Advancing Electrification: Development of Electric Motorcycles Ninja e-1 and Z e-1, and Hybrid Motorcycles Ninja 7 Hybrid and Z7 Hybrid

In response to growing social pressure to accelerate motorcycle electrification, Kawasaki Motors has developed new mass-produced BEV and HEV models as a multi-pathway for achieving carbon neutrality. We optimized the packaging of electric components, such as traction motors and battery packs, for integration into motorcycles. For the HEV models, we have developed a technology that ensures optimal cooperative control between the internal combustion engine (ICE) and the traction motor, achieving motorcycle electrification.

Introduction

Preventing global warming requires realizing a CO_2-free society and achieving carbon neutrality. One example of the solutions for environmental issues is accelerated movement toward electrification. For instance, some municipalities set low-emission zones (LEZs) in urban areas, make it obligatory to attach environmental stickers to vehicles, and prohibit vehicles that do not meet environmental standards from entering the LEZs.

1 Background

In response to growing social pressure to accelerate motorcycle electrification, toward achieving carbon neutrality Kawasaki Motors has developed new mass-produced vehicles as a multi-pathway, including not only electric motorcycles but also a world-first* strong hybrid motorcycle that combines a traction motor with a 451-cm^3 two-cylinder internal combustion engine (ICE).

*Mass production models (excluding scooters) from a major power sports manufacturer as of October 6, 2023, per Kawasaki Motors, Ltd. research.

2 Development goals

We have developed core technologies to electrify batteries, motors, systems, and other components optimal for motorcycle packages in order to establish a new product concept that delivers both an exceptional riding experience and high environmental performance.

The concept of each product is as described below.

(i) Electric motorcycles (BEVs) (**Fig. 1**)

We specified zero emissions, low noise, and low vibration, which contribute to environmental conservation, as the desired characteristics of electric motorcycles. We decided to ensure the easy handling and comfortable feel typical of motorcycles, while introducing new functions specific to electrification and not available in conventional motorcycles that lead to the "Fun to Ride" (the pleasure of riding and joy of maneuvering them) experience.

(ii) Hybrid motorcycles (HEVs) (**Fig. 2**)

We specified superior riding performance, convenience, quietness at low speed, high controllability, and low emissions as the desired characteristics of hybrid motorcycles[1)].

As **Fig. 3** shows, we need to provide quietness, high maneuverability, and low emissions in our hybrid motorcycles by equipping them with an electric mode for urban areas and the like, while delivering a comfortable ride in the suburbs or at high speed like conventional motorcycles. The product concept is to combine these riding modes in a single vehicle package.

(a) Ninja e-1 (b) Z e-1

Fig. 1 Electric motorcycles (BEVs)

(a) Ninja 7 Hybrid (b) Z7 Hybrid

Fig. 2 Hybrid motorcycles (HEVs)

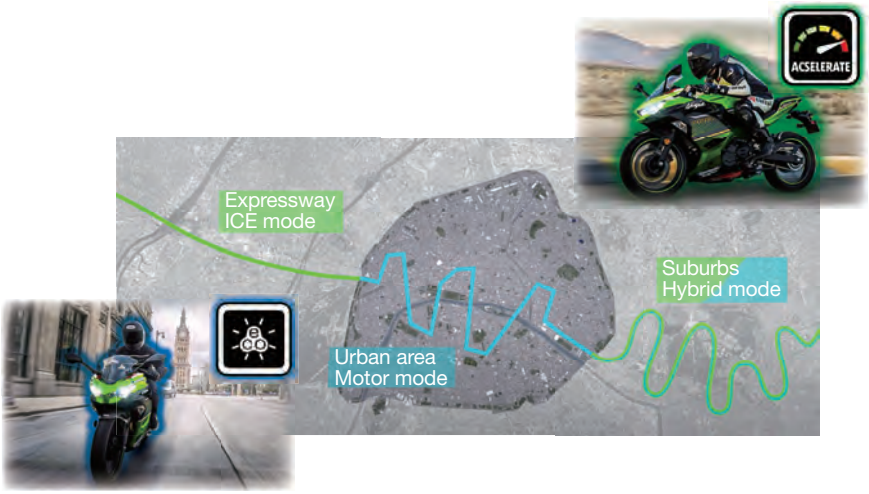

Fig. 3 Product concept of hybrid motorcycles

3 New technologies we developed

(1) Smaller and more powerful electric components (for BEVs and HEVs)

(i) Traction motors

For development efficiency, we designed the components of the traction motors for BEVs and HEVs, except for their motor cases, according to the same motor specifications (**Fig. 4**). This enabled us to develop their power units at the same time.

