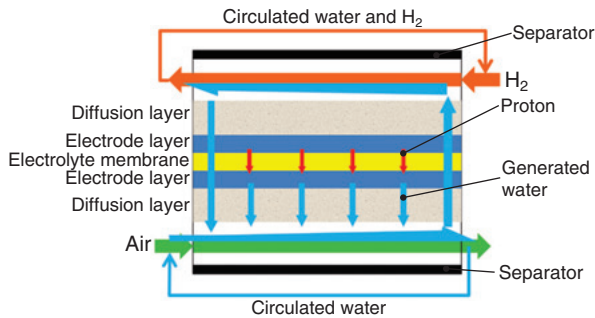


Fig. 5 Diffusion in MEA

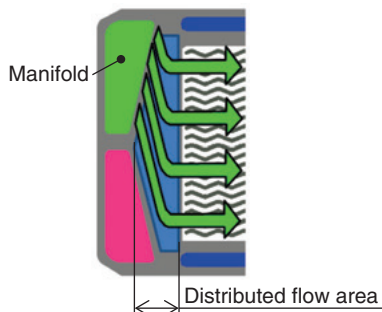


Fig. 6 Distributed flow area

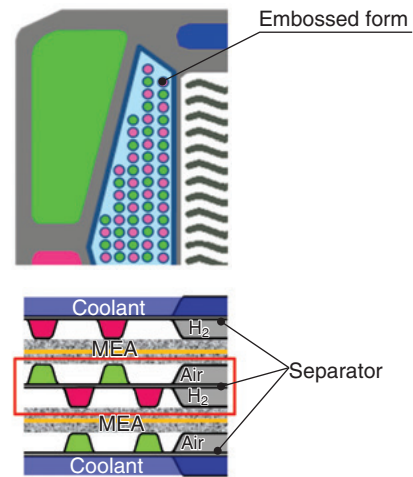


Fig. 8 Previous gas distribution structure

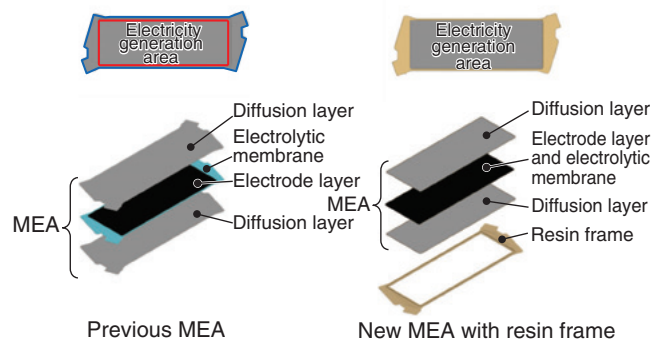


Fig. 9 Comparison of MEA structures

PEM from the air electrode to the hydrogen electrode, thereby enhancing its circulation, as well as to reduce the thickness of the MEA. In the diffusion layers, which are made up of carbon fibers, the density of carbon fibers was

