

High-durability and Cost-effective Fuel Cell Stack with New Structure

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ABSTRACT

A new structure fuel cell stack developed jointly with General Motors realized twice the durability at 1/3 of the cost while maintaining the output and safety performance of the previous fuel cell stack.

In order to increase durability, control-based temperature and humidity management was adopted and the stack structure was enhanced to achieve less iron elution from the bipolar plates, better cooling performance, and more stable power generation due to the stack end unit parts, etc.

To achieve lower cost, first the current density of the Membrane Electrode Assembly was increased and the power consumption of auxiliary devices that compensate for stack power generation was lowered, enabling maintenance of the same net power as the previous system with fewer cell layers. Next, the structure was simplified while enhancing the cooling performance of the bipolar plates. In addition, less platinum is used in the electrode catalyst of the Unitized Electrode Assembly, the polymer electrolyte membrane was thinned, and a fully automated line was applied from assembly of the Unitized Electrode Assembly to the stacking process.

1. Introduction

Areas around the world are continuing to experience major disasters due to climate change, such as heavy summer rains, massive hurricanes, large-scale forest fires, and sea level rise due to melting ice as temperatures rise in the Arctic region. It has been pointed out that the global warming at the root of this, that is to say the increase in the global average temperature over pre-industrial (1850-1900) levels, reached 1.1°C in 2011-2020 and is likely to reach 1.5°C by 2040⁽¹⁾. For this reason, hydrogen is attracting attention as an energy source to replace petroleum-derived fuels, as it does not emit CO₂ in use, which is a main factor in temperature rise⁽²⁾. Against this background, Honda is proposing the realization of “Use” to stimulate demand for hydrogen as part of measures to curb global warming⁽³⁾.

Honda has worked to achieve practical application of fuel cell technology since the 1980s⁽⁴⁾⁻⁽⁷⁾, and the CLARITY FUEL CELL^{(8), (9)} equipped with the previous fuel cell system was launched to limited markets in 2016. As the next stage, development has proceeded on a new structure fuel cell system with enhanced durability and lower cost to enable deployment to a wide variety of markets. A new

structure fuel cell stack developed jointly with General Motors realized twice or greater durability at 1/3 of the cost while maintaining the output and safety performance of the previous fuel cell stack. Honda is considering expanding application of this fuel cell stack to four areas including commercial use vehicles, construction machinery, and stationary power sources in addition to installation in a new fuel cell electric vehicle, as shown in Fig. 1⁽¹⁰⁾. This paper introduces the new structure fuel cell stack.

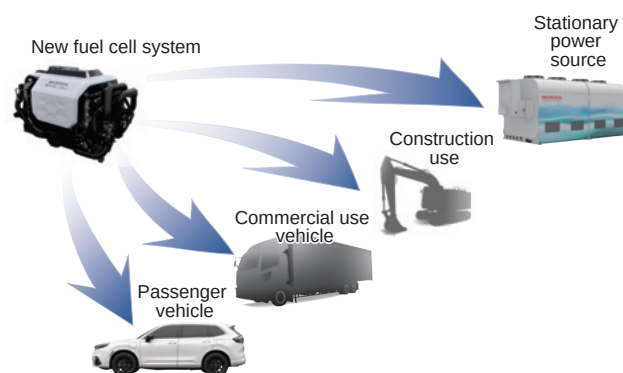


Fig. 1 Expanding application of fuel cell system

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2. Development Goals

The new structure fuel cell stack adopts a polymer membrane cell structure when stacked Membrane Electrode Assemblies (MEA) consisting of a polymer electrolyte membrane (PEM) sandwiched between hydrogen (anode) and air (cathode) electrodes, as shown in Fig. 2.

In this structure, hydrogen and the oxygen in the air are supplied to the MEAs, and chemical energy is directly converted into electrical energy by an electrochemical reaction. The power generation cell shown in Fig. 3 has a structure in which a Unitized Electrode Assembly (UEA) composed of an MEA and peripheral resin film is sandwiched between two bipolar plates (BPP) to configure flow channels that supply hydrogen and oxygen.

Factors such as contamination by iron and PEM drying due to higher temperatures in operation are known to

promote PEM degradation in the MEA^{(11), (12)}. Durability was increased by implementing countermeasures to address these factors.

