High heat-resistant Lithium-ion capacitor module for HINO TEAM SUGAWARA Dakar HEV

- Super-durable, excellent output performance and vibration resistance -

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ABSTRACT: Countries around the world are actively working toward the realization of a carbon-neutral society. In the field of motor sports, the adoption of sustainable fuels and the electrification of competition vehicles are progressing. HINO TEAM SUGAWARA participant of the Dakar Rally, which is well known as the world's toughest motorsports competition, also participated in the competition with a Hybrid Electric Vehicle (HEV) from January 2022. JTEKT supplied a high heat-resistant Lithium-ion capacitor module as the main power supply, contributing to HINO TEAM SUGAWARA finishing in 22nd place overall in the truck division.

KEY WORDS: hybrid vehicle, motor sports, lithium-ion capacitor, power electronics, motor, powertrain

1. INTRODUCTION

The Dakar Rally is known as the world's toughest motorsports competition and is a highly popular competition [(1)]. HINO TEAM SUGAWARA, which has been participating in the race since 1991, introduced a Hybrid Electric Vehicle (HEV) from 2022. High heat-resistant Lithium-ion capacitor module was adopted as the main power supply for this vehicle, contributing to the overall 22nd place finish in the truck category.

In the Dakar Rally, countries around the world are stepping up their efforts to realize a carbon-neutral society, and the number of teams using sustainable fuels and electric vehicles has been increasing in recent years.

2. REASONS FOR ADOPTING HEV AND REQUIRED PERFORMANCE OF POWER STORAGE DEVICES

2.1. Reasons for adopting HEV

Due to the revision of the race category, HINO TEAM SUGAWARA (8-liter class) conducted a spec comparison with competing vehicles in order to compete with large trucks equipped with 13-liter class engines, the maximum displacement of the current regulations.

As a result of comparing Hino's 2020 Dakar entry vehicle with the trucks that won top prizes in the truck category, it is concluded that an improvement in the power-weight ratio (vehicle output / vehicle weight) is necessary (Fig. 1).

HINO TEAM SUGAWARA aimed to shorten the race time while maintaining the light-weight advantage over rival team vehicles. The decision was made to adopt a hybrid system in order to use the motor to assist in the low rev range where engine output is difficult to generate, and to regenerate electric power during deceleration to make effective use of energy.

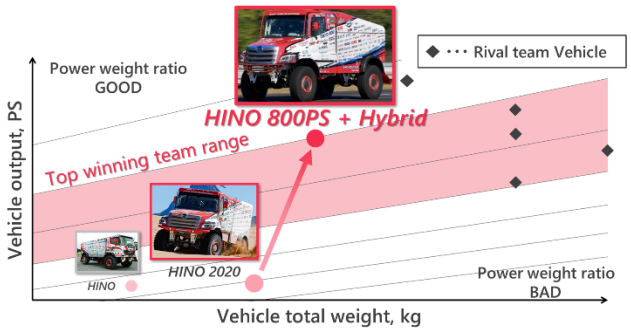

Fig. 1 Comparison of vehicle spec with rival teams
(Material provider: Hino motors)

2.2. Driving pattern / Requirement of power storage device

Fig. 2 shows the driving behavior in the special stage (SS) section where the race time is contested. Since the vehicle speed fluctuates rapidly and the accelerator opening is almost 0% or 100%, it can be seen that the driver repeats full-acceleration and full-braking.

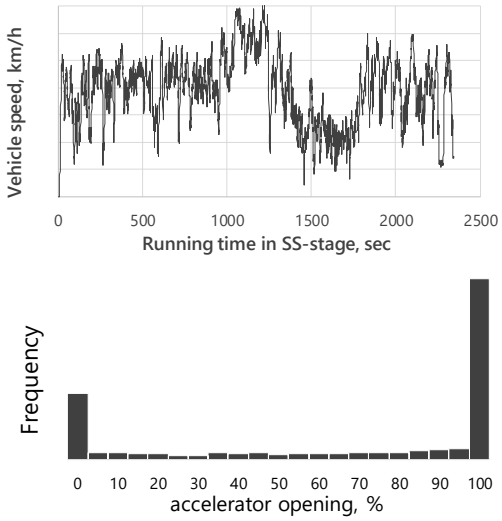

Fig. 2 SS section vehicle speed (upper) and accelerator opening (lower)
(Material provider: Hino motors)

Since HEVs frequently repeat acceleration assist (discharging) and regenerative braking (charging), power storage devices are required to have extremely high charge / discharge durability. On the other hand, the regenerated power is consumed immediately when re-accelerating, so a small energy capacity is sufficient.