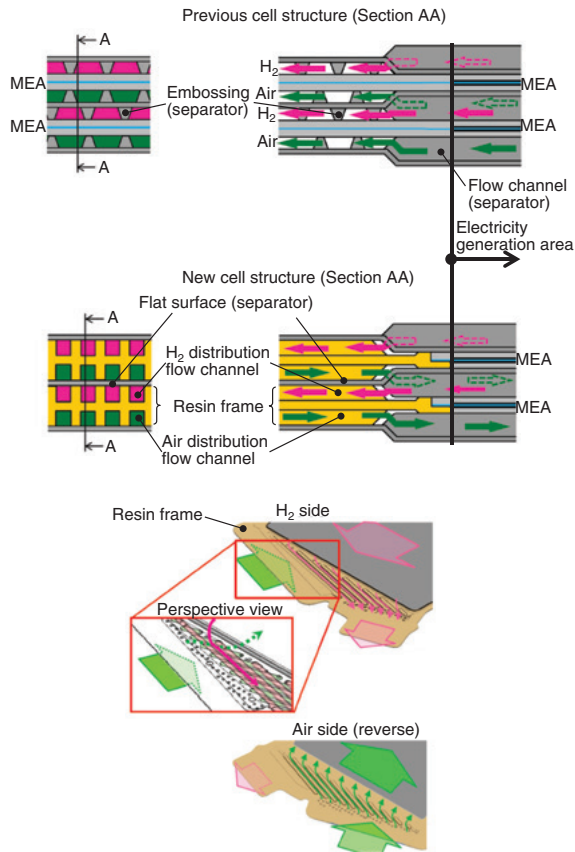


Fig. 10 Resin-framed MEA

made coarser to increase the porosity, thereby enhancing the gas diffusion performance as well as the water drainage performance. On the hydrogen electrode side, the increased hydrogen gas diffusion performance makes it possible to obtain adequate gas diffusion performance even when the diffusion layer thickness has been reduced. These measures enabled a reduction of 40% in the humidification amount compared to the previous version, which means that in the low-load range of operation where the generated water drainage force is diminished, the humidity within the electricity-generating surfaces could be lowered to 100% or less. As a result, it became possible to drain the generated water without condensing it, so that adhesion of the generated water to the flow channels no longer occurred, and the flow channel depth could be reduced by 26% while maintaining the stability of electricity generation. The reduction in overall MEA thickness through reduction of PEM and diffusion layer thickness combined to achieve a single cell thickness of 1 mm, representing a 20% reduction in thickness compared to the previous cell (Fig. 11). It was also no longer necessary to use gravity for draining generated water, so that even if the FC stack was structured to have the gas flow channels flow laterally, the stability of electricity generation could still be maintained, as shown in Fig. 12.

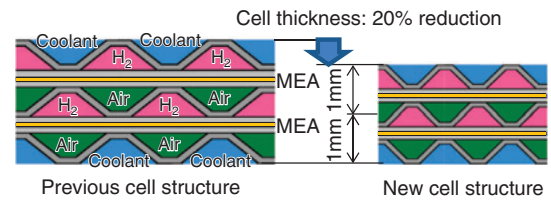
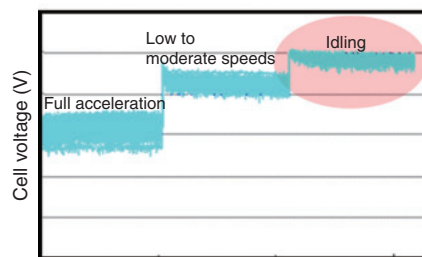
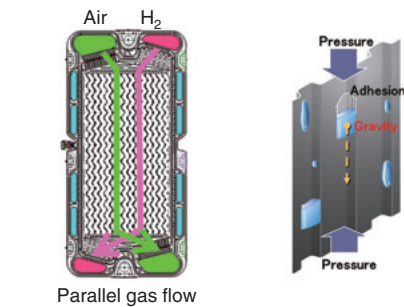
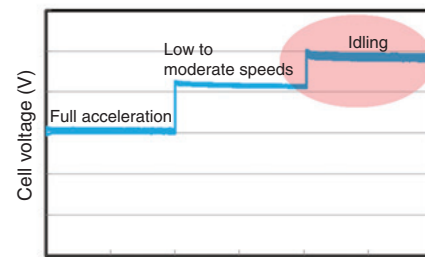
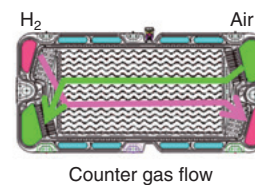


Fig. 11 Cross-section of cell structure



(a) V flow FC stack



(b) New FC stack

Fig. 12 Natural stabilized electricity generation

4.2. Reducing the Number of Cell Stacks

In order to reduce the number of cell stacks without changing the electricity-generating surface area in each cell, it is necessary to further increase the output per unit electricity-generating surface area. One way of doing this is to further increase the electric current density per unit surface area. On the air electrode side, however, there is an increase in the amount of water generated by electricity generation. This hinders the gas diffusion performance of air within the MEA, which raises the issue of possible deterioration in power output performance as a result. It is necessary, therefore, to eliminate the accumulation of generated water within the MEA (Fig. 13).

