

Development of Battery System for EV

Akihiro ANEKAWA* Koichi YAMAMOTO*

ABSTRACT

A battery system for EV use has been developed with the aim of realizing compactness and high durability. The system employs Toshiba SCiB lithium-ion batteries, which display good durability and power regeneration characteristics, as the power source. Sufficient numbers of batteries to provide the energy necessary for the driving range demanded for the vehicle have been connected in a densely packed configuration and fitted in a battery box case employing a seal structure providing good environmental resistance. Together with battery fans for cooling and high-voltage safety devices, this comprises a battery system designed to be installed compactly under the floor of the vehicle without sacrificing the interior comfort of the FIT EV. In addition to demonstrating that the batteries themselves displayed good durability, verification of the durability of the battery system indicated that the cooling system helped to ensure the maintenance of a high level of performance over the entire period of vehicle use.

1. Introduction

As one response to the depletion of fossil fuel reserves and the need to protect the global environment, Honda is advancing technological development efforts in the area of vehicle electrification, and is providing appealing products to the market. The FIT EV, which was made available for lease in the U.S. and Japan in summer 2012, achieves the highest electrical energy efficiency performance in its class (as of the commencement of leasing of the vehicles; figures approved by the EPA), and in addition combines this achievement with the driving pleasure offered by three-mode driving. Standing behind this achievement is a high-power 100 kW battery system with a capacity of 20 kWh. The fitting of the battery system under the vehicle floor in a high-density package also contributes to the interior comfort of the FIT EV. The battery system has also been provided with a cooling system in order to realize a higher level of durability, offering convenience and peace of mind to users throughout the entire period of vehicle use. This paper will discuss the characteristics of the batteries forming the foundation of the FIT EV battery system, the battery cooling concept and configuration based on those characteristics, and battery system durability.

2. Development Goals

Because batteries provide drive power for EV, if driving range is increased, it is generally necessary to fit an

increased number of batteries in the vehicle. This increases the volume and weight of the batteries. The FIT, which served as the base vehicle for the FIT EV, was well received for balancing a compact body with a high level of interior comfort. It was therefore necessary in the development of the battery system for the FIT EV to realize the essential level of energy while also focusing on reducing the size of the system in order to maintain this characteristic of the base vehicle.

In addition, it is necessary for the battery systems employed in EV, which consist of large numbers of batteries connected together, to maintain the vehicle performance over the entire period of use of the vehicle. Given that EV are fitted with numerous batteries, differences in the battery use environments can result in differences in the changes to battery characteristics. Changes in battery characteristics are affected by factors such as the batteries' temperature, state of charge (SOC), and current flow. Battery temperature is one of the factors exerting an effect on changes in battery characteristics, but because battery temperature is unevenly distributed within a battery system, differences in battery characteristics occur. A cooling system developed on the basis of an understanding of changes in battery performance in relation to battery heat generation characteristics and battery unit temperature, able to realize a uniform temperature environment for multiple batteries, is therefore an important device in terms of maintaining vehicle performance.

The following two main goals were set for the

* Automobile R&D Center

development of the EV battery system.

- (1) A battery layout contributing to the realization of a high level of interior comfort
- (2) A battery system that maintains a high level of durability

3. System Configuration and Performance

3.1. Cooling System Configuration and Performance

In designing the cooling system, particular consideration was given to environmental temperatures and the status of traffic infrastructure in the U.S., quick-charging needs in Japan, and factors that would affect battery temperature. The battery system used in the FIT EV is positioned under the vehicle's floor, and uses external air as a cooling air flow. Because of this, the system would be affected by exhaust heat from the drive system while the vehicle was in operation (Fig. 1) and radiant heat from the road surface when it was parked (Fig. 2). In addition, when the vehicle was parked outdoors the battery system would also be affected by heat as the temperature inside the vehicle increased due to the effect of heat from the sun (Fig. 3). In an EV, which employs a larger number of batteries than an HEV, it is essential to develop cooling systems based on consideration of these effects.