To determine the rated power, which is continuously available, and the peak power, which is only available within limited time, we need to select suitable traction motor specifications.

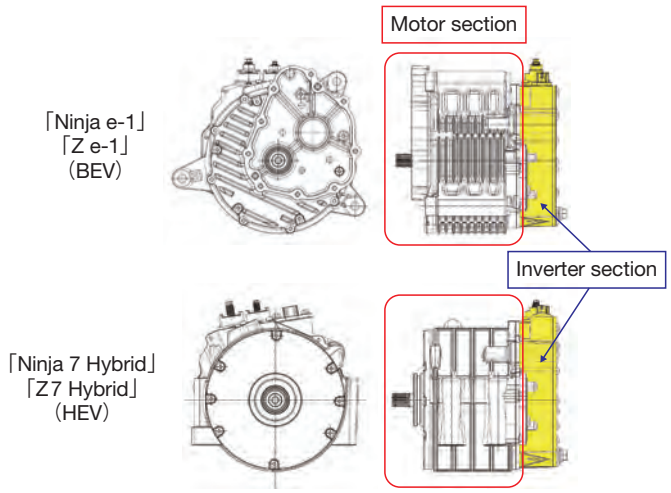

Fig. 4 Traction motor

We selected a rated power of 6.0 kW or more for the traction motor to ensure necessary and sufficient power performance in residential, urban, and other areas where the riding speed should be relatively low. On the other hand, we chose a peak power of 9.0 kW as an HEV development goal to achieve the acceleration at start equivalent to the 1,000-cm^3 class and a superior feeling of acceleration in all regions by combining a traction motor with a 451-cm^3 two-stroke ICE. These specifications also provide acceleration performance that covers 80% of user riding data in zones with general speed limits of 50–60 km/h or less in urban areas, where BEVs are assumed to be used, in the traction motor for BEVs by achieving the same rated and peak power as HEVs[2].

A feeling close to ICE braking by an ICE has been achieved by adjusting the regenerative charging amount setting in BEVs.

(ii) Battery packs

① Battery pack for HEVs

We set the following concepts to develop a new battery pack for HEVs.

- Power performance for acceleration that delivers a feeling of exhilaration (maximum power of 11 kW)
- Ability to store necessary energy for EV mode
- Light and compact

To achieve the above concepts, we developed a lithium-ion battery that combines high power and high energy density, shown in **Fig. 5**.

As this battery has high power discharge performance beyond 300 A, the temperature that rises due to high-current charging or discharge must be efficiently cooled down. To solve this problem of heat buildup, we designed a structure to efficiently let heat out. Specifically, the cell, which is the source of the heat, and the aluminum exterior case to come into direct contact with each other. They are, separated only by a material that is both an excellent insulator and has high thermal conductivity. In addition, the battery has a cooling structure that directs the wind generated by the motorcycle's forward motion straight to it through a duct installed on the right side of the motorcycle body as shown in **Fig. 6**.

Fig. 5 Battery pack for HEVs

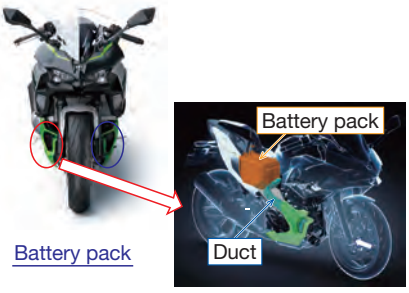

Fig. 6 Battery cooling

② Battery pack for BEVs

Like the battery pack for HEVs, a lithium-ion battery that combines high power and high energy density is used.

This battery can also be removed from the vehicle and charged indoors as shown in **Fig. 7**, as well as charged in-vehicle. Vehicles have two battery slots. The max. power (9 kW) and the max. mileage (72 km WMTC CLASS-1) can be achieved by having the two batteries connected at the same time. In addition, vehicles can run with only one of the batteries. The battery pack also includes the function of monitoring the statuses (such as charge and temperature status) of the two batteries and automatically switch between the two connected batteries as needed.