The separators form gas flow channels that supply hydrogen and air to the MEA, and where those gas flow channels and the MEA come into contact, water generated by electricity generation condenses in the diffusion layers and ends up accumulating there so that hydrogen and air can no longer be supplied to the MEA in a uniform manner. Attention was therefore turned to the fact that the accumulation of generated water can be eliminated by narrowing the ridges where gas flow channel and MEA come into contact, as shown by the neutron visualization test results in Fig. 14, and the gas flow channel pitch was made narrower.

In the case of stamped metal separators, however, narrowing the pitch of the gas flow channels increases the elongation ratio of the sheet during press forming so that cracks may form in the gas flow channel and the sheet may become thinner in places. This can be avoided by dividing up the press forming over a number of times, which, however, tends to reduce productivity. In the present

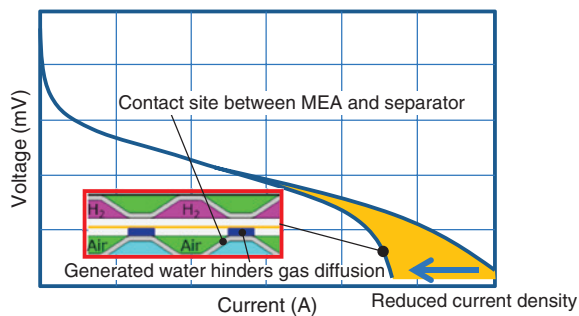


Fig. 13 I-V characteristic

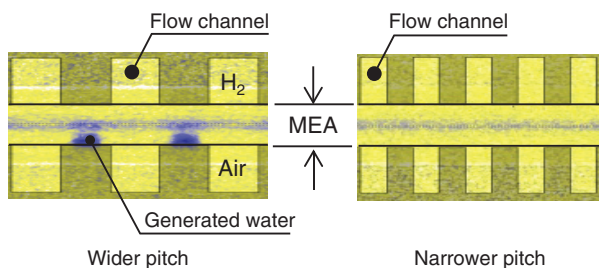


Fig. 14 Comparison of flow channel pitches

development, reduction of the gas flow channel depth yielded a 35% narrower gas flow channel pitch and still managed to achieve a sheet elongation ratio on a par with previous versions (Fig. 15).

As a result, the accumulation of generated water on the channel ridges was eliminated even when the electric current density was increased, and the gas diffusion performance of air was ensured. This made it possible to increase the electric current density by a factor of 1.5 compared to previous FC stacks, which made it possible to increase power output performance per unit surface area by a factor of 1.5 (Fig. 16). These measures realized power

