High Heat-resistant Lithium-ion Capacitor Module for HINO TEAM SUGAWARA Dakar HEV

1. Introduction

The well-known Dakar Rally is considered by some to be the world's toughest motorsports competition. HINO TEAM SUGAWARA, which has been participating in this rally since 1991, began use of a hybrid vehicle (HEV) in 2022. For this vehicle's main power supply, high heat-resistant lithium-ion capacitor modules from JTEKT were used, contributing to the team placing 22nd overall in the truck category.

In recent years, the Dakar Rally has also seen an increase in the number of teams using sustainable fuels and EVs as countries around the world accelerate their efforts toward realizing a carbon-neutral society.

2. Performance Levels Required of the Dakar HEV and Power Storage Devices

Due to modifications to the race categories, HINO TEAM SUGAWARA (8-liter class) conducted a comparison of competitor vehicle specifications to enable their vehicle to compete with the race times of large trucks equipped with 13-liter class engines, which is the maximum displacement under current regulations. By comparing their vehicle from the 2020 rally with the top vehicle in the truck category from that year, they concluded that improvements to the power-weight ratio (horsepower/vehicle weight) were necessary.

The team's decision to use an HEV stemmed from three desires: to have a vehicle that is lighter than those of other teams, to effectively utilize energy by regenerating power during deceleration, and to shorten race times by using motor power to make focused improvements to the low-speed range where engine power can be difficult to generate.

Drivers frequently accelerate and decelerate during the Special Stage (SS) of the rally, in which teams compete for the best race time. For the majority of this stage, drivers either have their foot off the accelerator pedal or are driving at full throttle, resulting in a driving pattern where full acceleration and full braking are repeated.

Because the power storage devices used in HEV systems frequently repeat driving assistance (discharging) and power regeneration (charging), they are required to be capable of withstanding extremely high levels of charging and discharging.

For this reason, power storage devices used in the HEV system of Hino's Dakar truck must be capable of inputting and outputting large amounts of power and are required to be both compact and lightweight. Although high-output power storage devices are suitable for this task, lithium-ion capacitors are most suitable due to their high energy density. Furthermore, power storage devices must be durable and reliable enough to withstand the repeated charging and discharging of large currents, as well as safe enough to withstand dangers such as vehicle rollover. Because JTEKT's lithium-ion capacitors are capable of meeting these performance requirements, they were selected as the main power source for the HEV system of the Dakar truck.

3. Lithium-ion Capacitors

3. 1 Structure/General Features

Lithium-ion capacitors have a structure that combines the graphite-based negative electrode of a lithium-ion secondary battery with the active carbon-based positive electrode of an electric double layer capacitor (EDLC). This provides them with input/output characteristics that enable large amounts of power to be supplied and regenerated instantaneously, which is the advantage of EDLC. Lithium-ion capacitors are also highly durable in withstanding repeated charging and discharging and feature a volumetric energy density that is approximately three times of EDLC, resulting in their increased usage in various industrial fields.

Moreover, lithium-ion capacitors are considered to be an extremely safe type of power storage device due to the fact that their material composition does not cause a thermal runaway reaction, which is a problem for lithium-ion secondary batteries.

3. 2 Features of JTEKT Lithium-ion Capacitors

For the first time ever, the operating temperature range of a lithium-ion capacitor has been adapted to the required temperature range for vehicle cabins (–40 to 85°C), which was achieved through improvements to the electrolytic solution using JTEKT's patented technology, as well as by controlling the compatibility of the electrolytic solution and electrode materials.

With their improved heat resistance, lithium-ion capacitors are highly effective at suppressing performance deterioration caused by self-heating (Joule heating) during the charging and discharging of large currents, enabling them to achieve a level of durability not possible with conventional capacitors.

JTEKT's high heat-resistant lithium-ion capacitors are also highly safe, as evidenced by the results of power storage device safety testing in which no ignition or explosion occurred during crush testing (50% crushing) performed in compliance with the SAE International standard "Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing (SAE J 2464)."

