Kawasaki
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KAWASAKI TECHNICAL REVIEW

Special Issue on Powersports & Engine







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Working for the happiness and joy of all those whose lives Kawasaki touches

Kawasaki
Let the Good Times Roll





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Interview with President Hiroshi Ito

Toward Further Growth in the Powersports & Engine Segment

Hiroshi Ito
Senior Managing Executive Officer
Representative Director, President and Chief Executive Officer, Kawasaki Motors, Ltd.

How are the environment and business situation surrounding the Powersports & Engine segment?

In October 2021, our company was spun off from Kawasaki Heavy Industries and relaunched as Kawasaki Motors. Since the spin-off, our independent growth strategy has benefited from the increased demand for outdoor leisure activities during the COVID-19 pandemic, which provided a significant tailwind, allowing us to get off to a strong start.

However, more recently, as the pandemic has subsided, disruptions in the supply chain have eased, and distribution inventories have recovered across the industry, intensifying market competition. In terms of product-specific trends, the market for motorcycles in developed countries has remained relatively stable, while in emerging markets, demand is shifting toward scooters. As a result, our sports models, which are our area of expertise, are struggling in most countries, with a few exceptions.

For off-road four-wheelers, utility models are performing well, but recreational models are experiencing a slowdown, so careful monitoring is required. As for general-purpose engines, although demand has recently slowed due to inventory adjustments by equipment manufacturers, we expect a gradual recovery going forward.

Can you tell us about your future business strategy?

In 2018, we established our own "Vision 2030." This vision sets targets for achieving 1 trillion yen in sales and an operating profit margin of over 10% by 2030. We are working as one team across the company to achieve these goals.

For motorcycles, we are particularly focusing on emerging markets. The rise of new manufacturers, especially in China and India, has been remarkable, and as mentioned earlier, there is a shift in demand toward scooters. However, we still see significant growth potential in these markets. To differentiate ourselves from competitors and secure stable profits with sustainable growth, we plan to expand our lineup of small to medium-displacement models, which are in high demand in these emerging markets, while also strengthening our dealership strategies and enhancing our brand presence.

We are focusing particularly on off-road four-wheelers and personal watercraft (PWC) as key drivers for achieving our Vision 2030 goals. We will continue to introduce competitive new models and begin full-scale operations at our new factory in Mexico starting in 2024, aiming to increase sales.

Looking ahead to further growth beyond 2030, we are also exploring entry into the reciprocating engine business for aviation applications, leveraging the engine technologies we have cultivated so far. The engines installed in our power sports products have the outstanding characteristic of being lightweight and compact, while still being able to generate high power output. Additionally, compared to turbo-shaft engines in the same class, they offer environmental advantages, with fuel consumption rates that are 30%–50% better. Looking forward, we also plan to develop hydrogen engine versions in the future.

Can you tell us about your future initiatives in technology development, including efforts toward carbon neutrality?

Last year, we took the industry lead by unveiling four models of sport-type EV/HEV motorcycles.

We have long believed that achieving carbon neutrality requires a multi-pathway approach. In addition to electrification, we are tackling carbon neutrality through various options, including hydrogen fuel engines, biofuels, and e-fuels.

Furthermore, to strengthen our development capabilities, we are not only increasing our development personnel but also actively improving development efficiency. This includes advancements in analytical technologies that allow us to reduce the need for prototype vehicles.

Closing comments

Our vision is to remain a leading player in the high-value-added power sports and power unit fields. With our corporate mission "Let the Good Times Roll (Working for the happiness and joy of all those whose lives Kawasaki touches)," we will continue to take on challenges aimed at achieving sustainable growth and realizing our goal of becoming the "Good Times Company."

Technology Development Strategies in the Powersports and Power Unit Areas
–To Become the Top Brand–

Hiroshi Tomomori
Director, Managing Executive Officer, Kawasaki Motors, Ltd.

Introduction

Setting a goal of achieving sales of 1 trillion yen in our 2030 Vision, Kawasaki Motors aims for sustainable growth as a leading player in the power unit area, which spans across high added-value powersport vehicles, such as motorcycles and off-road four-wheel vehicles, as well as engines for lawn mowers. We have been growing rapidly, achieving 337.4 billion yen in 2020 and 604 billion yen in 2023, and promoting technology development to achieve our vision, also eyeing the possibility of moving up the schedule for the initial goal.