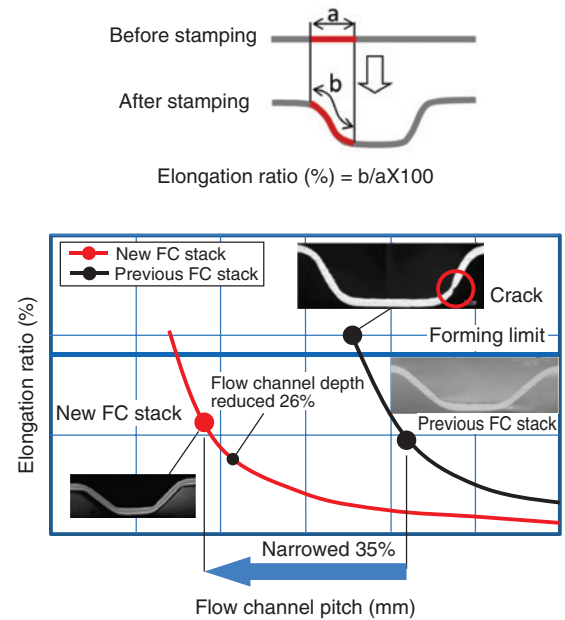


Fig. 15 Narrowed flow channel pitch

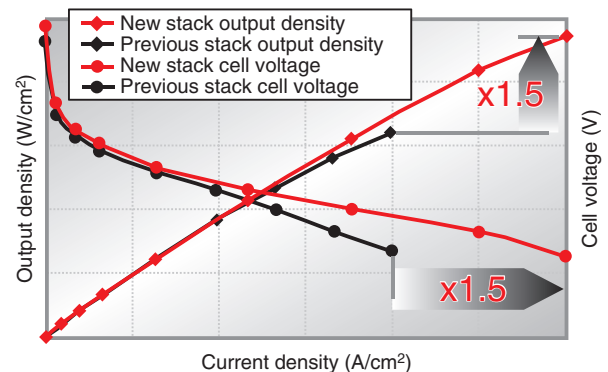


Fig. 16 Comparison of cell output density

output on a par with previous FC stacks while allowing the number of cell stacks to be reduced by 30% (Fig. 17).

The technology for achieving this kind of lighter weight and greater compactness realized increases (by comparison with former versions) of 60% in the volume power density and 35% in the weight output density of the FC stack by reducing the cell thickness and the number of cell stacks. This achieved the world's top level of volume power density at 3.1 kW/L (Fig. 18).

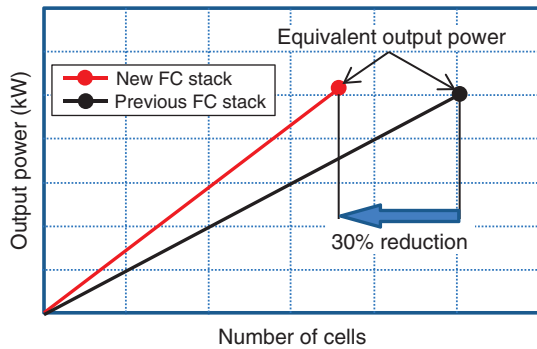


Fig. 17 Reduced number of cells

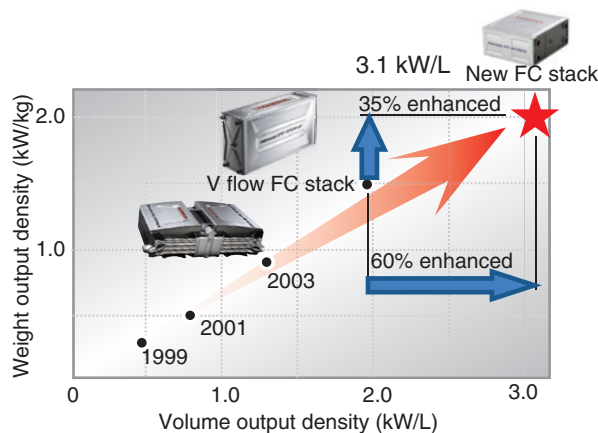


Fig. 18 Comparison of stack output density

5. Enhancing Impact Resistance

Installing the FC stack under the hood at the front of the vehicle involves exposure to greater impact force on the FC stack in a front-end collision than the previous center tunnel installation. This means it is necessary to enhance the impact resistance. As shown in Fig. 19, therefore, a part that protrudes vertically with respect to the cell was added, the end plates at either end of the FC stack were held together by a connection bar that also holds in place the protruding part added to the cell. The bar-connected, single-box stack structure developed in this way is thus able to limit displacement of the cell without fracturing, even under great impact force. As a result, this FC stack achieved

impact resistance four times greater than that of the former panel-connected structure.

