Development of Electric and Hybrid Motorcycles Aimed at Achieving Both High Riding and Environmental Performance

CO_2-free and carbon-neutral are required to prevent global warming. In the automotive industry as well as other industries, efforts are being made to achieve CO_2-free and carbon-neutral.

Given this social situation, Kawasaki is developing batteries and motors that are suitable to be packaged into motorcycles (with reduced size and increased power) in order to develop electric and hybrid motorcycles and offer them as near-future mobility that has both high riding and environmental performance.

Introduction

CO_2-free and carbon neutral are required to prevent global warning. The Ministry of Economy, Trade, and Industry has formulated the “Green Growth Strategy Through Achieving Carbon Neutrality in 2050” in collaboration with the relevant ministries and agencies. This includes the electrification of new cars by the mid-2030s. In response, the automotive industry has declared that it will make every effort to achieve carbon neutrality.

1 Background

As a solution to environmental issues, low-emission zones have been established in urban areas in some regions; these zones mandate that entering vehicles have an environmental sticker, and entry of motorcycles that do not satisfy environmental standards is restricted. Though few countries have legislated restrictions on the sale of new gasoline or diesel vehicles, many countries are planning to do so. Movement toward electrification is accelerating. Given the social push that is demanding efforts to spread electric vehicles be accelerated, as a new solution, Kawasaki is working hard to develop hybrid motorcycles with the aim of offering such motorcycles as near-future mobility.

2 Development overview

To realize a new product concept that achieves both high riding performance and environmental performance, we are developing core technologies for electrification, such as batteries, motors, and systems suitable to be packaged into motorcycles.

(1) Concept of electric motorcycles

We have defined quietness, zero emissions, and “fun to ride” (the joy of riding and the fun of maneuvering) as characteristics that electric motorcycles should have.

We aim to achieve “fun to ride” as a characteristic that conventional motorcycles lack while achieving low noise and zero emissions.

(2) Concept of hybrid motorcycles

We have defined riding performance and convenience equal to or better than those of conventional motorcycles, high quietness and high controllability during low-speed operation, and low emissions as characteristics that hybrid motorcycles should have.

We aim to achieve high comfort during riding in suburbs and at high speeds as with conventional motorcycles, while simultaneously achieving high quietness and high controllability in addition to reducing emissions by enabling electric riding in urban areas as shown in **Fig. 1**.