4. High Heat-resistant Lithium-ion Capacitor Module

4. 1 Performance Required of the Modules and Selection of a Base Design

In using our high heat-resistant lithium-ion capacitors for the Dakar HEV truck, it was necessary to construct a module with cells connected in series and supply a large current to the inverter within a specified voltage range. Because this module must be robust enough to protect the cells from severe vibrations and shocks during the race, we created an improved design based on our vibration/shock-resistant module developed for railways.

4. 2 Structure and Functions of the Vibration/Shock-resistant Module

Figure 1 shows the structure and exploded-view drawing of the module. The cells are protected from external forces via a structure in which a high heat-resistant lithium-ion capacitor cell (capacitance: 2 000 F) is sandwiched between two resin frames. Using this same structure, the number of cell series can be changed as desired up to a maximum of 36 series per module, enabling flexibility in response to various voltage requirements.

When cells are connected in series, the positive and negative tab-leads are connected directly to the busbar using ultrasonic welding, which eliminates unnecessary wiring and suppresses increases in module internal resistance. Specially shaped terminals are used for all positive and negative terminals of the module. This structure prevents reverse connections, ensuring worker safety when a high-voltage system is constructed by connecting multiple modules in series.

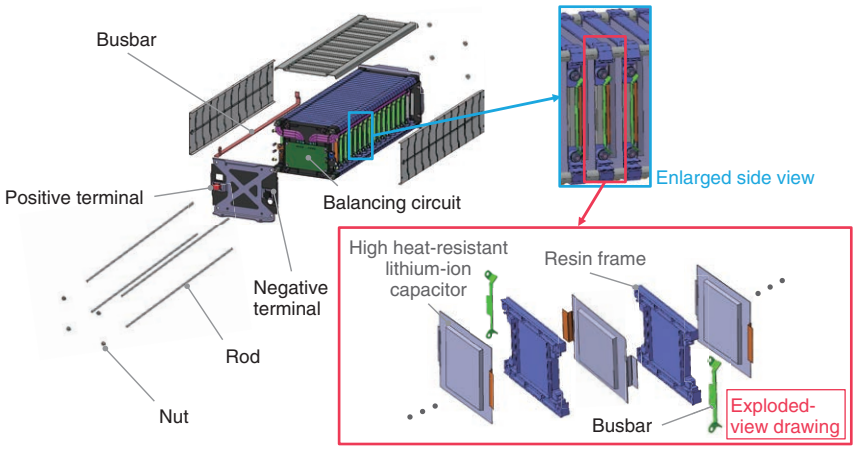
The module features a built-in balancing circuit to compensate for voltage variations (storage capacity variations) between cells connected in series, and has a communication function for constantly transmitting monitoring information, such as cell temperature and cell voltage, to the outside.

The vibration and shock resistance of this module has been confirmed to be in compliance with Category 1 Class B of the JIS standard "Rolling stock equipment - Vibration and shock tests (JIS E 4031: 2013)," while its safety has been confirmed to meet the safety requirements in JIS standard "Secondary lithium cells and batteries for use in industrial applications - Part 2 (JIS C 8715-2: 2019)."

4. 3 Improvements Made for Mounting to the Dakar HEV

Although the standard module has simple dustproof and waterproof functions, when used for the desert course of the Dakar Rally, these dustproof and waterproof functions are enhanced by using a sealing material to close the gaps around the outer periphery of the module.

Furthermore, a simple heat dissipation mechanism was added to prevent cells from overheating when the HEV system is used for long periods, such as during the Special Stage (SS) of the rally. **Table 1** shows the specifications of the vibration/shock-resistant module that has undergone a series of improvements.



(Materials provided by Kyoho Machine Works, Ltd.)