Greater compactness and enhanced impact resistance enabled installation of the FC stack on top of the drive motor so that the FC power train achieved a compact size on a par with conventional V6 engines. This made it possible to realize the first FCV to be made commercially available in a five-passenger sedan package.

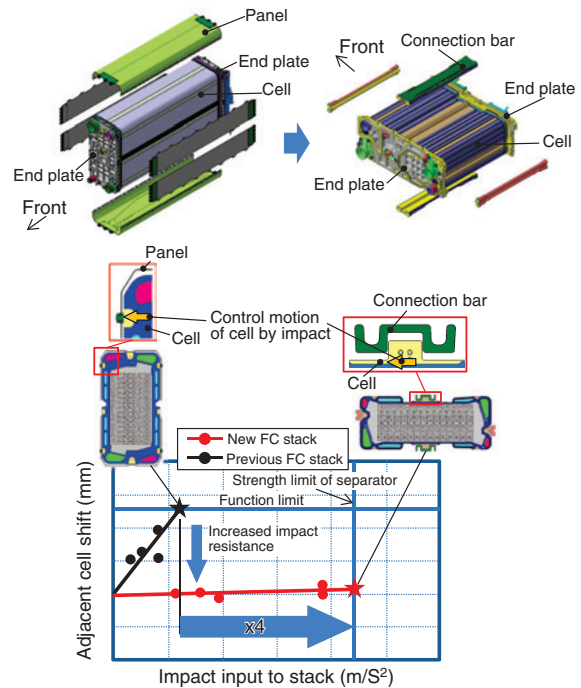


Fig. 19 High impact resistance stack

6. Enhancing Low-Temperature Starting Performance

In the former FC stacks, power output performance at start-up was heightened by enhancing generated water drainage performance by means of the V Flow cell structure and by reducing heat mass by 40%. In the present development, low-temperature starting performance was enhanced by reducing the heat mass and lowering the specific resistance of MEA components.

First, the specific resistance of MEA components was lowered by reducing the thickness of the PEM, optimizing the ion exchange capacity, and making the diffusion layers thinner. The resistance of the PEM in a low-humidity environment was also reduced by achieving uniform humidity in the MEA surface; this was done by establishing a counter gas flow. These measures succeeded in lowering the electrical resistance of the FC stack by one-third in a -20°C environment, which enhanced the power output

performance immediately after start-up. Reducing the depth of the separator flow channels and the number of cell stacks yielded a lighter-weight and more compact FC stack as well as a reduction in the amount of coolant kept in the cell. This achieved a 12% reduction in heat mass which made it possible to raise the rate of power output increase so that the time taken to reach 50% power output when starting at a temperature of -20°C was shortened by one-half relative to the previous FC stack (Fig. 20).

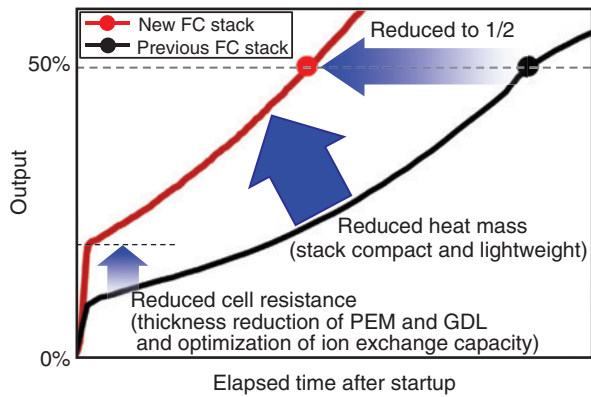


Fig. 20 Comparison of low-temperature performance (operated at -20°C)