For these reasons, power storage devices must be able to charge and discharge large amounts of power with a small energy capacity, and must be compact and light-weight. In other words, high power type devices are preferred, among which Lithium-ion capacitors with excellent energy density are more suitable.

Furthermore, it is essential to ensure durability and reliability against repeated charging and discharging of large currents, and to ensure safety against overturning of vehicles. These required performances match the features of high heat-resistant Lithium-ion capacitors, and they have been adopted for the main power supply of the Dakar HEV.

3. LITHIUM-ION CAPACITOR

3.1. Device configuration and general features

It consists of a graphite-based negative electrode for Lithium-ion battery and the activated carbon-based positive electrode for Electric Double Layer Capacitor: EDLC (fig. 3) [2] [3].

While maintaining the excellent input / output performance and charge / discharge durability that are the features of EDLC, it has 3 to 5 times higher volume energy density and is used in various industrial fields. In addition, it has a very high level of safety due to the material composition that does not cause the thermal runaway reaction, which is a problem in Lithium-ion battery [4] [5].

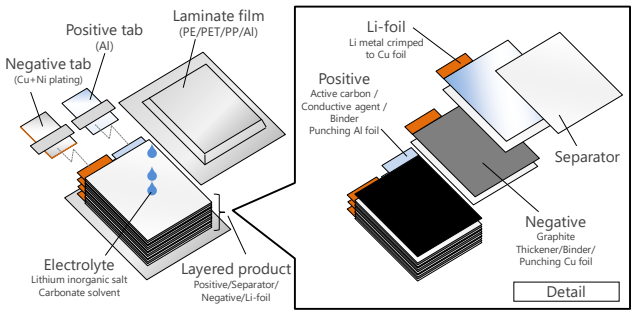

Fig. 3 Structure of Lithium-ion capacitor

3.2. Improved heat resistance and other advantages

By improving the electrolyte and controlling the material compatibility between the electrolyte and electrode, we were able to adapt the operating temperature range of Lithium-ion capacitors to -40 to 85°C, which is the temperature required for passenger compartment of automobile (world's first)

Along with the improvement in heat resistance, it exerts a significant effect of suppressing performance deterioration due to self-heating (Joule heat generation) during large-current charging and discharging, and has a high durability performance that cannot be achieved with conventional technology [6]

In addition, high heat-resistant Lithium-ion capacitor have even higher safety than before. No ignition or explosion occurs even in a crushing test (50% crushing) according to SAE J 2464: Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing.

4. HIGH HEAT-RESISTANT LITHIUM-ION CAPACITOR MODULE

4.1. Performance requirements and base design selection

When using a high-heat-resistant Lithium-ion capacitor in the Dakar HEV, it is necessary to construct a module in which multiple cells are connected in series to supply a specified voltage and current to the inverter. Modules are required to be robust enough to protect the cells from severe vibrations and shocks during the race. Based on the robust vibration and shock-resistant module developed for railways, the base design was improved for the Dakar Rally [7]

4.2. Module structure and function

Fig. 4 shows the structure and development view. The high-heat-resistant Lithium-ion capacitor cell is sandwiched between two resin frames to protect it from external forces. The number of cells in series can be changed arbitrarily up to 36 series per module, allowing flexible response to various voltage requirements.

The module has a built-in balancing circuit for correcting voltage (State of Charge) variations between cells connected in series, and has a communication function to transmit constant monitoring information such as cell temperature and cell voltage to the outside.