In addition, the MEA is a thin membrane that calls for high processing accuracy, and thus the manufacturing process is complex, and platinum (Pt) is also required, which is a cost issue in terms of popularization^{(13), (14)}. Therefore, a development goal was to achieve lower cost by simplifying the structure and material substitution.

3. Lower Fuel Cell Stack Cost

Figure 4 compares the fuel cell stack cost for the previous and new structures. As the cell cost accounts for the majority of the stack cost, the current density of the MEA was increased and the power consumption of auxiliary devices that compensate for stack power generation was lowered while maintaining the same net power as the previous fuel cell system. This enabled to use 15% fewer cell layers compared with the previous stack.

In addition, as shown in Fig. 5, the fuel cell stack consists of a cell unit structure in which BPP and UEA are stacked, and a stack structure that functions to fasten and

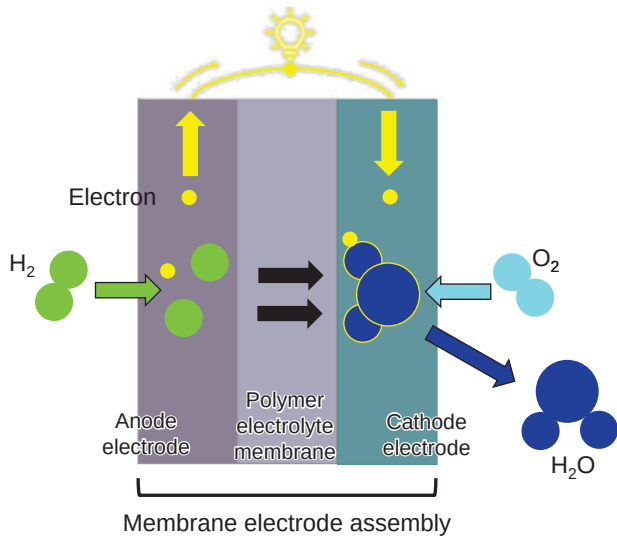


Fig. 2 Mechanism of electricity generation in stack

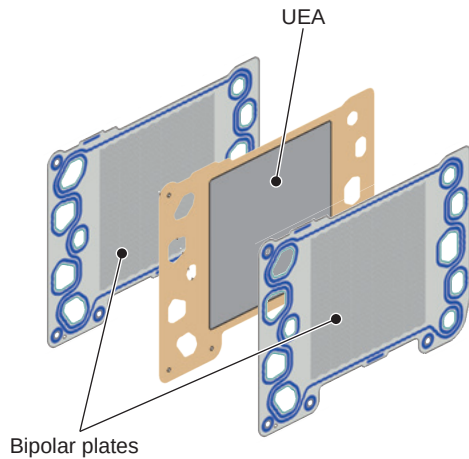


Fig. 3 Structure of cell in new stack

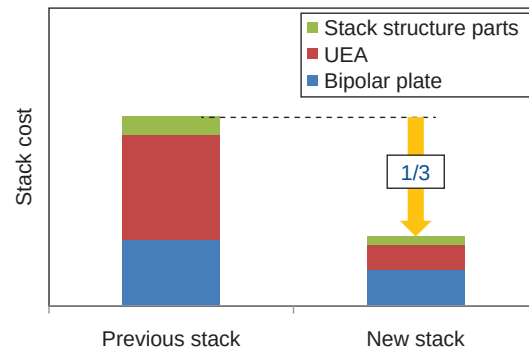


Fig. 4 Stack cost

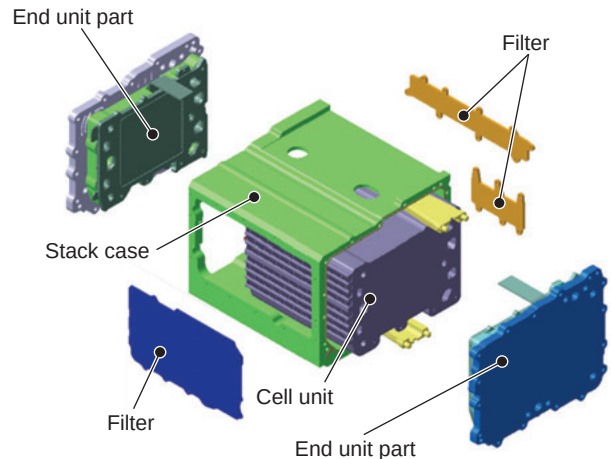


Fig. 5 New fuel cell stack

protect the cell unit. By lowering the cost of each of these parts, the new structure fuel cell stack realized a cost 1/3 that of the previous stack.

