Development of a New Battery System for Hybrid Vehicles

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Abstract

A new battery system for the new TOYOTA PRIUS has been developed. The new battery has a rectangular module with six cells linked in series. Due to the simple structure which places the rectangular modules side by side, and other parts in battery pack also being made more compact, an approx.60% decrease in the battery pack volume and 30% decrease in weight have been realized. Also, improvements in the electrode configuration and materials used in the battery have improved battery performance.

1. Introduction

Toyota Motor Corporation launched the Prius, the world's first mass-production hybrid vehicle, in December 1997. The Prius, which was born within the context of worldwide concerns for saving energy and preventing global warming, and which has sold over 30,000 units thus far, has demonstrated the form of automobiles to come. With the aim of introducing the Prius into the North American and European markets, this vehicle was developed by setting targets to ensure suitable drive performance for all use environments, to further improve fuel economy, and to reduce exhaust emissions. In terms of the battery system, which occupies a significant area of the luggage compartment, we successfully addressed the issue of size reduction. These feats have greatly contributed to improving the product appeal of this vehicle. This paper describes how the new battery system was made more compact and lightweight.

2. Battery Module Construction

The battery configuration of the previous Prius comprised a 7.2V cylindrical module, which consisted of six 1.2V cylindrical nickel metal hydride batteries that were connected in series. 40 modules are assembled into a holder, connected in series, and placed in the vehicle (Fig. 1). In contrast, the battery of the new Prius is a rectangular module which consists of six cells combined in series. To ensure heat dissipation, the module is thin with a wide surface area. The case is made of plastic, which was selected based on its resistance to the alkaline electrolyte, electrical insulation between cells, formability of the modular shape, weight, etc. The rectangular modules, when combined into a battery pack, reduced dead space and require a minimum amount of space for cooling. Thus, a compact package has been realized.

3. Battery Pack Construction

In the new battery pack, 38 modules are stacked in series and bound from both sides to form a single pack. The expansion force of the modules and the lateral force that is applied by the vehicle are received by the end plates at each end, the holding rod, and the lower case. The vertical and longitudinal forces that are applied by the vehicle are received by securing the modules to the case. The lower case has the function of providing strength to the modules as well as of securing the modules. Consequently, it has become possible to reduce the volume and discontinue use of a holder. As a result, a compact and lightweight package has been successfully created. Furthermore, because the new battery pack is made of metal, the shield paint that was needed for preventing electromagnetic noise on the previous plastic pack is no longer necessary.

4. Battery System

To ensure electrical safety, the component parts of the high-voltage system are enclosed in the battery pack, as in the previous Prius (Fig. 2). These parts consist of a system main relay (SMR) with a built-in current sensor, a service plug with a built-in fuse, and a battery electronic control unit (ECU). To efficiently use the dead space in the vehicle, the battery cooling blower that was included in the battery pack of the previous Prius has been relocated outside of the battery pack. These parts have also been made more compact and lightweight.

· SMR with built-in current sensor

The SMR opens and closes in unison with the ON/OFF operation of the ignition key. When it is turned OFF, it cuts off the high-voltage system to ensure safety.

It functions similarly when the vehicle is involved in a collision or when there is a malfunction in the system. The current sensor is used for calculating the state of charge (SOC) of the battery. The parts that were all placed separately in the previous model are now housed in a single case (thereby losing excess area) in order to achieve a compact package. At the same time, the specifications have been optimized and the individual parts have been also made more compact (Fig. 3).

· Service plug with built-in fuse

The fuse prevents electric shocks and fire in the vehicle when the battery short-circuits, such as in the case of a collision. The service plug ensures safety while the vehicle is being serviced by mechanically cutting off the circuit. The specifications have recently been optimized by such things as revising the amperage capacity, and it has been made more compact.

· Battery ECU

Based on the current, voltage, and the temperature of the battery, the battery ECU calculates the SOC and transmits it to the vehicle control system. It also monitors the battery for abnormalities. By improving its interior circuit design, success has recently been achieved in making it more compact.

· Battery cooling blower

The fan diameter has been increased by efficiently using dead space in the vehicle. Thus, the blower itself has been made more compact and lightweight while providing the same airflow volume as the previous small-diameter dual-fan system.

Through these improvements, reductions of approximately 60% in volume and approximately 30% in weight of the overall battery pack have been achieved when compared to the previous Prius. As shown in Fig. 5, the luggage space of the new Prius has been increased considerably, and access through the trunk has been made possible.