In the case of the battery cooling method, two methods of cooling, direct and indirect, were considered as candidates. Direct cooling would use external air to provide a cooling air flow in the interior of the battery box case, and the air would directly exchange heat with the batteries. In the case of indirect cooling, heat would be transmitted from

the lower surfaces of the batteries to heat transfer members and the battery box case, and heat would be exchanged with cooling air passing through the two-fold structure of the case. Direct cooling would offer a higher level of battery cooling performance, but it would be essential to attempt to prevent foreign matter, dust and grit, and moisture in the external air introduced in this method from infiltrating the battery connections. Based on study of the amount of heat generated by the batteries as a result of user modes of use, indirect cooling, which would make it possible to use a compact battery box configuration without any structures to assist in preventing dust and moisture, was selected for application in the FIT EV.

Figure 4 shows the structure used for indirect cooling. Heat transfer materials are positioned between the bottoms of the cells and the battery case, and transmit the heat generated by the batteries to the battery box case. Fin-shaped guides that increase the cooling surface area and create a homogeneous cooling air flow across the battery box case are positioned in the cooling air channels in the two-fold structure of the battery box. When the cooling air flow, introduced by two battery fans, passes through the cooling air channels in the battery box, it exchanges heat with the batteries indirectly.

In designing the cooling structure, repeated simulations were conducted to design a structure able to efficiently cool all of the batteries and control battery temperature within a prescribed range. Figure 5 shows the flow of cooling air

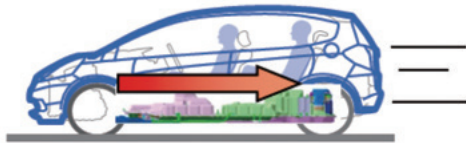


Fig. 1 Influence of exhaust heat during vehicle operation



Fig. 2 Influence of radiant heat from road

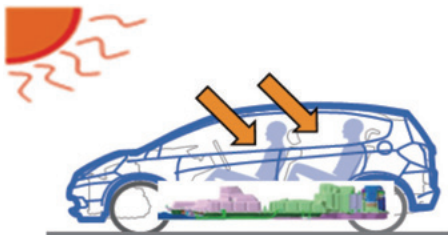


Fig. 3 Influence of sunlight when vehicle is parked

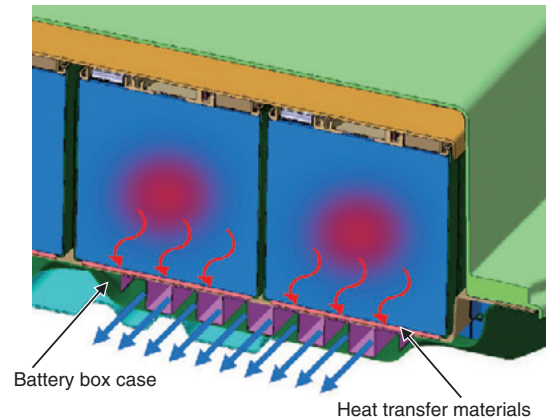


Fig. 4 Indirect cooling configuration

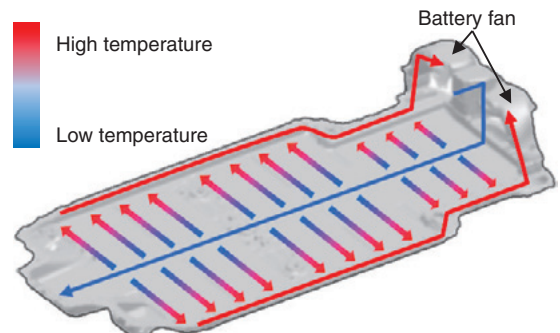


Fig. 5 Cooling air flow in battery box case

through the battery box case. The cooling air provides heat exchange as it passes through the battery box case. Figure 6 shows a comparison of the results of a test conducted to verify battery system cooling performance with results obtained when the cooling system was not employed. When the cooling system was not employed, it was not possible to control the increase in the temperature of the batteries with repeated vehicle operation and battery charging, and the upper limit temperature for the maintenance of battery durability was exceeded. By contrast, in the case of the battery system using the cooling system, temperature increase was controlled and the upper limit temperature was not exceeded, helping to enable continuous vehicle operation without power save.