3.1. Simplification of BPP Structure and Review of Materials

In consideration of BPP cost, the base material surface coating was changed, the inter-cell seal structure was changed, and the peripheral covering structure used to help prevent water exposure was eliminated, as shown in Fig. 6.

As shown in “External shape” and “Coating structure” in Fig. 6, the BPP base metal surface that was a factor increasing cost was changed from the previous gold coating to a less expensive carbon (C) and titanium (Ti) coating. In addition, the previous BPP seal structure used a seal that covered the base material plate with rubber. As shown in “Seal structure,” the new BPP structure was simplified by adopting a BPP structure in which two base material plates are sealed by welding, and a seal structure using metal beads and micro seals.

In addition, the previous BPP used a cell outer covering structure that covers the outer periphery of the cell with a resin frame and rubber to help prevent exposure of the

metal areas after stacking. As shown in “Outer insulation structure,” the new structure adopts the filter structure shown in Fig. 5 that helps prevent water exposure from the outside and also enables ventilation of the hydrogen, and eliminates the complex cell outer covering structure⁽¹³⁾.

3.2. Change in UEA Materials and Structure and Introduction of Fully Automated Production Line

The UEA adopted the structure shown in Fig. 7, and used just 1/5 of the amount of the precious metal Pt contained in the electrode layers compared with the previous UEA, which had been a factor increasing cost. In addition, the previous system used a membrane product (single membrane) from a cooperating supplier, but adoption of a proprietary coating process thinned the PEM to 3/5 of the previous thickness, which helped realize a lower UEA cost.

A Pt alloy catalyst with high catalytic activity was also used in the electrode layers. Increased catalytic activity and a thinner PEM resulted in lower resistance, which compensated for the decline in performance due to lower Pt content and provided output performance equivalent to or better than that of the previous UEA. Also, the peripheral resin structure no longer uses the flow channel structure present in the previous UEA structure, and instead adopts a structure with flow channels only on the BPP side⁽¹⁴⁾.

In order to realize lower cost, the materials and structure were changed, and production technologies were also developed to increase production efficiency.

The previous processing times differed for each process, as shown in Fig. 8, making it a challenge to link and fully