Our core competencies are ① product competitiveness based on the launch of new products that overwhelm competitors both in terms of quality and quantity, industry-leading electrification, support for CASE (Connected, Autonomous, Shared, and Electric), and other strengths and ② strong brand power rooted in customer value as a top manufacturer that combines innovation and tradition. We promote efficient and agile technology development to ensure our advantage over competitors, leveraging these strengths.

Our departments developing motorcycles, off-road four-wheel vehicles, personal watercrafts (PWC), utility engines, and other products cooperate with one another and learn from each other, while developing technologies individually.

1 Motorcycles

The motorcycle business targeting advanced countries is our primary source of revenue. In this area, we promote technology development to flexibly address global affairs and demands, for example, by actively launching high added-value models powered by the internal combustion engine (ICE), while accelerating the development of products that follow the trend toward a decarbonized society, including EVs, HEVs, and hydrogen engines.

(1) To become the top electric vehicle brand

One of our technology development strategies is to ensure and enhance the “Fun to Ride” (the pleasure of riding and the joy of taking control) that we have established with ICE vehicles with our electric vehicles as well, and, of course, low noise and low (zero) emissions, which are features of electric vehicles. We have released

Innovation

Fig. 1 Innovation–launch of EVs, HEVs, and motorcycles

Tradition

Fig. 2 Tradition–40th anniversary of the Ninja and 100th anniversary of the MEGURO

four EV or HEV models to become the top electric vehicle brand.

・Ninja e-1 and Z e-1 (EVs): The Ninja e-1 and Z e-1 are pure electric full-size sport motorcycles. We developed technologies that satisfy a wide range of customers' desires, packing these models with EV-specific functions, such as the walk mode in addition to the riding mode selection function and the e-boost function, by leveraging powerful acceleration and great response in the low engine speed region.

・Ninja7 Hybrid and Z7 Hybrid (HEVs): The Ninja7 Hybrid and Z7 Hybrid are the first strong hybrid motorcycles in the world. Their 600-cm^3 class bodies are equipped with a hybrid unit consisting of a four-stroke two-cylinder 451-cm^3 engine and an AC synchronous motor. By providing an EV mode and two hybrid modes, We developed according to the (greedy) model concept to allow customers to ride as they like. For example, customers can select the fuel-efficient performance of the 250-cm^3 class or the power performance of the 1,000-cm^3 class by switching between the hybrid modes.

(2) Entry in new areas

・Elektrode (EV): The Elektrode is an electric bike for kids we developed to deliver the spirit of "Fun to Ride" to children as well. With high durability, a sporty appearance, and no emissions or exhaust sound, this is the smallest strategic electric model for carbon neutrality that even small children can easily handle to experience the joy of riding. This bike, developed with the development technology of the KX, is an entry model for future professional motocross riders.

・noslisu and noslisu e: We developed technologies for three-wheel electric vehicles under the concept of delivering comfortable and easy mobility to everyone. With the technologies and experience we acquired from making motorcycles, we realized the stability unique to three-wheel vehicles with the natural controllability of bicycles using our proprietary two-wheel steering mechanism for a smooth ride. The frame and the link mechanism for the front wheels also create a nimble style filled with functional beauty. The specifications for power-assisted bicycles and electric vehicles that require a driver's license support free lifestyles by delivering a sense of security, convenience, and joy to a wide range of users.

Fig. 3 Elektrode

Fig. 4 noslisu and noslisu e

(3) Continuously launching new ICE models

We have continued to launch new ICE models, introducing advanced technologies, improving products, and enhancing equipment to offer a wider range of purchase choices for customers. This is also important to ensuring stable operating revenue.

・Ninja H2 SX: The Ninja H2 SX combines state-of-the-art technologies as a 1,000-cm^3 supercharger model equipped

Fig. 5 Ninja H2 SX

with advanced driving assistance (forward collision warning, adaptive cruise control (ACC), backward blind spot detection (BSD), and auto high beam). We plan to deploy the advanced driving assistance function to the main models, starting with the technology development for this model.

・Ninja ZX-4R: The Ninja ZX-4R has a body equivalent to a 250-cm^3 class model equipped with a 399-cm^3 parallel four-cylinder engine with best-in-class performance. This supersport model offers ample power with sharp, nimble handling. With electronically controlled throttles, a quick shifter, and a full-color TFT (thin film transistor) liquid crystal meter that supports connectivity, the innovations of this model have revitalized the tradition of the 400-cm^3 class four-cylinder engine, which was once discontinued, attracting a wide range of customers across the world.