3.2. Battery Layout

Because the average voltage of the SCiB is lower than that of a typical lithium-ion battery, it would be essential to use a large number of cells in order to increase voltage and help ensure the necessary energy. Because of this, the volume of the FIT EV battery system, composed of large numbers of SCiB, would be greater than that of a system using typical lithium-ion batteries. At the same time, it was also important to install the battery system in the vehicle without sacrificing the interior comfort of the base FIT. This necessitated study of densely packed battery layouts. Figure 7 shows a diagram of a section of a battery module, the basic component of the battery system. The use of

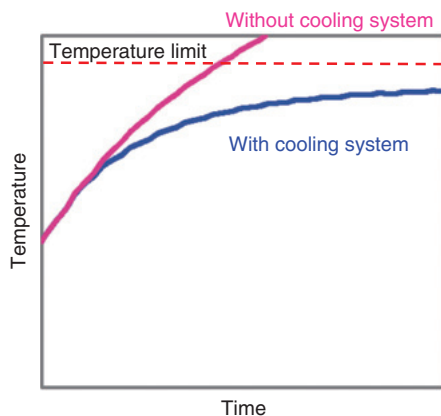


Fig. 6 Results of cooling tests

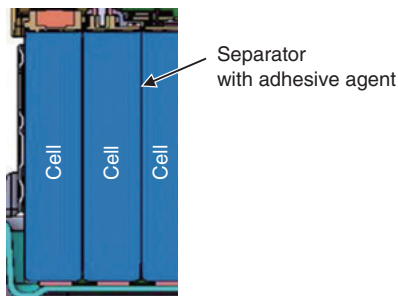


Fig. 7 Structure of battery module connection (Overview)

indirect cooling made spaces between the cells for the flow of cooling air unnecessary, and it was therefore possible to bond the cells together using only separators between them to create a densely packed layout while also realizing strength as a module. By this means, it was possible to balance the battery layout with good interior comfort.

3.3. Features of Lithium Titanium Oxide (LTO) Batteries

Typical lithium-ion batteries use metal oxides and carbon materials as the active materials at the cathode and anode, respectively. The SCiB employed in the new FIT EV resembles a typical lithium-ion battery as it also uses metal oxides as the active materials at the cathode, but is distinctive in using LTO at the anode. Figure 8 shows the results of a differential thermal analysis of the anode materials during occlusion of Li with the electrolyte as a means of evaluating the thermal stability of LTO as an active material for use in electrodes⁽¹⁾. In Fig. 8, results for hard carbon are added to a graph drawn in Reference (1) in the References section. The vertical axis of the graph shows the reaction heat capacity with the electrolyte. The graphite used in typical lithium-ion batteries displays a high heat-generation peak at around 240°C, but the heat generation of the LTO is less than one-tenth this level. Similarly, the LTO's level of heat generation is lower than that of the hard carbon used as an anode material in lithium-ion batteries, and it thus displays high heat stability.

Figure 9 shows the electrical potential characteristic of a typical lithium-ion battery, and Fig. 10 shows the potential characteristic of the SCiB.