(2) e-boost function and WALK mode function (for EVs and HEVs)

The new motorcycles realize e-boost control to instantaneously extract the traction motor's power during acceleration as a new function that will be a fun element. We created this new boost function by setting an appropriate serviceable time and recovery time according to the battery power and temperature.

The new motorcycles are also equipped with WALK mode as a convenient function that uses the traction motor. They can move backward without engaging the reverse gear by inversely rotating the traction motor. This means that they can move forward and backward at very low speed depending on the rotation direction of the traction motor, so they can be maneuvered more easily than conventional motorcycles.

(3) Cooperative control of the motor and ICE (hybrid)

We designed hybrid motorcycles to have three characteristic riding modes by using different features of the traction motor to be combined with the ICE. Specifically, to enhance the element of fun, SPORT-HYBRID mode adds the e-boost function (**Fig. 8**) to instantaneously provide the motor's maximum power at

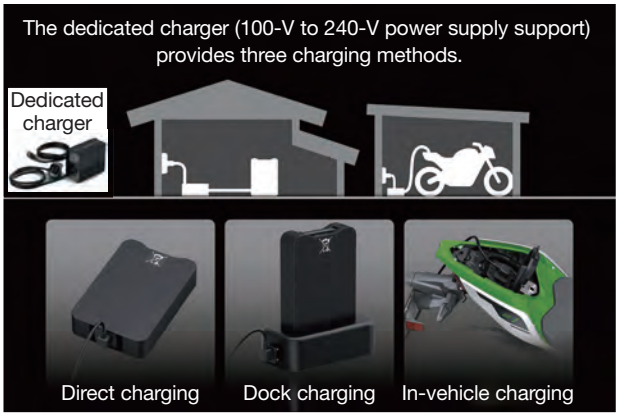

Fig. 7 Battery pack for the BEV & Charging system

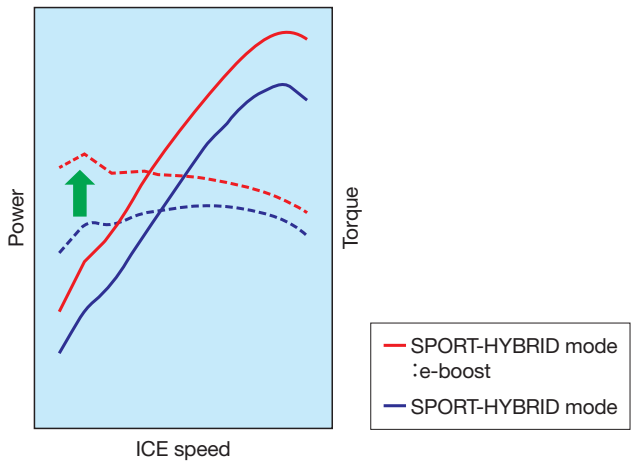

Fig. 8 e-boost function (performance curve)

the intended time when the rider wants to speed up. In ECO-HYBRID mode, only the motor is used to start the motorcycle, which can run with lower emissions using the function to automatically switch between the motor and the ICE and the function to stop idling. In EV mode, the motorcycle can run using just the traction motor in restricted zones and in residential areas in the early morning or late evening, where quietness is important.

(i) Hydraulic electronic control clutch

To operate these three modes we have adopted a parallel hybrid system, in which the traction motor and the ICE have a parallel relationship via a clutch. EV mode, where only the traction motor is used for power, and HEV mode, which uses both the traction motor and the ICE for power are switched by engaging and disengaging the clutch as shown in **Fig. 9**.

The torque generated both by the traction motor and the ICE is carefully controlled to smoothly and naturally achieve the shift from the start state, driven by the motor, to ICE driving in the ECO-HYBRID mode and motor assist through e-boost in the SPORT-HYBRID mode. The HEV-ECU electronically controls the hydraulic clutch for seamless switching between traction motor driving and ICE driving.

The HEV-ECU controls the clutch oil pressure and adjusts the clutch engagement level according to vehicle information including throttle input and vehicle speed to smoothly start the vehicle. In addition, the rider can shift between EV mode and HEV mode without operating the clutch because the clutch is automatically engaged and disengaged. In other words, any rider can easily enjoy riding these motorcycles just by operating the accelerator regardless of their skill.