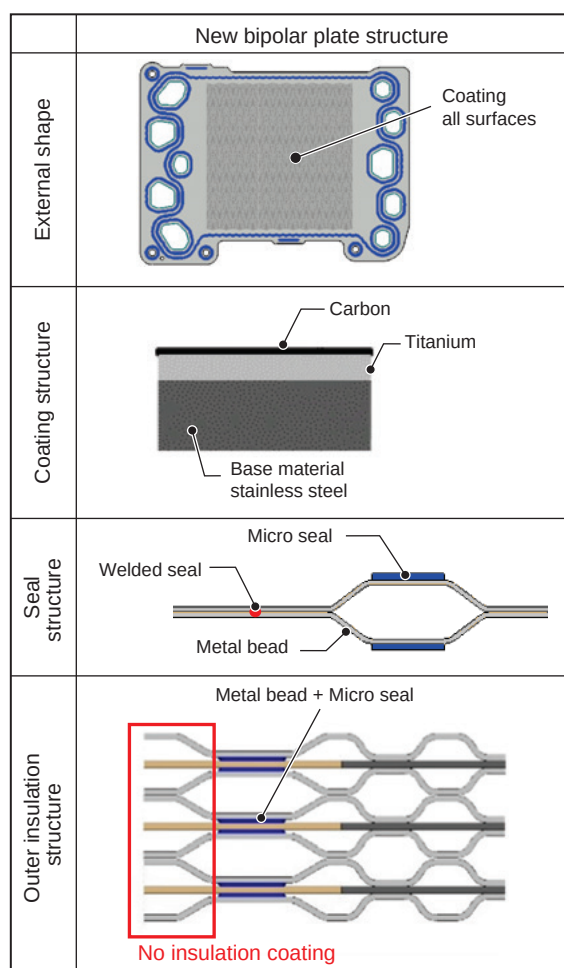


Fig. 6 Bipolar plate structure for cost reduction

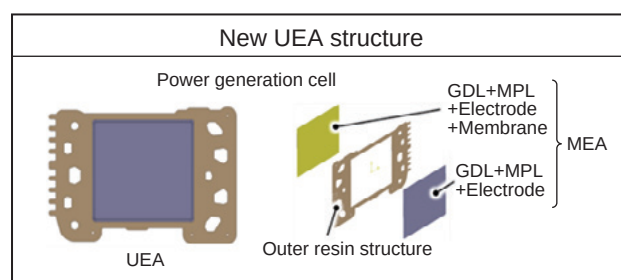


Fig. 7 UEA cost reduction structure

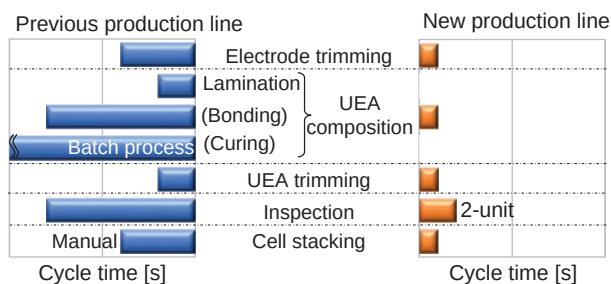


Fig. 8 Cycle time for each process

automate the series of processes from electrode trimming to cell stacking. This limited the potential increase in production efficiency, and was a factor increasing cost. Therefore, the processes for the new structure fuel cell stack were consolidated and the processing times were shortened, realizing the fully automated line shown in Fig. 9. The processes in order from left to right of trimming the electrodes from the roll, laminating the trimmed electrodes with film, assembling the UEA, inspecting the quality, and then stacking with the BPP are all fully automated.

The details of that initiative are as follows. First, the previous peripheral resin structure used injection-molded parts, but the new structure UEA adopts a resin film. In addition, use of a sandwich structure at the junctions between the film and the electrodes enabled elimination of the impregnation (Bonding) process that melted the resin to create a physical joint in the previous model. The adoption of film coated with sealant that has finished primary curing as the material also enabled shortening of the adhesive Curing process time so that it completes within the Lamination process time. This realized integrated processing of the two types of electrodes and the resin film, and consolidated the UEA assembly process from three processes into a single process. In addition, the Electrode trimming, UEA trimming, and Cell stacking processes were fully automated, and technology that conforms to the specifications was developed for the UEA Inspection process. This achieved shorter and more uniform cycle times.

Furthermore, as stable material input is needed to realize a fully automated line, technology was applied to reliably pick and place sheet film material, as shown in Fig. 10. This film material is packed in containers in the flat stacked condition alternating with interleaf so that foreign matter does not adhere to the adhesive part. The film and interleaf are in close contact inside the container, and thus there was the issue that when the robot removes the interleaf, the film below may stick and be removed together with the interleaf. Therefore, a mechanism was adopted to pinch and peel off

a part of the interleaf while holding down the periphery, as shown in Fig. 11, which realized stable pick and place operation.

The above realized a fully automated line from electrode roll loading to cell stacking, which increased production efficiency with 1/8 of the personnel and 1/3 of the depreciation cost per cell compared with the previous line.

3.3. Simplification of Stack Structure

The structural parts of the previous stack are divided into cell stack parts and structural parts that protect the cells, as shown in Fig. 12. The cell stack parts consist of