While the electrical potential of the anode of a typical lithium-ion battery drops to close to 0 V when the battery is charged, the potential of the anode of the SCiB remains constant at around 1.5 V. Because of this, the average voltage of the SCiB is 2.3 V, a low figure compared to the average of 3.6 V for a typical lithium-ion battery. When the electrical potential of the anode of a lithium-ion battery drops to a level close to the potential for lithium plating, lithium metal can precipitate on the anode. Plating of lithium metal is a factor in the formation of lithium

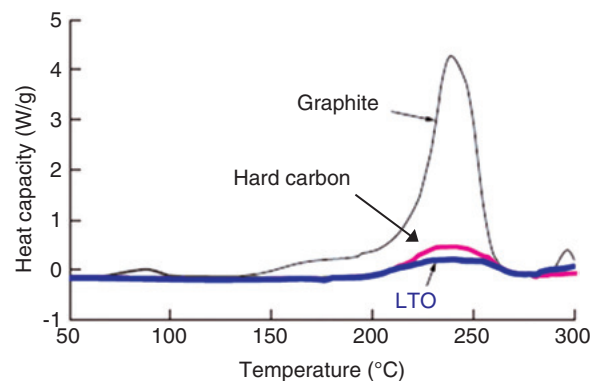


Fig. 8 Reaction heat capacity of cathode material with electrolyte during Li occlusion

dendrites (needle-shaped crystals), and this can result in declines in the battery's reversible capacity and durability. In the case of a typical lithium-ion battery, when the battery is fully charged, particularly at low temperatures, fine control of battery voltage is necessary to attempt to prevent plating of lithium metal, and this can prevent a full charge from being attained or can extend the time taken to reach full charge, among other issues. By contrast, in the case of the SCiB, the potential of the anode does not drop to close to the potential for plating of lithium metal. Because of this, plating does not occur, meaning that the battery maintains its reversible capacity and displays increased durability.

3.4. SCiB Performance

Figure 11 shows the regeneration characteristics of different types of batteries at each SOC at -10°C . As the graph indicates, the SCiB displays good regeneration performance.

By contrast with standard Li-ion batteries, SCiB are reported as displaying a high level of durability⁽¹⁾, but they are prone to performance decline in the form of decline in capacity and increase in resistance due to

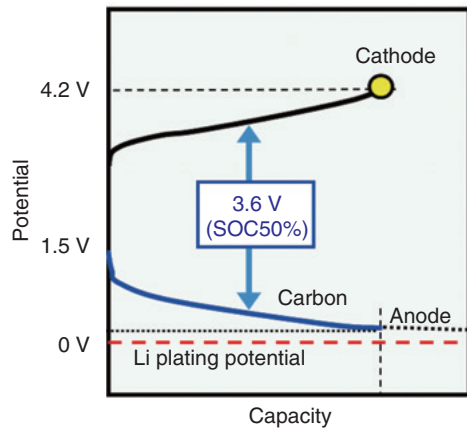


Fig. 9 Potential characteristics (Typical lithium-ion battery)

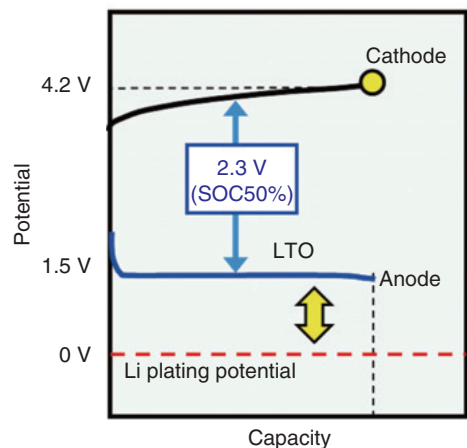


Fig. 10 Potential characteristics (SCiB)

the effect of SOC and temperature. As a representative example, Figure 12 shows the results of test verification of the change in resistance for two standard temperature settings. It is clear that the increase in resistance is greater at 45°C . The fact that performance decline increases in proportion to temperature is a characteristic the SCiB shares with typical lithium-ion batteries. And like a typical lithium-ion battery, the performance change in the SCiB can be considered using the 1/2-power rule⁽²⁾.

Figure 13 shows the results of applying the 1/2-power rule to the time in the results shown in Fig.

