Technology of BEV Powertrain for Mid-Size SUV

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ABSTRACT: Toyota Motor Corporation has launched a new battery electric vehicle (BEV) that incorporates the newest evolutions in BEV powertrain systems and vehicle platform innovations. This new BEV uses newly developed large-format battery cells. In addition to achieving the key performance targets, these cells also incorporate new technologies to increase battery energy density and reduce battery deterioration. The BEV battery cooling system features a chamber structure that separates the cooling plate and battery cells. The battery pack also incorporates a newly developed high-resistance coolant with low conductivity. BEV system efficiency is improved by leveraging technologies that were originally developed for HEVs and the development of new systems. For example, radiant heating and a newly developed heat pump system were adopted that extend the EV driving range in cold conditions. Newly developed SiC semiconductors were also adopted that greatly improve power consumption. This paper discusses the technology of the new BEV system.

KEY WORDS: battery electric vehicle, lithium-ion battery, power electronics, eAxle, SiC semiconductor

1. INTRODUCTION

CO_2, a greenhouse gas, is recognized as one of the causes of climate change. To create a sustainable society in which future generations can live in peace of mind, Toyota Motor Corporation is working toward the realization of carbon neutrality. To this end, Toyota continues to develop a portfolio of high-efficiency technology options to meet the needs of customers around the world. These options include hybrid (HEVs), plug-in hybrid (PHEVs), battery (BEVs), and fuel cell electric vehicles (FCEVs), as well as vehicles powered by hydrogen engines. This portfolio approach is believed to have the greatest impact toward achieving the goal of carbon neutrality.

BEVs have always been a part of Toyota's carbon neutral strategy. As regional regulations and preferential tax policies for BEVs help to create markets that encourage more widespread BEV adoption, Toyota developed a BEV system and battery that were first adopted for the C-HR and UX models launched in 2020.

The first models released to help realize the latest carbon-neutral objective were the bZ4X and RZ in 2022. The bZ4X is built on a dedicated BEV platform, and a new BEV system has been developed for this dedicated BEV and the others to follow. This newly developed BEV system maintains the same high level of safety and reliability as Toyota's HEV and PHEV lineup, while satisfying the following BEV performance requirements.

- A high-capacity and long-life battery
- A highly efficient drive unit
- A charging unit compatible with various charging standards

This paper discusses this newly developed BEV system developed for the bZ4X and RZ models.

2. Development of New BEV System

2.1. Overview

The new BEV system contains four redesigned components:

1) Front and rear eAxles
   a. Optimized to create the optimum package
   b. Improved motor topologies to meet power requirements
   c. Optimized inverter design for BEVs
2) Electricity supply unit (ESU)
   a. Integrates the DC relay and branching functions of high voltage components
   b. Higher charge power
   c. Reduction in size and weight
3) High-voltage battery
   a. Large capacity battery installed under the floor

b. Allows selection from two types of battery modules, ensuring flexibility in battery cell supply.

4) Thermal management

a. Optimal heat control of battery, powertrain, and HVAC system

b. Effective air conditioning of the occupants

See Table 1 for a more detailed description of the front and rear motors, as well as the battery pack options developed for the bZ4X and RZ. Figure 1 shows the layout of the different components in the vehicle.

Table 1 BEV System Specifications

Vehicle		C-HR/IZOA/UX	bZ4X		RZ
Drive system		FWD	FWD	AWD	AWD
Front eAxle	Output	150kW	150kW	80kW	150kW
	Inverter semiconductor	Si	Si	Si	Si
Rear eAxle	Output	–	–	80kW	80kW
	Inverter semiconductor			Si	SiC
Battery	Number of cells	288 cells	96 cells	96 cells	96 cells
	Total energy	54.3kWh	71.4kWh (Type A cell/module) 72.8kWh (Type B cell/module)		
	Nominal voltage	355.2V	355.2V	355.2V	355.2V

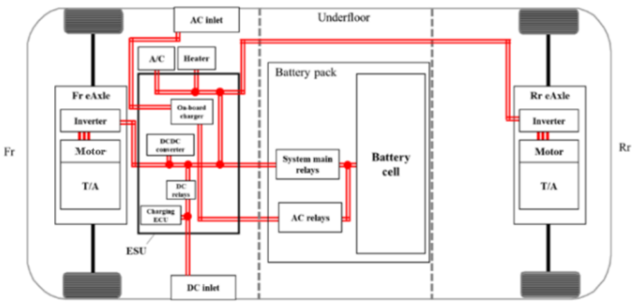


Fig. 1 BEV System Structure

The key principles that directed the design of the new BEV system are as follows.