(ii) Torque command distribution

The torque demanded by the rider is determined based on the input from throttle operation, and the amount of torque commanded for distribution to the ICE and the traction motor is properly controlled according to the status of each component as shown in **Fig. 10**.

When the battery pack charge is low, a charge torque

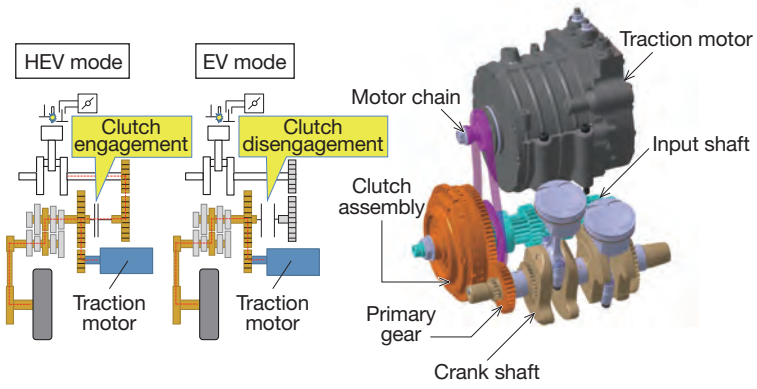

Fig. 9 Hybrid power delivery system

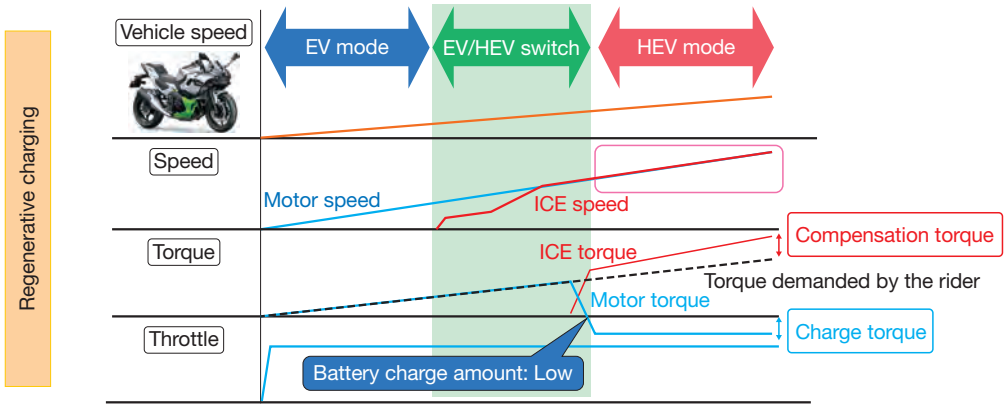

Fig. 10 Torque-based control

command is issued to the traction motor to compensate for the shortfall in the torque demanded by the rider. This is done by issuing a torque command to the ICE so that the torque determined by the input from the throttle remains constant. This results in battery charging without sacrificing the feel of the ride, enabling riders to enjoy riding motorcycles without worrying about the remaining battery charge.

If the ICE cannot sufficiently compensate for the torque the rider demands during acceleration, the torque command for the shortfall is issued to the traction motor to assist the ICE torque so that the rider can keep riding the motorcycle without losing the sensation of acceleration. This control system allows the rider to control the vehicle status in various conditions and provides suitable drivability for fun, ecological friendliness, and comfort.

Conclusion

We introduced recently developed the Ninja e-1 and Z e-1 and Ninja7 Hybrid and Z7 Hybrid models featured in this article. The Ninja e-1 and Z e-1 are the first BEV models from Kawasaki, while the Ninja7 Hybrid and Z7 Hybrid are world-first strong hybrid motorcycles. These four motorcycles have already been mass produced as 2024 models. We developed these BEV and HEV models, which provide unprecedented market appeal, by incorporating the e-boost function enabled by the traction motor. The cooperative control technology that pairs the ICE and traction motor delivers power seamlessly.

We will continue to develop motorcycles that contribute to the future of global environment, providing a fulfilled life and dream to riders across the world by allowing a wide range of riders to have "Fun to ride," "Ease of riding" even with electrification.

References

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