Fig. 1 Internal structure of vibration/shock-resistant module

Table 1 Specification of high heat-resistant lithium-ion capacitor module for the Dakar HEV

Specification	Characteristic value
No. of series	2 000F 33 series
Combined capacitance	60.6 F
Operating voltage range	72.6 ～ 125.4 V
Average voltage	99 V
Dimensions (incl. mounting bracket)	W222×D651×H172mm
Weight	20 kg or less
Communication method of balancing circuit	CAN communication

4. 4 Construction of a High-voltage Power Supply

Six of the aforementioned modules were assembled into an aluminum frame and connected in series to construct a power supply capable of approximately 600 V. An interface circuit was also added to collectively aggregate communication information from the balancing circuits of the six modules and transmit it to the HEV system's ECU via CAN communication. **Figure 2** shows the module when mounted to the vehicle.

(Materials provided by Hino Motors, Ltd.)

Fig. 2 High heat-resistant lithium-ion capacitor module when mounted to vehicle

5. The Dakar HEV Race Truck

5. 1 Vehicle Specifications

Table 2 shows the specifications of the Dakar HEV equipped with high heat-resistant lithium-ion capacitor modules. 280 PS of HEV output is added on top of the 800 PS engine output to achieve a maximum output of exceeding 1 000 PS.

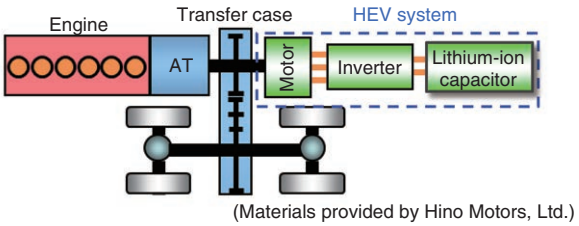
Table 2 2022 Dakar HEV truck specifications

Specification	Characteristic value
Base vehicle	HINO 600 series
Engine type	4-stroke diesel Straight 6-cylinder
Displacement	8.866 L
Max. engine output	800 PS (588kW)/2 800 min^{-1}
Max. HEV system output	280 PS (206kW)
Max. output	1 080 PS (794kW)
Drive system	Full-time AWD
Transmission	AT (6 forward/1 reverse)
Vehicle weight	8 600 kg
Fuel tank	800 L

(Materials provided by Hino Motors, Ltd.)

5. 2 HEV Drive System Layout

Figure 3 shows an image of the HEV drive system layout. Because the engine and HEV system are connected via the transfer case, the vehicle is capable of running on its own should an HEV system malfunction occur.



(Materials provided by Hino Motors, Ltd.)

Fig. 3 HEV drive system layout

6. The Dakar Rally Main Round

Upon completion of the Dakar Rally, the high heat-resistant lithium-ion capacitor modules were removed from the vehicle and disassembled to check the performance of the individual cells. The measurement conditions used comply with the IEC standard "Lithium ion capacitors for use in electric and electronic equipment - Test methods for electrical characteristics (IEC 62813-2015)."

Figure 4 shows the results of these tests. The results showed that both the capacitance and internal resistance were almost the same as before the race, and no deterioration was observed. This demonstrates the ability of JTEKT's high heat-resistant lithium-ion capacitors to withstand usage in the harsh environment presented by the Dakar Rally.

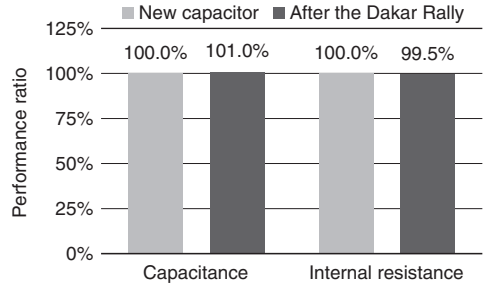


Fig. 4 Performance comparison of high heat-resistant lithium-ion capacitor before and after the Dakar Rally

7. Conclusion

Although the vehicle itself suffered various troubles during the race, the high heat-resistant lithium-ion capacitor modules exhibited no serious problems and continued to demonstrate stable performance throughout. To further shorten race times in the 2023 Dakar Rally, JTEKT will continue its efforts aimed at assessing the performance limits of its high heat-resistant lithium-ion capacitor modules.

(Electrical Power Storage Device Dept.)