1) A strong commitment to reliability addressing range anxiety to realize the following objectives for the BEV battery.

- Lower battery capacity change due to deterioration
- Smaller change in EV range between summer and winter
- Shorter charging time
- Long term durability and reliability

2) Achieve a high-efficiency powertrain, including, when appropriate, technology developed for HEVs to realize the following objectives for the BEV system.

- Longer EV range
- Excellent power consumption performance

3) Achieve a smaller and lighter powertrain to realize the following objectives for the BEV.

- High power density motor/inverter
- More efficient packaging with minimal infringement on occupant space.

4) More economical BEV system

- Cost reduction by enlarging battery and integrating components

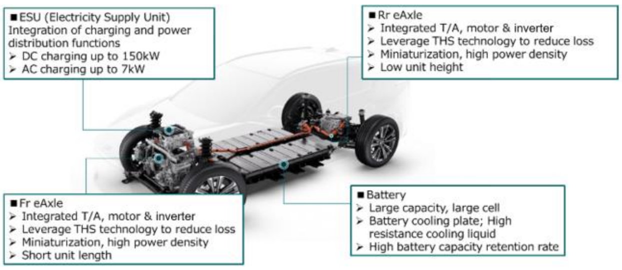


Fig. 2 Development Items of BEV System

2.2. Development of eAxle

The eAxle was redesigned for the new BEV platform. To achieve the new BEV system design targets, HEV design knowhow was leveraged to achieve a smaller and highly efficient system. The resulting unit, shown in Fig. 3, integrates the gears, motor, and inverter into a compact structure. This unit achieves higher BEV system efficiency and contributes to achieving world-class power loss. In addition, the optimized front and rear unit shapes greatly contribute to the vehicle package.

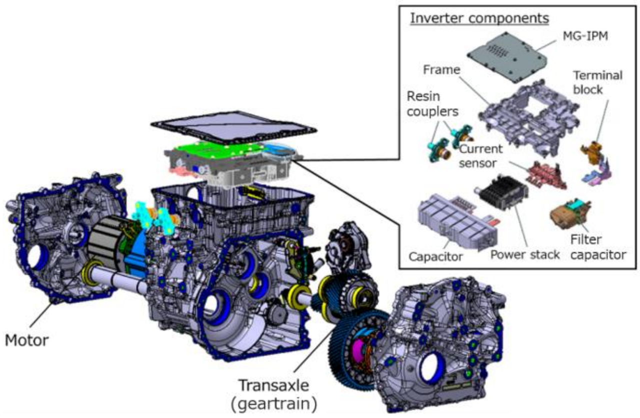


Fig. 3 eAxle Structure

The key improvements in the new design are as follows.

- Newly developed low-viscosity transaxle oil (Fig. 4)
- Newly developed low-loss inverter semiconductor
- Motor topology changes