5. Cooling performance

One of the issues in using a plastic battery case is cooling. Because plastic has a lower thermal transmission rate than metal, the temperature of the electrode in the battery would be higher than in the previous cylindrical type. To resolve this problem, countermeasures from the perspective of "reducing internal resistance" as well as "improving heat dissipation were taken". In terms of reducing internal resistance, the vertical/horizontal ratio of the electrode and the construction of the current collector were optimized and the internal composition was improved. In terms of improving heat dissipation, the cells were made thinner to reduce the temperature differences in the plates and the heat radiation surface area was increased to improve cooling performance.

The cooling system uses the cabin air in the air-cooling system. This is the optimal cooling method for the Prius, taking into consideration the battery's operating temperatures, amount of heat generated, installability and cost factors.

The flow of the cooling air in the battery pack is described in Fig. 4. In the cylindrical module battery pack, the air that is used for cooling the lower modules is then used for cooling the upper modules, creating temperature differences. However, in the rectangular module battery pack, the cooling air is distributed to every module, making it less susceptible to creating temperature differences. Furthermore, because this battery pack has smaller temperature variances, it was possible to reduce the number of battery temperature sensors.

Due to the improvements described thus far, it become possible to reduce both the battery's maximum temperature and the temperature variances when compared to the previous Prius. In the long term, the reduction of the battery's maximum temperature is advantageous in extending the service life of the battery. Fig. 6 shows a comparison of the previous and new Prius models during hill climb. Even under such stringent driving conditions, a reduction in both the battery temperature and temperature variances has been achieved with the new model.

6. Battery performance

The internal resistance of the battery has been reduced and its output performance has been improved compared to the cylindrical type. Fig. 7 shows the relationship between the discharge time and voltage at a fixed output. Although the number of modules in the new battery pack has been reduced from the previous 40 to 38 modules, an equal or greater battery pack output performance has been achieved. Furthermore, because the number of modules has been reduced without reducing the output voltage, this change could be made without making any changes in the specifications of the electric system components in the vehicle.

7. Battery service life

Fig. 8 shows the relationship between the on-vehicle charging/discharging pattern that is converted into distance driven and the rise in the internal resistance. In addition to the new model's improved output compared to the cylindrical type, the service life of the new model is equal to or greater than that of the cylindrical type. Further studies in this field are currently being conducted.

8. Summary

As is described above, the battery system of the new Prius has successfully achieved a dramatic reduction in both size and weight in its new package. However, the issue is reducing cost still needs to be tackled further if hybrid cars are to popularize on a large scale. To this end, further technological development to advance towards this goal is planned.