・Ninja 500 and Z500: We succeeded in reducing the weight of Ninja 400 and Z400, widely accepted in the market, while increasing their engine capacity, enhancing their capability as products with a new full LCD (liquid crystal display) meter, and evolving their design at the same time. We developed these models with rational designs and launched them as global strategic models.

・ELIMINATOR: We developed this model by evolving the Low & Long style and considering nimble and natural handling with the aim of resurrecting this once discontinued name. The combination of the traditional design and latest technologies allows you to enjoy riding this attractive model without getting overly worked up. This model particularly gathered attention by adopting a dash cam ahead of most products in Japan. One of our technology development goals with this model was a short time-to-market, which was made possible by using our simulation technology without making prototype vehicles.

(4) To become the top off-road vehicle brand

As the off-road vehicle market is expected to stably expand, our room for growth is also large. We aim to become the top brand in the off-road dual-purpose motorcycle segment by enhancing our product lineup.

・KX450: Over the course of its 50-year history, the KX450 has evolved with advanced technologies to be the best motocrosser for professionals based on the concept of it being all-rounder bike. This model is equipped with a new engine with higher controllability and a new chassis with more stable front wheels and related components even compared to the proven previous model. We will continue to develop the best model for professionals.

Fig. 6 Ninja ZX-4R

Fig. 7 Ninja 500

Fig. 8 ELIMINATOR

Fig. 9 KX450

Fig. 10 W175

Fig. 12 RIDGE XR

(5) Competitiveness enhancement in emerging countries

We are establishing lower-cost procurement and production methods, mainly by developing a strategy model for India.

・W175: The W175 was developed as a model that inherits this tradition. We are launching this model in the Indian and other markets to increase our market share in Asian countries and increase procurement in India and strategically deploy those parts to other models as a foundation for cost reduction.

2 Off-road four-wheel vehicles

Because the strong growth of the off-road four-wheel vehicle market in North America is expected to continue, we have developed technologies to establish this area as our core business that will surpass our motorcycle segment, launched competitive models, and actively promoted the enhancement of production factories.

・TERYX KRX4 1000: The market is shifting to large, high-performance models for families and the development of such models is heating up. The performance enhancement of this model is just a stepping stone, and is a new starting point for further technology development as customers demand much higher performance models.

・RIDGE XR: The RIDGE XR is a model that supports both utility and recreational uses to accommodate a variety of situations. We successfully launched this reliable model that provides comfort even in severe ambient temperature environments by adopting a four-cylinder engine to achieve a linear response, smooth acceleration characteristics and full cabin and HVAC (heating ventilation and air conditioning) specifications.

3 Personal watercrafts (PWCs)

Whereas a high performance engine and hull make PWCs “Fun to Ride” and gives them their enduring popularity, development to support different uses such as towing wakeboards and transportation for recreational purposes has been taking on greater importance.

・JETSKI ULTRA 160LX, ULTRA LX-S ULTRA, and LX-S ANGLER: As an increasing number of models with functional and equipment enhancement have been launched in the PWC market, we developed the JETSKI ULTRA 160LX and ULTRA 160LX-S equipped with a highly demanded naturally aspirated engine. The ULTRA 160LX-S ANGLER is a derived product that has specifications and equipment to enjoy fishing, serving as a means of sea

Fig. 11 TERYX KRX4 1000

Fig. 13 JET SKI ULTRA160 LX-S ANGLER

transportation to fishing spots, and sometimes, as a fishing boat. We will continue technology development to provide specifications and equipment for the expanding range of marine recreation scenarios.

4 Utility engines

(1) To become the top mower engine brand

・FX820V EVO: We developed the FX820V EVO as a new-generation engine with higher power and fuel efficiency as well as lower emissions as the computerization of fuel supply is advancing in the commercial mowing market in the U.S. This model has been highly appreciated since it has 20% higher engine power performance and 10% to 20% higher fuel efficiency compared to our conventional class with the same displacement as a model with three valves including two inlet valves and enjoys higher workability as a mower.

(2) Autonomous mower

To further expand our top market share, we have started developing key technologies for autonomous riding mowers by supplying autonomous riding mower systems and suitable engines to address increasing demand for labor-saving due to chronic labor shortages and rising wages in the landscape industry in North America. We will develop the control technology for stable autonomous riding using the vehicle structure specific to riding mowers with an eye to launch.