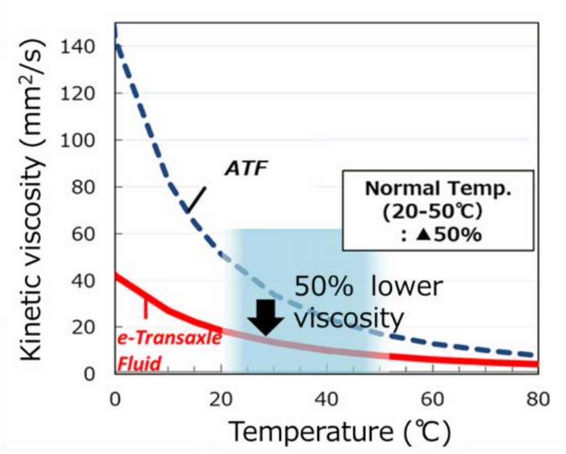


Fig. 4 Low-Viscosity Transaxle Oil

- Newly developed low-loss inverter semiconductor

In addition to the Si power semiconductors, the rear inverter also adopts SiC devices. Both high breakdown voltage and low ON-resistance were achieved by adopting a field-relaxed trench MOS structure. In addition, power loss was reduced by more than 50% by increasing the gate voltage to reduce ON-resistance and increasing the switching speed by about three times faster than Si devices. This helped to improve the overall system efficiency and raise output per chip 2.8 times.

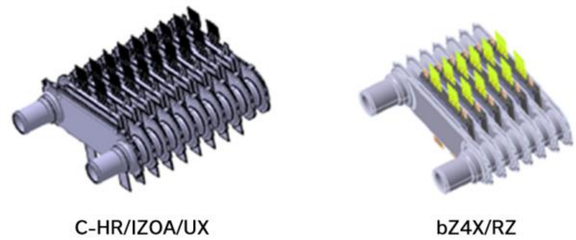


Fig. 5 Inverter Element

- Motor topology changes

The new BEV system motors use rectangular wires instead of the round wires used in previous motors (Fig. 6). Higher packing in the slot results in higher density and efficiency. The motor design was optimized. On the rotor, the placement and size of the magnets was refined (Fig. 7). On the stator, the wire coil design was modified, resulting in top-class high-speed and high output performance (Fig. 8). Finally, system efficiency was improved by implementing a dual path cooling strategy using an electric oil pump and an oil cooler. This design change further improves efficiency.

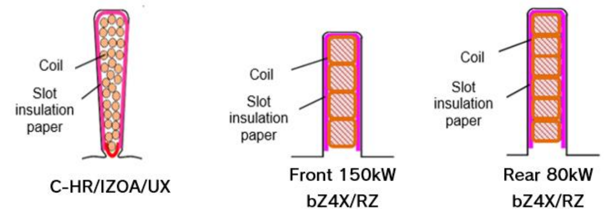


Fig. 6 Motor Coil Structure

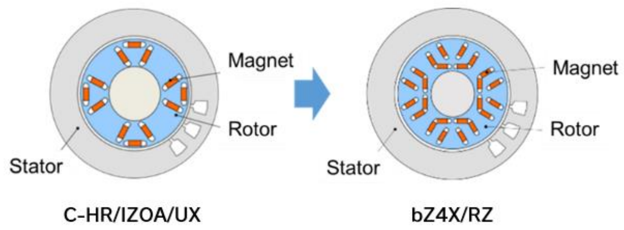


Fig. 7 Magnet Placement

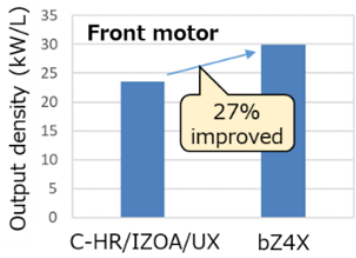


Fig. 8 Output Performance

2.2. Development of electricity supply unit (ESU)

For the bZ4X, the DCDC converter, AC charger, DC relay and distribution box (power distribution function) were combined into a newly developed single unit called the electricity supply unit (ESU). There are primarily two benefits for combining these units. First, the battery space within the pack can be maximized by moving the distribution box and DC relay outside the battery pack. Secondly, the high voltage wiring and cooling can be simplified by packaging the power conversion function into a single unit.

To meet regional requirements, the bZ4X has an 11 kW charger for the European market and a 7 kW charger for other markets. To make these two different chargers easily and economically, the 7 kW charger was built into the ESU and the 11 kW charger was attached to the ESU. This way, one ESU can have both 7 kW and 11 kW chargers (Fig. 10).

A BEV has multiple high-voltage components and requires a more advanced response to electromagnetic compatibility (EMC) issues. These issues were resolved by adding an appropriately sized ferrite core at an appropriate position in the ESU to adjust the impedance of the entire system.