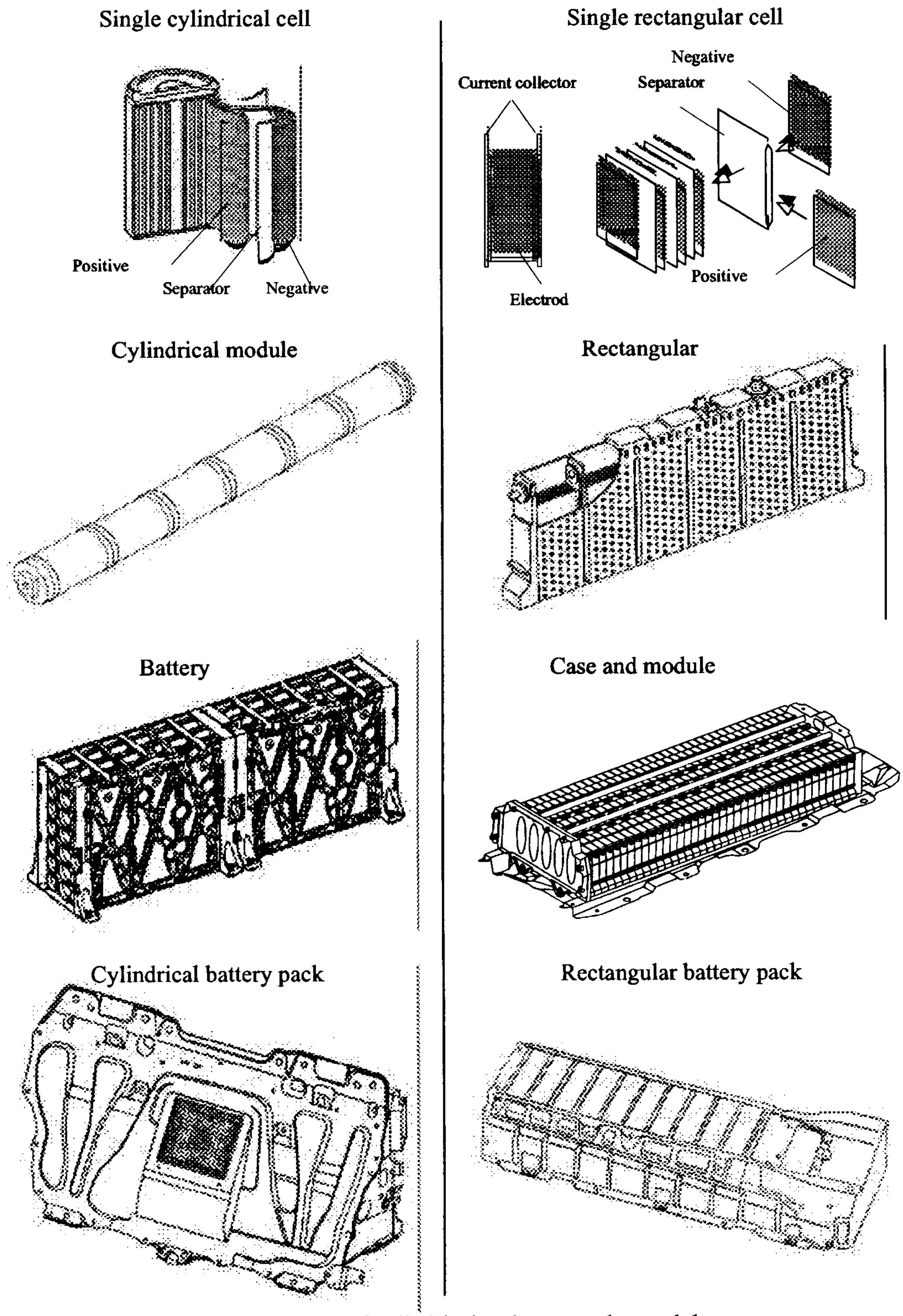

Fig.1 Comparison of cylindrical and rectangular modules

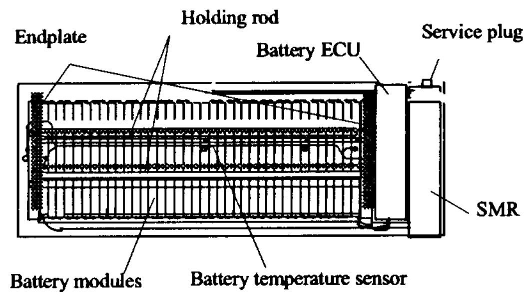

Fig.2 Battery pack configuration

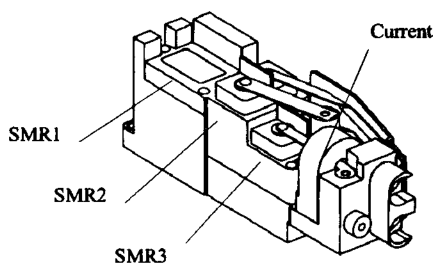

Fig.3 SMR with built-in current

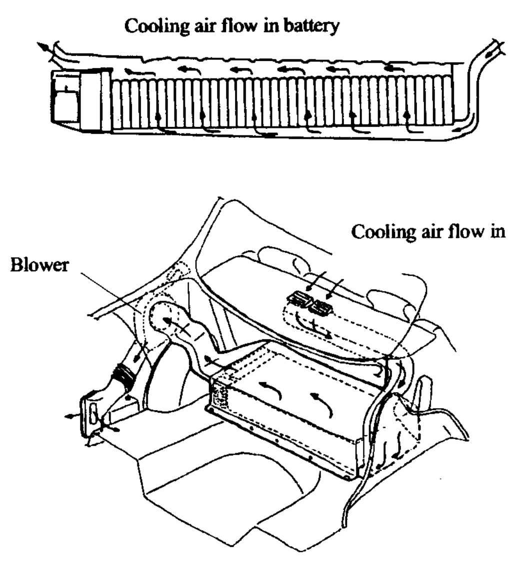

Fig.4 Battery