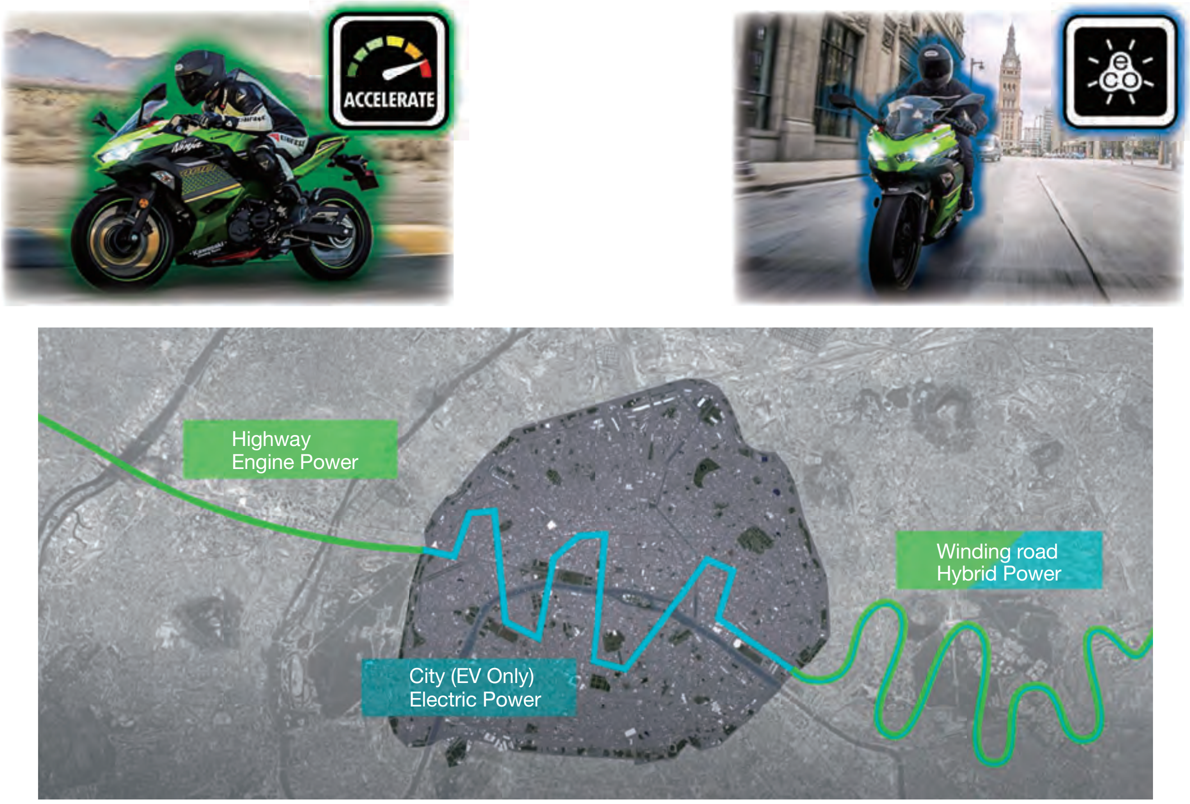


Fig. 1 Product concept

(3) Technical challenges

The following are the key technical challenges in the development of electric and hybrid motorcycles.

① Reduced battery size and increased battery output (for both electric and hybrid motorcycles)

Batteries that provide comfortable acceleration, that withstand repeated acceleration and deceleration, and that are sufficiently compact and inexpensive to be mounted onto motorcycles need to be developed.

② Reduced motor size and increased motor output (for both electric and hybrid systems)

Motors that have high efficiency in the high frequency operation region, that are sufficiently compact to be mounted onto motorcycles, and that have high environmental resistance (cooling and vibration resistance).

③ Efficient layout of electric motorcycle components and creation of fun (electric systems)

Components that engine motorcycles do not have, such as traction batteries and motors, need to be arranged efficiently, and as with engine motorcycles, vehicles that make riding fun need to be developed.

④ Cooperative control of the motor and engine (for hybrid systems)

There is a need to improve the torque characteristics and fuel economy by making the most of the respective strengths of motors and engines.

3 Development of elemental technologies

(1) Reduced battery size and increased battery output

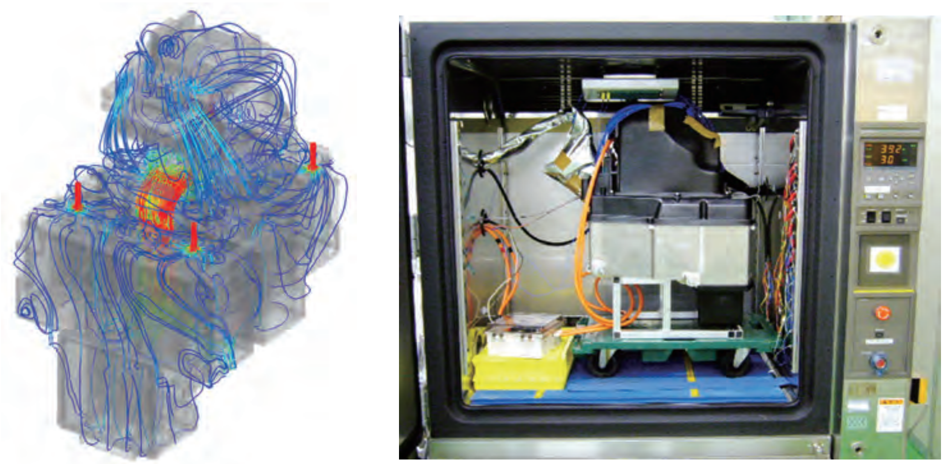
There are many types of batteries, including lead acid batteries, nickel-metal hydride batteries, and lithium-ion batteries. To achieve a reduced size and increased output, we selected lithium-ion batteries, which have high output and high energy density while being relatively inexpensive.

Lithium-ion batteries require efficient cooling because they get hot and deteriorate if charged and discharged frequently and repeatedly [1]. To address this problem, we conducted the analyses, including CFD, and the tests shown in **Fig. 2** over and over again for optimization.

Cell output performance is known to greatly depend on the cell's condition. Therefore, we are developing technologies to detect the pack condition, such as the temperature, charge state, and deterioration state, to estimate the output performance based on the detection results; and to reflect the detection results in vehicle control as shown in **Fig. 3**.