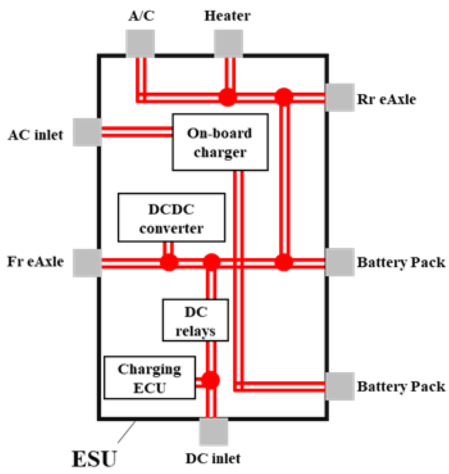


Fig. 9 Structure of ESU

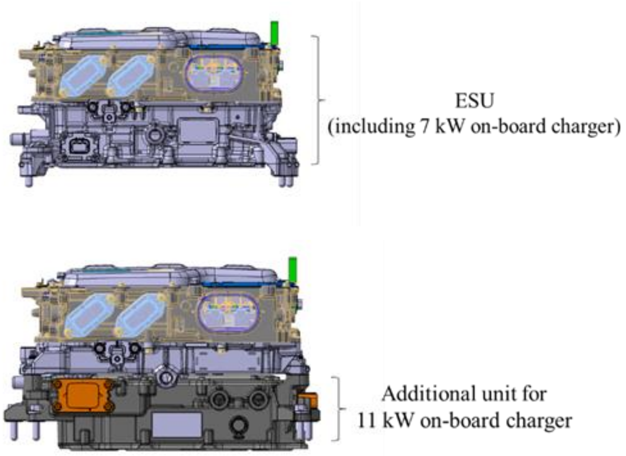


Fig. 10 On-Board Charger Layout

2.3. Development of high-voltage battery

Table 2 shows the specifications of the newly developed BEV battery. Compared to the battery used for the C-HR/IZOA/UX launched in 2020, the battery energy and energy density are 30% and 13% higher, respectively.

The new dedicated BEV platform was designed to improve ride comfort, noise and vibration (NV), and body rigidity. The BEV battery offers improved energy density and reduced deterioration over time and use, in addition to achieving a high level of safety and reliability.

This BEV battery includes a new thermal management approach that maximizes battery output power and quick charging performance. Two different type of battery cell modules, both interchangeable, were designed to fit in the battery pack. This strategy allows for flexibility in battery cell supply. Based on the cell module type selected, the resulting battery pack demonstrates differences in performance such as battery energy and output power (Table 3).

Table 2 Battery Pack Specifications

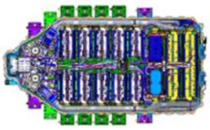
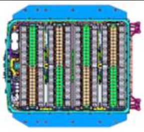
	C-HR/IZOA/UX	bZ4X/RZ
		
Cell number	288 cells	96 cells
Nominal voltage	355.2V	355.2V
Total energy	54.3kWh	71.4kWh (Type A)
Battery weight	415kg	481kg
Cooling system	Air cooling	Water cooling

Table 3 Battery Cell Specifications

Cell module type		Type A	Type B
Cell number		96 cells	96 cells
Cell dimensions	Height	103mm	104mm
	Length	39.8mm	79.2mm
	Width	308mm	148mm
Nominal voltage Battery pack		355.2V	355.2V
Total energy		3.7V	3.7V
Nominal capacity Battery cell		201Ah	205Ah
Max output current		900A	750A
Max input current		400A	250A

The key technologies integrated into the design of the new BEV are as follows.

1) A vehicle platform designed for battery integration, leading to improved performance.
2) A chamber structure that separates the cooling plate from the battery cells; and the adoption of a newly developed high resistance coolant with low conductivity.
3) Heat insulation between the cells to prevent heat transfer in the event of thermal runaway in a cell.
4) Insulation for parts to protect cell terminals from conductive debris that may be ejected from inside a cell during a cell thermal runaway.
5) New battery thermal management to minimize the temperature increase in the pack while maximizing the battery power performance and quick charging performance.
6) A new module structure that minimizes the increase in battery internal resistance during quick charging.
7) A new large-format battery cell that reduces the overall number of pack parts, contributing to lower overall pack costs.
8) Improved battery cell materials to increase the battery cell energy density and reduce the rate of capacity loss.