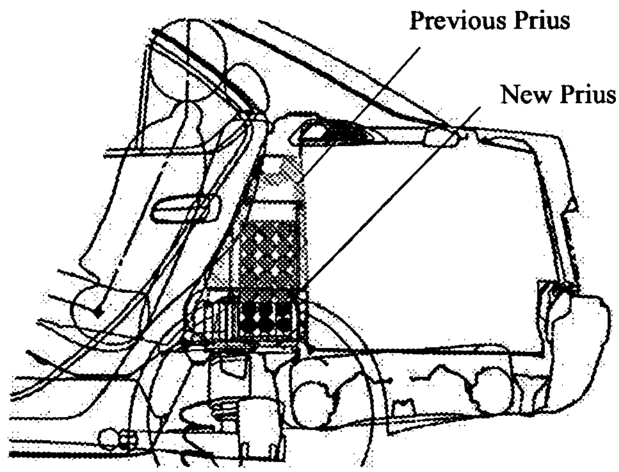

Fig.5 View of battery pack installed on

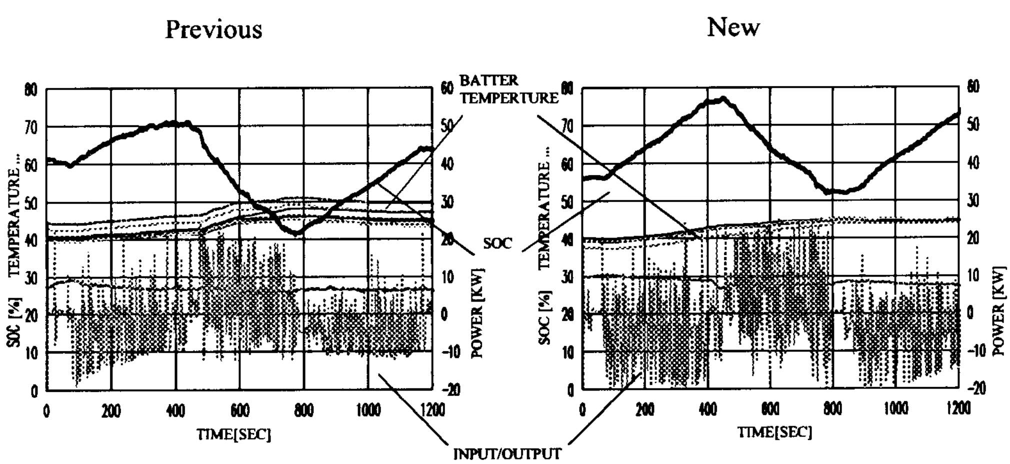

Fig.6 Actual driving data (hill climb)

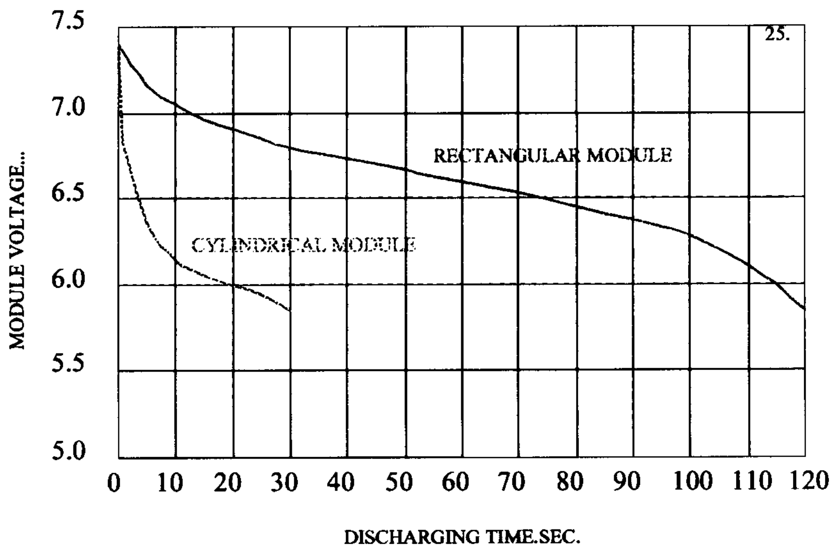

Fig.7 Battery

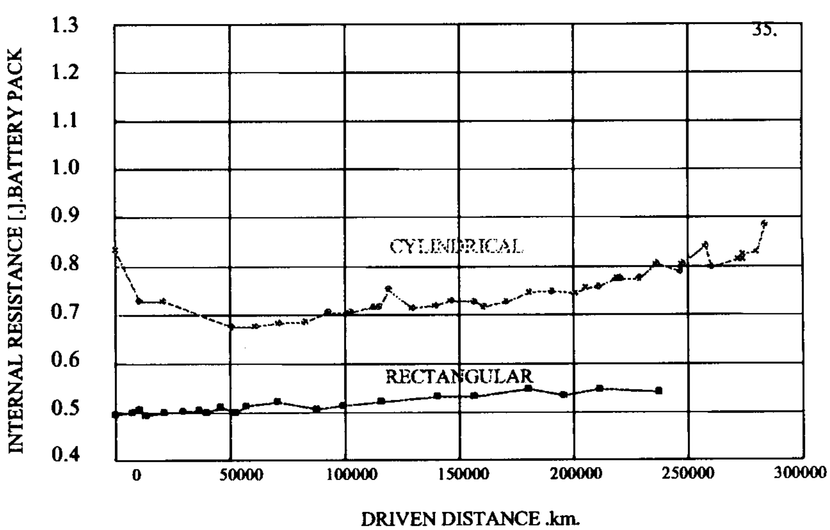

Fig.8 Relationship between driven distance and internal