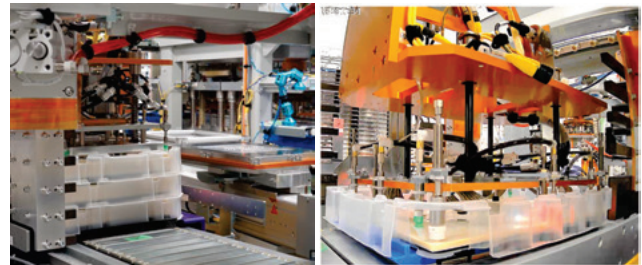


Fig. 10 Pick and place hand

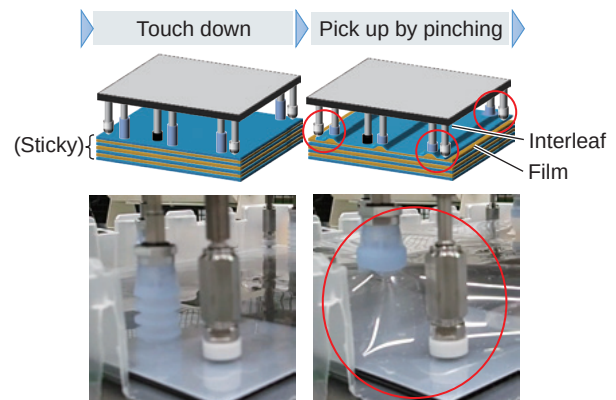


Fig. 11 Pick up by pinching

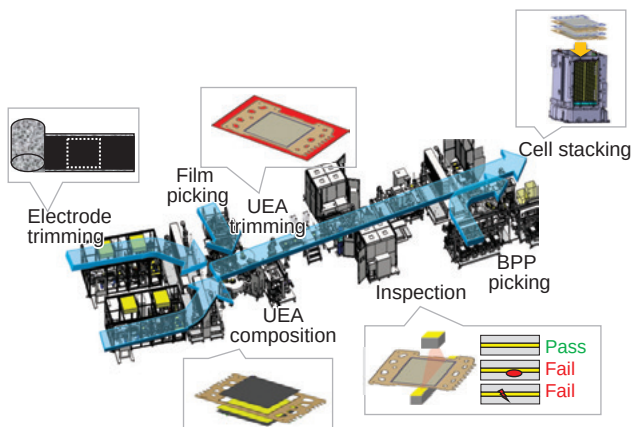


Fig. 9 Overview of new production line

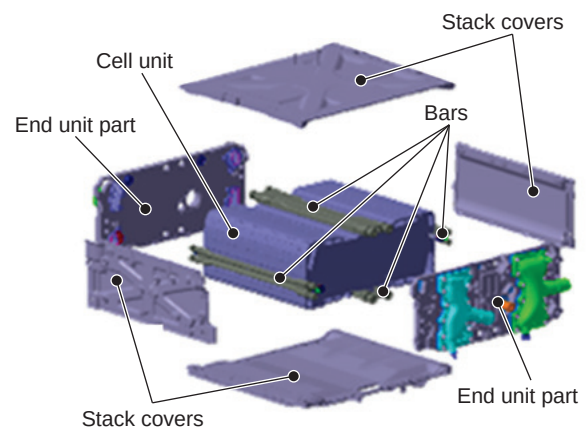


Fig. 12 Previous stack structure

the end unit parts and four bars that are used to stack the cells, and the structural parts that protect the cells are four stack covers that cover the outside of the cell stack. In order to use fewer parts, the new structure fuel cell stack has a stack case structure that performs the cell stacking and cell protective functions and integrates the four bars and stack covers of the previous stack into a single structure. This consolidated eight parts into one, as shown in Fig. 13.

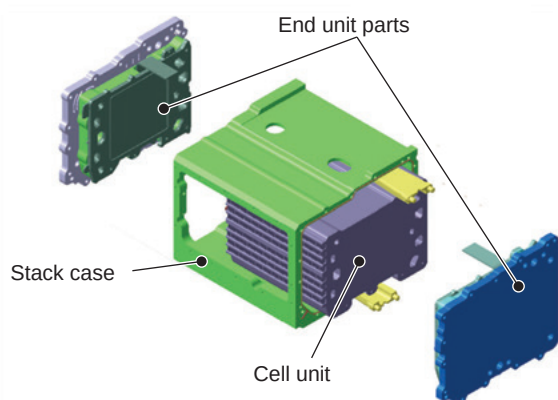


Fig. 13 New stack structure

4. Enhancement of Fuel Cell Stack Durability

The new structure fuel cell stack applies the following technologies to achieve twice the durability or greater through a combination of stack structure and control.