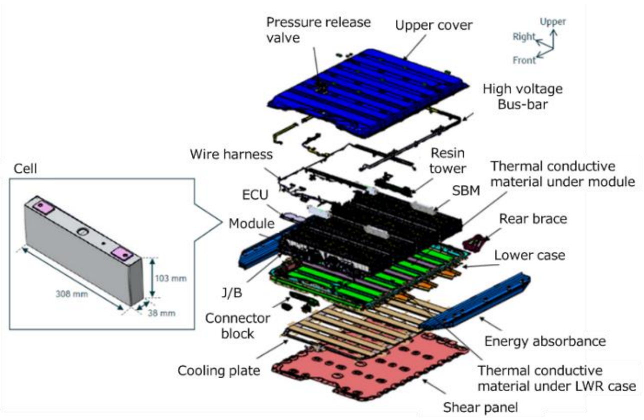


Fig. 11 Battery Pack Structure

2.4. Development of thermal management

Issues with BEVs include shortened battery life due to high battery temperatures and the deterioration of cruising range in the winter. An innovative thermal management system was developed to help resolve these issues (Fig. 12). Specifically, the following measures were adopted.

1) Thermal control technology that optimally controls the battery, powertrain, and HVAC system by connection with a thermal circuit.
2) Effective air conditioning of the occupants in conjunction with the powertrain cooling and warming-up requirements

Measure 1) improved the heating efficiency of the heat pump system with a simple refrigeration cycle while maintaining the battery at the optimum temperature. Measure 2) was realized by adopting integrated control technology for the radiant heater (Figs. 13 and 14) that efficiently warms the feet and the air-conditioning environment in the passenger compartment.

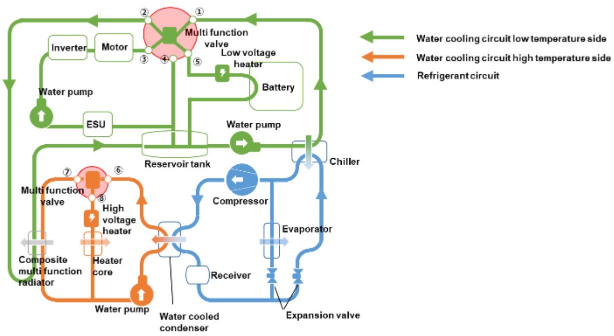


Fig. 12 Thermal Management System

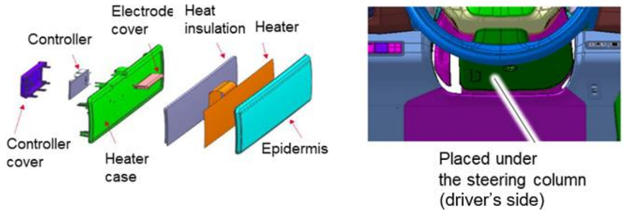


Fig. 13 Radiation Heater

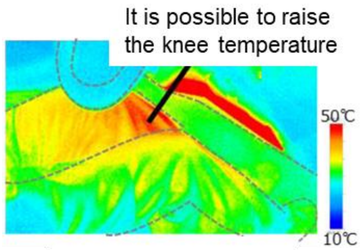


Fig. 14 Effect of Radiation Heater

3. CONCLUSIONS

- As one solution for achieving carbon neutrality, the bZ4X and RZ were launched on Toyota's first dedicated BEV platform in 2022.

- While focusing on safety and reliability as the highest priority, Toyota developed a BEV system that aims to enhance the strengths of BEVs while helping to overcome the weaknesses.

- This new system achieves excellent efficiency through the utilization of low-loss technologies cultivated through HEV development and through the development of new technologies unique to BEVs, thereby making a significant contribution to the realization of carbon neutrality.

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