7. Enhancing Manufacturing Productivity

As shown in Fig. 21(a), the previous MEA manufacturing technique involved coating a microporous layer on the diffusion layer and coating an electrode layer on the PEM, building up the respective stacks by patterned coating. This production method included portions that did not involve causing gases to flow from the manifold to the flow channels, and so that did not contribute to electricity generation. The MEA was formed as a single entire unit, so the shape became very complex and there were many portions of the diffusion layer and PEM that were wasted. In the present development, a resin frame is placed around the circumference of the MEA, as shown in Fig. 9. Squaring off the shape of the MEA, which is the electricity-generating component, made it possible to form the microporous layers and electrode layers in sheets on a diffusion layer that is in roll form. After that, the MEA shape could be squared off using a multiple-cavity punching. This process therefore became capable of high-volume continuous flow, as shown in Fig. 21(b). In order to coat the microporous layer and electrode layer in sheet form on the diffusion layer, it is necessary to place a flat membrane coating with few undulations in it on the porous diffusion layer surface. An ink with

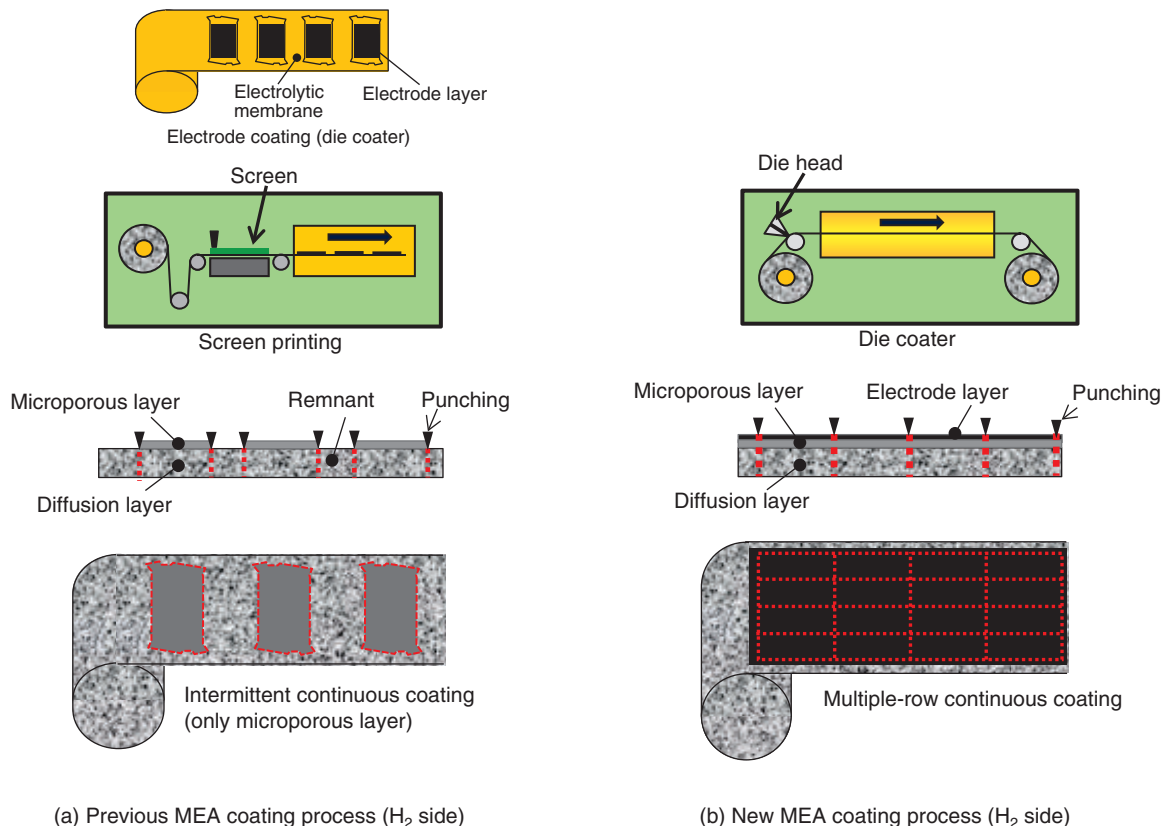


Fig. 21 MEA coating process (H_2 side)

water-repellent properties was therefore developed that would not soak into the diffusion layer, which resulted in a technology for producing a smooth electrode layer in sheet form at high speed. Having the shape of the MEA squared off meant that the electrode layer could be inspected in sheet form for defects, allowing only the areas of good quality to be selectively cut out for use. This technology used for MEA production became possible to apply here, as well.