(2) Reduced motor size and increased motor output

Traction motors are required to have high torque characteristics in the low rpm range, which is a weak point



(a) Analysis (b) Test

Fig. 2 Optimization of battery pack cooling

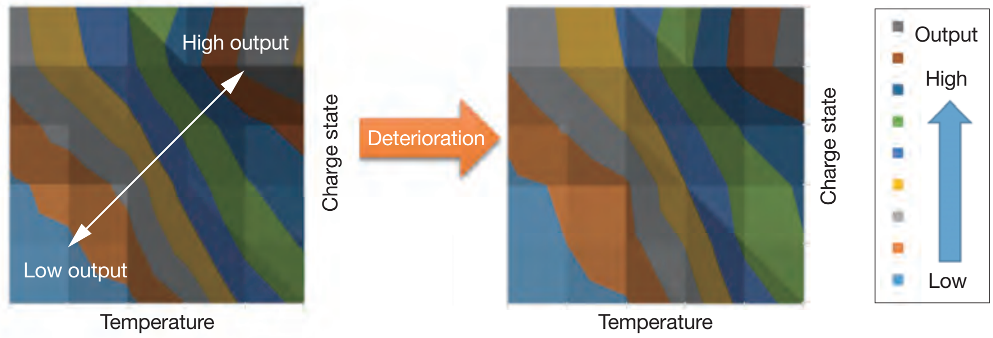


Fig. 3 Detection of battery pack condition

of engines; to have high rpm characteristics at maximum rpm; and to have high efficiency in the high frequency operation region. In addition, the traction motors must be mounted within a limited space; therefore, both electric motorcycles and hybrid motorcycles are required to have smaller, lighter motors, which also leads to cost reduction [2].

Focusing on regions where motorcycles are operated frequently, we are attempting to design motors that have the highest efficiency in such regions as shown in **Fig. 4**. Hybrid motorcycles run while switching between the engine and motor; therefore, we are developing motors that have high efficiency at a low rpm, which is a weak point of engines.

To increase the output and to reduce the size, more heat must be cooled with a smaller radiation area; therefore, we have adopted an oil cooling system with high

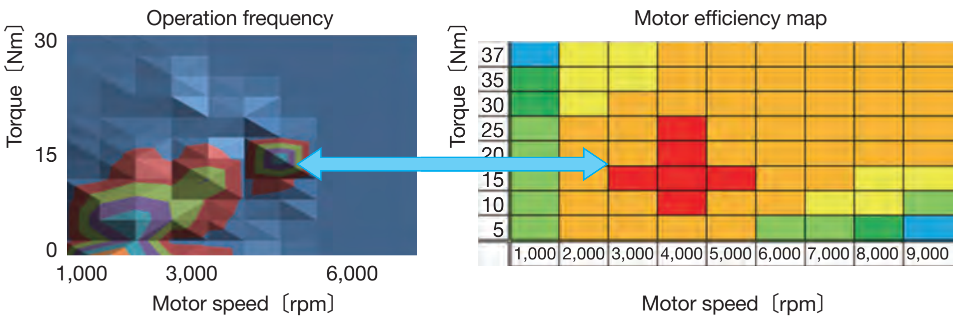


Fig. 4 Optimization of the high efficiency region of the traction motor

heat removal capacity. Oil can be given electrically insulating properties, and high cooling effects can be obtained by allowing the oil to flow through the motor to directly cool the heat sources, such as the coil, core, and magnet. We are conducting analysis to identify a flow channel that enables effective cooling and are developing the cooling structure shown in **Fig. 5**.

(3) Efficient layout of electric motorcycle components and creation of fun

For electric vehicles, there is a need to consider the layout of components that engine motorcycles do not have, such as batteries and motors. For batteries in particular, special requirements must be considered—for example, the center of gravity, the power cable length, measures against electric shock, and protection in the case of falling.

Figure 6 shows a typical component layout for an electric vehicle. This vehicle requires a high drive voltage; therefore, almost all the high-voltage parts are housed in the battery pack, which is placed inside the frame. This protects the high-voltage parts and reduces the cable length. Also, the quick charge CHAdeMO connector is positioned near the battery pack, facilitating easy handling during maintenance and at other times.