- Enhanced PEM durability by temperature and humidity control
- Less iron elution by changing the BPP coating
- Enhanced cooling performance by changing the BPP cooling structure and changing the aspect ratio
- Enhanced thermal insulation of stack end unit parts and measures to help prevent the entry of water from auxiliary device flow channels

4.1. Enhanced PEM Durability by Temperature and Humidity Control

It is known that when the PEM of a polymer electrolyte fuel cell contains an insufficient amount of water in the condition with a high membrane temperature, the chemical stability of the membrane drops, resulting in rapid decomposition⁽¹²⁾. This makes it necessary to maintain an appropriate membrane temperature and humidity. In order to achieve a lower coolant temperature, the amount of coolant is electrically controlled by an auxiliary device with enhanced performance⁽¹⁵⁾. In addition, use of a proprietary model to estimate the transfer rate of the water contained in the input air with high accuracy realized auxiliary device control that enables to suppress membrane degradation and maintain the optimum humidity.

4.2. Less Iron Elution by Changing the BPP Coating

Chemical deterioration of the PEM of a polymer electrolyte fuel cell progresses when contaminated by iron⁽¹¹⁾, and thus less iron elution from the BPP substrate is needed. The BPP structure uses a full-surface coating of carbon and titanium that suppresses exposure of the stainless steel base material, achieving 1/10 of the iron elution and increasing corrosion resistance.

4.3. Enhanced Cooling Performance by Changing the BPP Cooling Structure and Changing the Aspect Ratio

The new structure fuel cell stack uses a structure that successively stacks BPP and UEA, and flows hydrogen and air between the UEA and BPP and coolant inside the BPP, as shown in Fig. 14.

As shown in Fig. 15(a), the previous structure flowed coolant every two cells, meaning that some cells did not contact the coolant. The new structure adopts a cell-by-cell cooling structure in which the coolant comes into contact with every cell, as shown in Fig. 15(b). This achieved a lower temperature difference between cells.

In addition, the aspect ratio of the cell power generation part was changed, making it easier to achieve more even in-plane flow of the coolant inside the cells. This combination

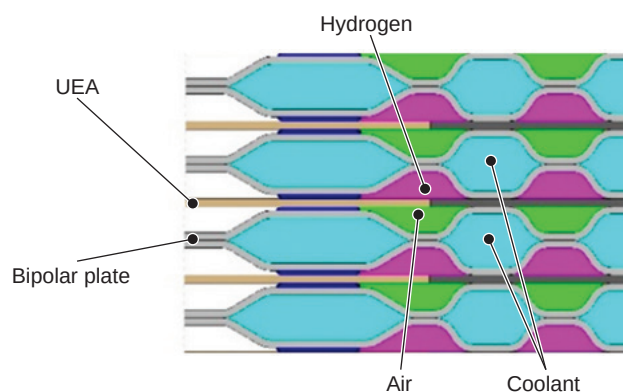


Fig. 14 Structure of cell unit in new stack

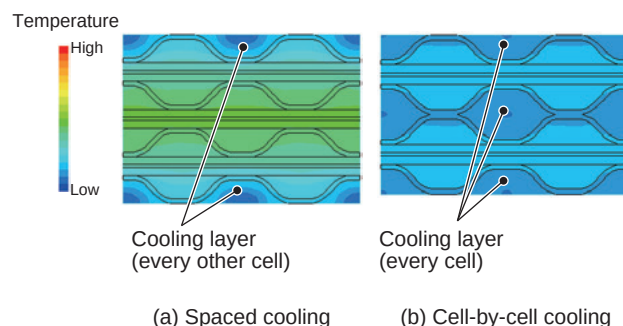


Fig. 15 Temperature distribution inside cell predicted by CFD

of the change in the cell cooling structure and the cell aspect ratio also lessened the in-plane temperature difference in both the horizontal and vertical directions, as shown in Fig. 16, and enhanced the cooling performance.