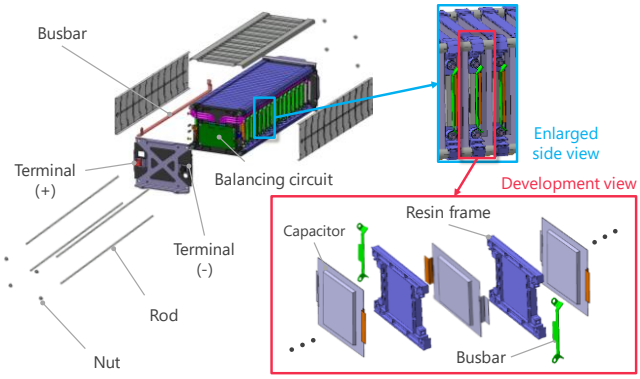

Fig. 4 Internal structure of the module
(Material provider: Kyoho Machine Works)

Vibration and impact resistance complies with JIS E 4031: Railroad Vehicle Equipment - Vibration and Shock Test Method (2013) Category 1 Grade B. Regarding safety, it has been confirmed that it satisfies the safety requirements of JIS C 8715-2: Single Cells and Battery Systems for Industrial Lithium-ion Batteries - Part 2 (2019).

4.3. Improvements for Dakar HEV installation

The standard module has simple dustproof and waterproof functions, but since the Dakar HEV runs through the desert, the gaps around the module are filled with a sealant to enhance the dustproof and waterproof functions.

In addition, a simple heat dissipation mechanism was added to prevent the cell from overheating when the HEV system is used for a long time, such as when time-attacking in the SS section. Table 1 shows the specifications of the vibration / shock resistant module that has undergone a series of improvements.

Table 1 Module specifications for Dakar HEV

Item	Characteristic value
Series number	2000 F / 33 series
Combined capacitance	60.6 F
Voltage range	72.6 to 125.4 V
Average voltage	99 V
Dimensions (including mounting bracket)	W222 x D651 x H172 mm
Weight	20 kg or less
Communication method	CAN communication

4.4. Construction of high voltage power supply

The six modules mentioned above were built into an aluminum frame, and the modules were connected in series to construct an approximately 600V power supply. In addition, an interface circuit was added to collectively aggregate the communication information of the six balancing circuits and transmit it to the ECU on the HEV side via CAN communication. Fig. 5 shows the state of installation in the vehicle.

Fig. 5 Photo of module installed in Dakar HEV
(Material provider: Hino motors)

5. OVERVIEW OF THE DAKAR HEV

5.1. Vehicle specification

Table 2 shows the vehicle specifications of the Dakar HEV equipped with a high heat-resistant Lithium-ion capacitor module. The HEV output of 280 PS is added to the engine output of 800 PS, achieving a maximum output of over 1,000 PS.

Table 2 Specification of Dakar HEV 2022

Item	Characteristic value
Base vehicle	Hino 600 series
Engine	In-line 6-cylinder 4-cycle diesel engine
Displacement	8.866L
Max. output (engine)	800PS (588kW)/2800 rpm
Max. output (hybrid system)	280 PS (206 kW)
Max. output (Total)	1,080 PS (794 kW)
Drive system	Full-time 4WD
Transmission	AT (6 forward speeds, 1 reverse speed)
Vehicle weight	8,600kg
Fuel tank	800L

5.2. Drive system layout

Fig. 6 shows an image of the drive system layout of Dakar HEV. In the event of a problem with the hybrid system, the engine and HEV system are connected via a transfer, allowing the vehicle to run even with the engine alone.

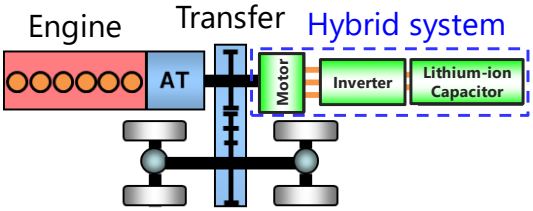

Fig. 6 Drive system layout of Dakar HEV
(Material provider: Hino motors)

6. DRIVING IN THE DAKAR RALLY

Fig. 7 shows the results of extracting part of the driving data in the Dakar Rally SS section. While the vehicle is running, the HEV system frequently repeats acceleration assist (discharging) and regenerative braking (charging) of high power, and the temperature rise of the high heat-resistant Lithium-ion capacitor module is remarkable. It takes about 5 to 6 minutes to reach the allowable upper limit temperature of the module from room temperature (A in the figure).