Electric vehicles generally run at fixed speeds, but this vehicle is equipped with a stepped manual transmission. This enables the rider to feel the motor characteristic of greater torque in the low speed range.

Also, this vehicle is equipped with a lever operated to adjust the amount of motor regenerative braking as shown in **Fig. 7**, empowering the rider to feel the fun of

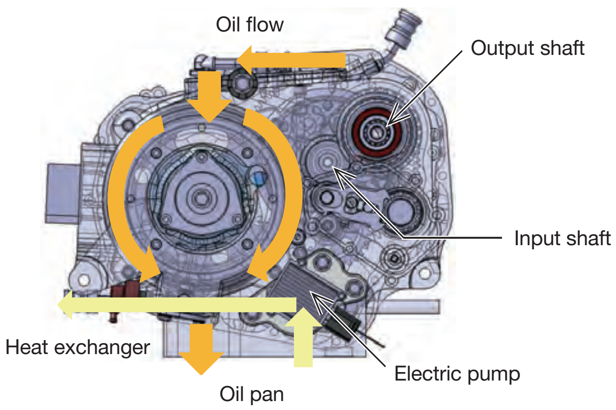


Fig. 5 Oil cooling structure of the traction motor

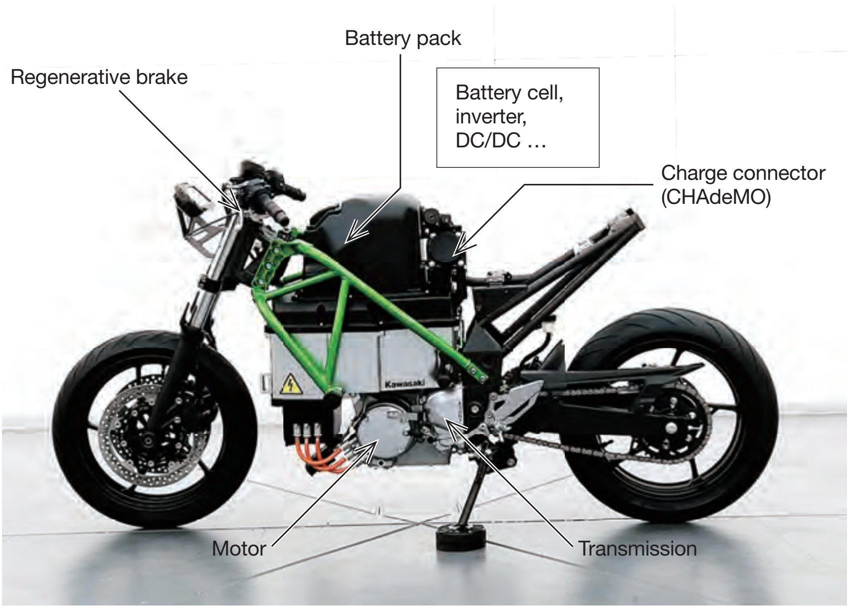


Fig. 6 Electric vehicle components

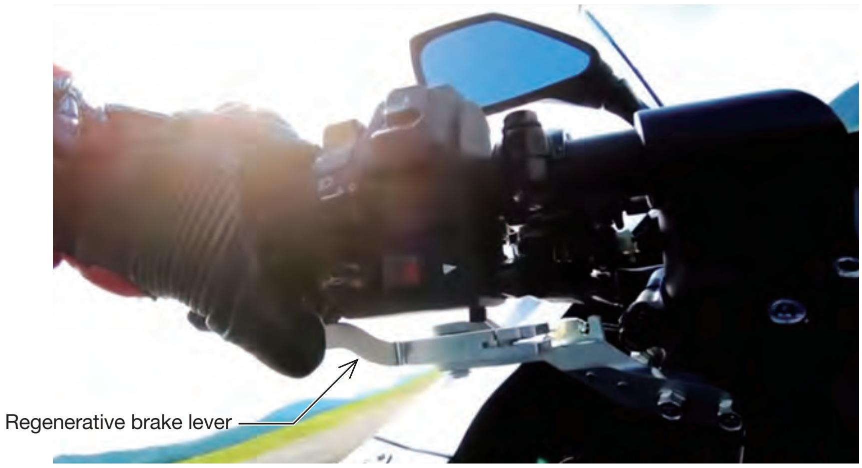


Fig. 7 Regenerative brake operation

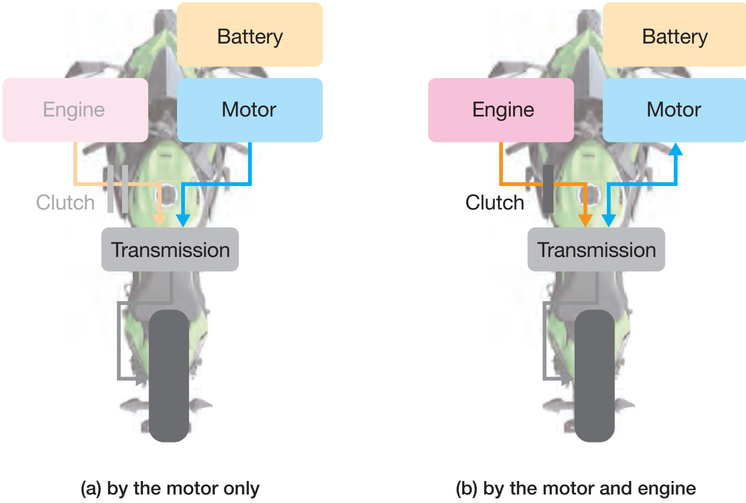


Fig. 8 Hybrid system configuration

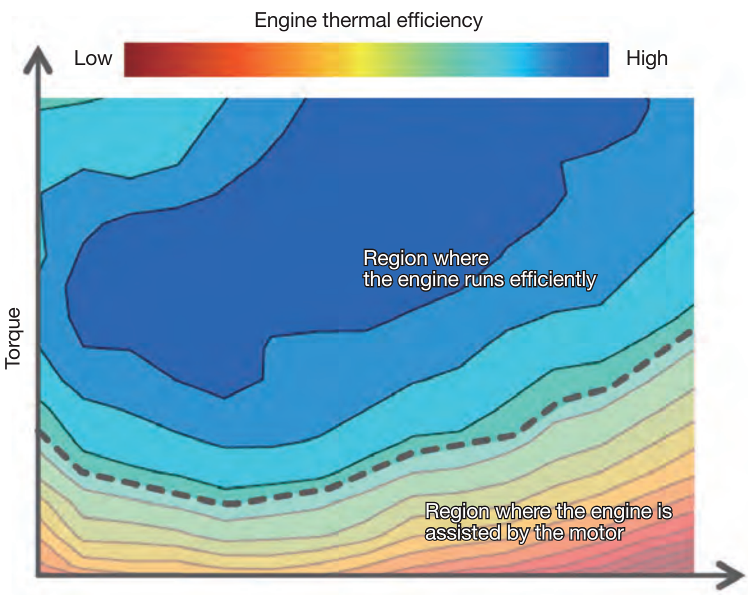


Fig. 9 Thermal efficiency characteristics of the engine

maneuvering[3].

(4) Cooperative control of the motor and engine

The developed hybrid system is a parallel hybrid system in which the motor and engine are connected in parallel via the clutch as shown in **Fig. 8**. The vehicle can be run by the motor only **(a)** or by the motor and engine **(b)**, which can be selected by clutch operation. This enables the rider to select the riding mode and power distribution according to the situation, thereby achieving a good balance between environmental performance and riding performance[4, 5].

Generally, engines have lower thermal efficiency in a lower torque range as shown in **Fig. 9**. Therefore, engine vehicles have lower fuel economy in low torque ranges, such as when starting or running at low speeds.

Hybrid systems use the torque from the motor to assist the engine in the low torque range, which is a weak point of engines. Hybrid systems also reduce fluctuations in thermal efficiency across the entire system, thereby improving fuel economy. In addition, during running, the motor is operated as a generator to shift the engine's activation point toward the high efficiency side by the power generation load, which secures power distribution that can recover the electricity consumed to assist the engine while simultaneously enhancing the fuel economy during normal running.

Conclusion

With regard to small motorcycles, commercialization of electric vehicles is proceeding gradually around the world. This is because thanks to the technological evolution of batteries and motors, performance and cost can be better balanced than before in this class of vehicles.

However, as for medium- and large-sized motorcycles, many challenges remain to be solved, as the required performance of these motorcycles is quite different from that of small motorcycles. We will continue this development, aiming for the early establishment of core technologies for commercialization.

Towards carbon neutrality in the future, we are planning mobility development using hydrogen fuel, which is a source of clean energy.

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