4.4. Enhanced Thermal Insulation of Stack End Unit Parts and Measures to Help Prevent the Entry of Water from Auxiliary Device Flow Channels

If the voltage becomes unstable, the electrodes degrade, leading to a drop in durability. In order to perform stable power generation, it is necessary to provide the stack end unit parts with thermal insulation performance and to help prevent the entry of water from the flow channels of auxiliary devices into the air and hydrogen flow channels of the fuel cell stack. In the new structure fuel cell stack, the thermal insulation effect was enhanced by

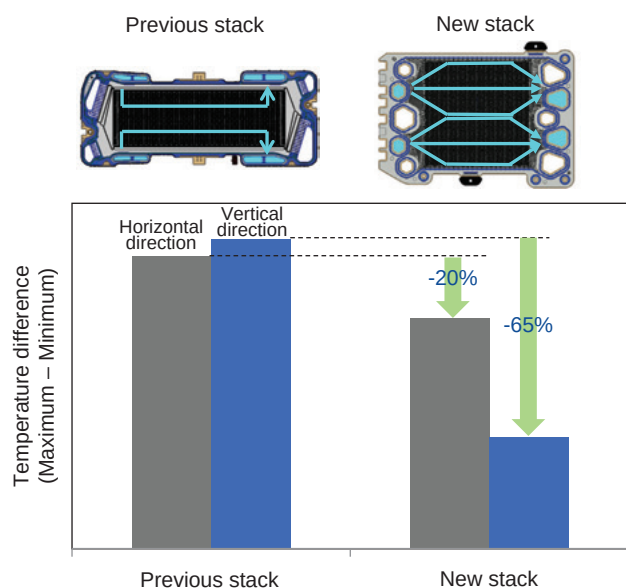


Fig. 16 Effect of changing cell aspect ratio

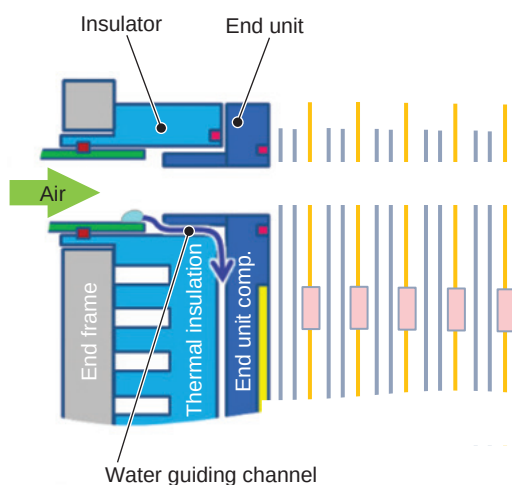


Fig. 17 New fuel cell stack end structure

providing insulator thickness, which helped to suppress the temperature drop due to natural heat dissipation from the cell end unit parts and achieve less temperature variance between cell layers. In addition, if water from the outside enters the UEA, power generation may become unstable, which is a factor resulting in lower UEA durability. Therefore, a water guiding channel was made in part of the insulator, as shown in Fig. 17, to realize a structure where water does not enter the UEA.

5. Conclusion

This paper introduced a fuel cell stack with a new structure developed jointly with General Motors. The features of the newly introduced technologies compared with the previous fuel cell stack are summarized below.

(1) Introduction of the following technologies helped to suppress PEM degradation and increase durability.

- Enhancement of the cooling efficiency helped to reduce auxiliary device power consumption and equalize the PEM temperature, suppressing membrane degradation.
- Review of the BPP base material and the UEA coating material achieved lower cost and also suppressed iron elution to 1/10 or less of the previous stack.
- Review of auxiliary devices and flow channel structures enabled appropriate control of the amount of water vapor in the supply gas and the amount of water exhaust.

These technologies helped to suppress PEM degradation.

(2) Technologies such as the following helped to reduce the number of parts and shorten the production time, etc., resulting in lower cost.

- By increasing the current density of the UEA and lowering the power consumption of auxiliary devices, 15% fewer cell layers are needed compared with a previous fuel cell stack of the same output.
- Adoption of new BPP and UEA shapes achieved a simpler structure and enhanced cooling efficiency.
- The times required for each cell assembly line process could be leveled, which helped to realize full automation of the entire production process and enabled shortening of the production time.

As a result, the newly developed fuel cell stack achieved twice the durability at 1/3 of the cost while maintaining the same net power as the previous system.

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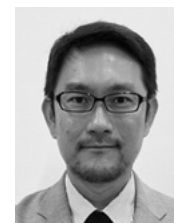
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