When the module temperature is low (A in the figure), the HEV system repeats acceleration assist and regenerative braking at maximum output. On the other hand, when the module temperature is near the allowable upper limit (B in the figure), the output of the HEV system is restricted in order to prevent the Lithium-ion capacitor module from overheating. At 80% HEV system output compared to normal, module temperature rise was rate-limiting. It was found that further enhancement of the heat dissipation performance of the module is necessary to maximize HEV system performance.

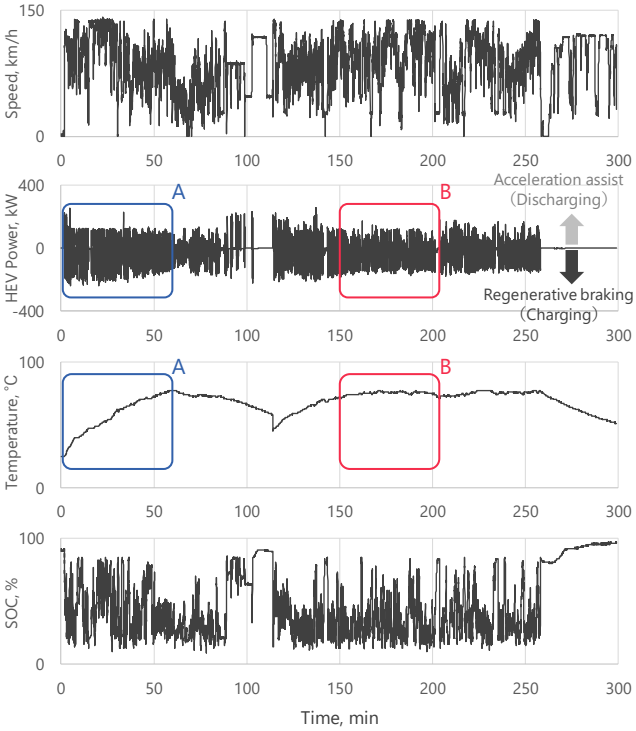

Fig. 7 SS section running data excerpt (30 minutes)

7. AFTER RUNNING THE DAKAR RALLY

After the Dakar Rally finished, the high heat-resistant Lithium-ion capacitor module was removed from the vehicle and disassembled to check the performance of the cell itself. The measurement conditions conform to IEC 62813-2015: Test methods for lithium-ion capacitors for electrical and electronic equipment - Electrical characteristics.

Figure 8 shows the results. Both the capacitance and internal resistance are almost the same as before the race, and no deterioration is observed. Even in the harsh usage environment of the Dakar Rally, the excellent durability performance of the high heat-resistant Lithium-ion capacitor was demonstrated.

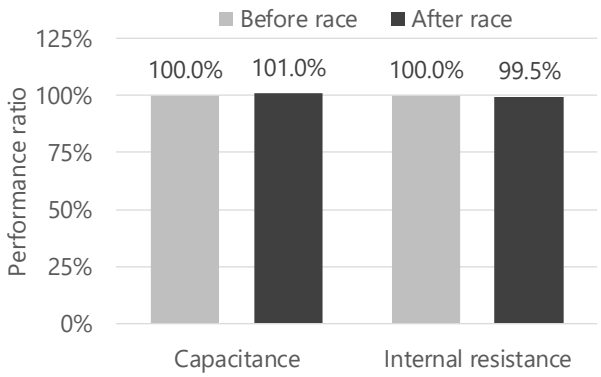

Fig. 8 Performance verification results
(Comparison of before and after the race)

8. CONCLUSION

Various vehicle troubles occurred during the race, but high heat-resistant Lithium-ion capacitor module continued to demonstrate stable performance without any serious troubles, and contributed to HINO TEAM SUGAWARA finishing in 22nd place overall in the truck division.

In order to further shorten the race time, we will continue our efforts to determine the limit performance of high heat-resistant Lithium-ion capacitor for the next Dakar Rally.

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