As a result of these measures, the portions that were wasted in production were reduced, allowing the amounts of diffusion layer and PEM used to be reduced by 40%. A production technology that achieves high-volume continuous flow and cost reduction was created (Fig. 22).

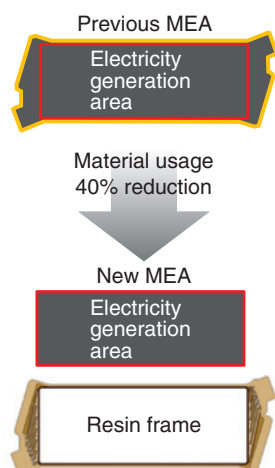


Fig. 22 Reduction of material usage

8. Conclusion

In the present development the FC stack was made lighter weight and more compact, its impact resistance was increased, and its low-temperature starting performance and MEA manufacturing productivity were enhanced.

- (1) In reducing the thickness of cells and the number of cell stacks in the FC stack, the volume power density was increased by 60% and the weight output density by 35% compared to previous FC stacks. This achieved the world's highest level of volume power density at 3.1 kW/L.
- (2) In conjunction with the greater compactness, the gas was caused to flow in a horizontal direction, which reduced FC stack height. This enhancement of both impact resistance and compactness made it possible to install the FC stack under the hood at the front of the vehicle.
- (3) Reducing the MEA resistance and heat capacity made it possible for the time taken to reach 50% power output at a low temperature to be shortened by one-half relative to the previous FC stack.

- (4) Squaring off the shape of the MEA and making the area not used for electricity generation into a resin frame around it both increased MEA manufacturing productivity and achieved a 40% reduction in the amount of high-cost materials used.

References

- (1) Inoue, M., Saito, N., Uchibori, K.: Next-generation Fuel Cell Stack for Honda FCX, Honda R&D Technical Review, Vol. 17, No. 2, p. 8-13
- (2) Saito, N., Kikuchi, H., Nakao, Y.: New Fuel Cell Stack for FCX Clarity, Honda R&D Technical Review, Vol. 21, No. 1, p. 16-23
- (3) Kimura, K., Kawasaki, T., Ohmura, T., Atsumi, Y., Shimizu, K.: Development of New Fuel Cell Vehicle CLARITY FUEL CELL, Honda R&D Technical Review, Vol. 28, No. 1, p. 1-8
- (4) Takenaka, H.: Genri to Denkyoku Hannou, Nenryodenchi Gijyutu to sono Ouyou, Tekunosisutemu, p. 91, (2000), (in Japanese)
- (5) Sato, M., Chiba, H., Inoue, M.: Development of CCM Water Content Distribution Measurement System for Fuel Cell Stack, Honda R&D Technical Review, Vol. 28, No. 1, p. 16-25
- (6) Nagumo, K., Inoue, M.: Numerical Prediction of Water Content Distribution of Catalyst Coated Membrane of Fuel Cell Stack using Simulation, Honda R&D Technical Review, Vol. 28, No. 1, p. 26-33
- (7) Iwanari, T., Miyajima, K., Furusawa, K., Inoue, M.: Real-time Measurement of Water Content of CCM in On-board Fuel Cell Stack System, Honda R&D Technical Review, Vol. 28, No. 1, p. 34-40

■ Author ■



Hideaki KIKUCHI



Hayato KAJI



Takayuki NISHIYAMA



Daisuke OKONOGI



Hitoshi HARATA