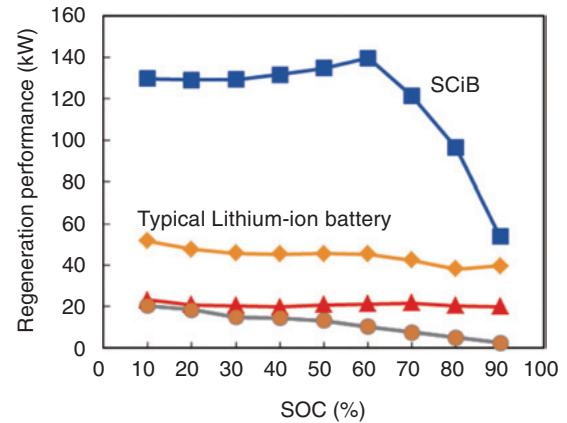


Fig. 11 Regeneration performance (-10°C)

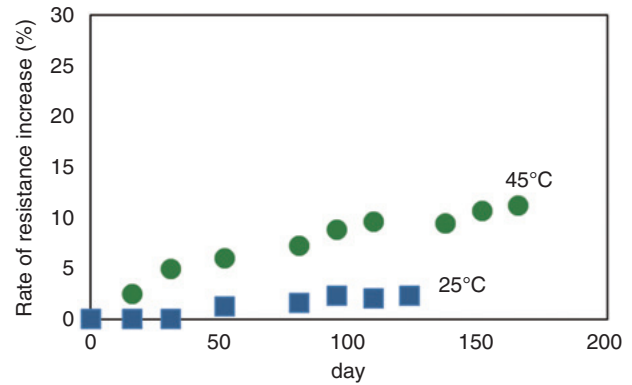


Fig. 12 Change in resistance

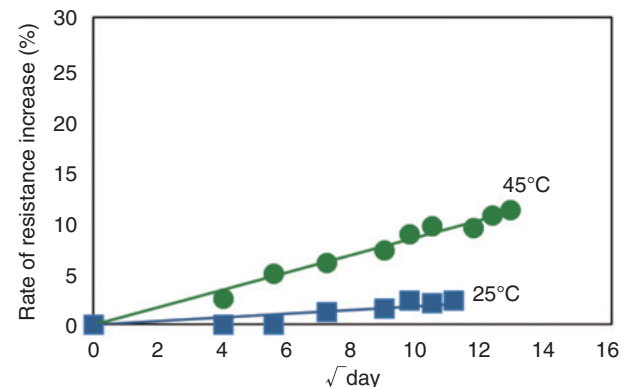


Fig. 13 Change in resistance

12. The increase in resistance displays linearity in relation to the 1/2-power of time. The coefficients of change in resistance performance for the respective temperatures can be obtained from the gradient of the line. Figure 14 shows performance change coefficients calculated from the results of tests of changes in capacity and resistance for a charge-discharge cycle and storage for battery units, based on modes of vehicle use. The performance change for the SCiB is greater for the charge-discharge cycle (vehicle operation) than for storage. An appropriate range of use was set for the SCiB based on this type of understanding of performance change.

In addition, it is possible to estimate the performance change for the SCiB during vehicle use based on the performance decline coefficients obtained from cycle tests and storage tests. This makes it possible to estimate and study changes in the performance of the SCiB in relation to modes of use for a variety of users. Furthermore, it is also possible to conduct tests of accelerated performance decline by setting high-load conditions based on user modes of use.

3.5. Battery System Durability

In developing a battery system for EV use it is essential to sufficiently verify the durability of the batteries based on factors including the temperature environment and road and charging infrastructure of the region in which the vehicles will be used. Because test results have indicated that temperature affects battery performance changes, it is also necessary to consider battery heat generation. EVs differ from HEVs in that batteries are their sole power source and, because of this, more current flows through the batteries the higher the vehicle speed, and the level of heat generated by the batteries is consequently greater (Fig. 15). During the development of the battery system, a range of vehicle speeds encompassing vehicle use conditions for different users was set based on the distribution of average speeds and battery current flow produced by vehicle use patterns

including highway driving, and EV durability tests were conducted with thermal loads applied to EV.

Figures 16 and 17 show the results of these EV durability tests for the SCiB and a typical lithium-ion battery.

The effect of the application of high-durability SCiBs and the ability of the cooling system to control battery temperature were indicated in test results. The batteries displayed around one-fifth the decline in capacity and one-half the increase in resistance of a typical lithium-ion battery over the period of vehicle use, indicating that the potential effect on the vehicle's driving range had been

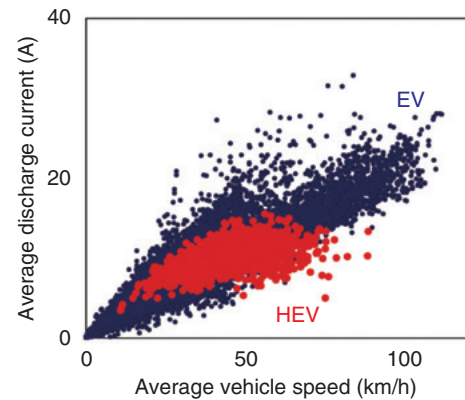


Fig. 15 Correlation between vehicle speed and battery discharge current

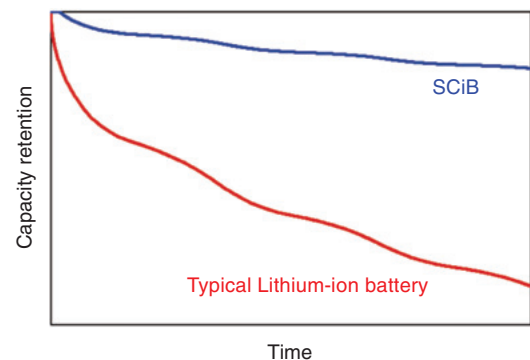


Fig. 16 Results of durability tests (Capacity)

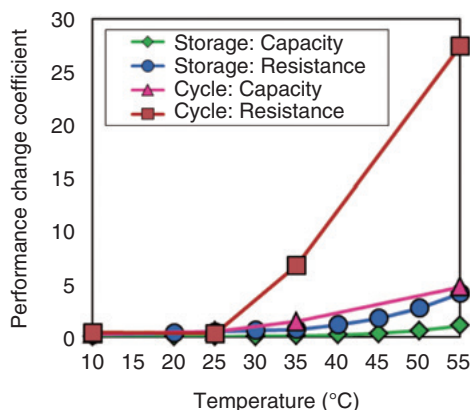


Fig. 14 Performance change coefficients (Storage, cycle)

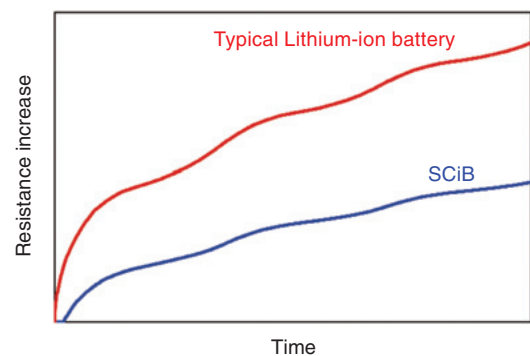


Fig. 17 Results of durability tests (Resistance)

controlled to a significant degree. In terms of the increase in resistance also, the results showed that the level was such that it would not affect the FIT EV's dynamic performance.

4. Conclusion

An EV battery system has been developed for use in the FIT EV. Employing a densely packed module configuration in order to increase compactness, the battery system is fitted under the floor of the vehicle, contributing to the good interior comfort of the FIT EV. The battery system employs indirect cooling, making it possible to efficiently cool all of the batteries. This has been verified as helping to control increases in battery temperature with repeated vehicle operation and charging. The combination of the high level of durability of the SCiB themselves and the effect of the cooling system have made it possible to offer a battery system that displays minimal battery performance decline resulting in a reduction in the vehicle's driving distance and offers a high level of durability for the entire period of vehicle use.

References

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■ Author ■



Akihiro ANEKAWA



Koichi YAMAMOTO