Fig. 14 FX820V EVO

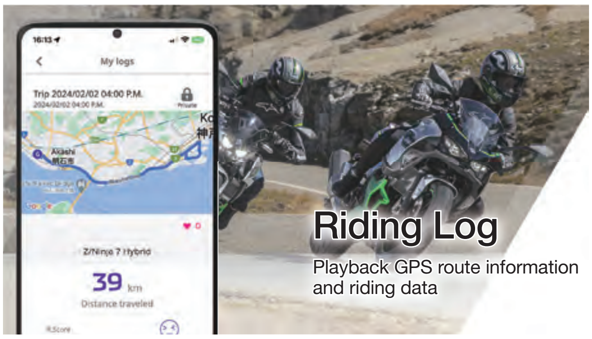

Fig. 15 RIDEOLOGY THE APP

5 ICT

(1) Connected vehicles

RIDEOLOGY THE APP is a smartphone application with a Bluetooth connection function. RIDEOLOGY THE APP for motorcycles allows users to check various vehicle information and change various vehicle settings from their smartphones. We facilitate interaction between customers and vehicles and support the joy of riding through the provision of these services, offering new value. We will continue to develop technologies to add new functions.

6 Taking on the challenge of new businesses

(1) Entry into the aviation business

We have promoted investment in and collaboration with VOLTAERO, a French electric and hybrid aircraft startup founded by a former CTO of the Airbus Group. We have developed technologies toward a trial flight using the engine of the Ninja H2 SX in 2025.

We are also developing a new six-cylinder engine.

(2) Development of hydrogen engines

We joined Hydrogen Small mobility & Engine technology (HySE), a technological research association established in May 2023. We have provided our four-cylinder supercharged engine for trial to promote the basic research of hydrogen engines. We have exhibited

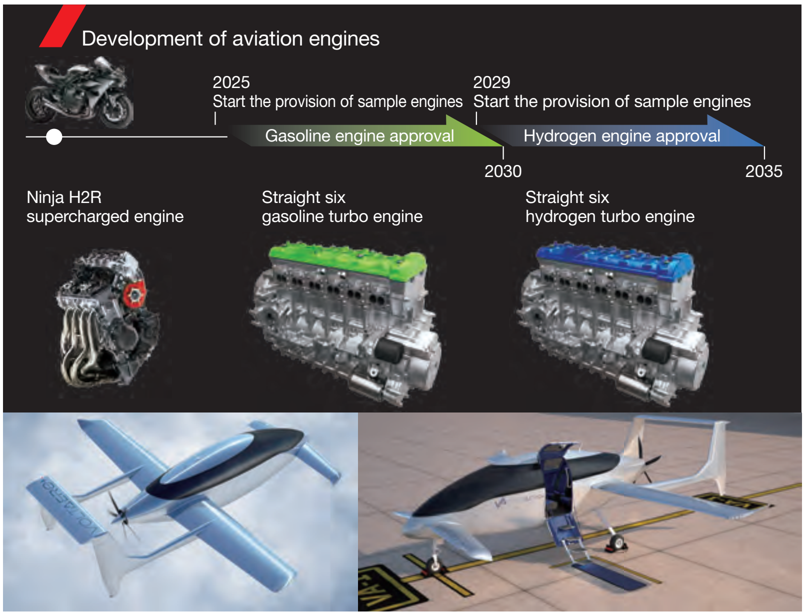

Fig. 16 Entry into the aviation business

Fig. 17 Hydrogen engine vehicles

Fig. 18 Factory in Mexico

experimental hydrogen engines in two-wheel vehicles at various domestic and international events. Moreover, a four-wheel vehicle with a hydrogen engine was already used in the Mission 1000 program in Dakar 2024, and has achieved results. We will continue technology development to provide alternative options toward the elimination of fossil fuels.

Production strategy

For the future growth of our company, it is important that both our high technology and more reasonable prices are loved by customers. So, cost strategy is now one of our development strategies. Local parts procurement through the deployment of new factories for overseas production has become very important for development strategies. We are gradually advancing with the establishment of development processes including this aspect.

Conclusion

We will work on creating a recycling society, aim for zero emissions, and realize a society in harmony with nature, setting sustainable global development as an important corporate mission.

We will attempt to achieve our vision as quickly as possible and eagerly deliver abundance to all countries and people around the world by both developing these products and strengthening our sales power to become a brand with the top market share in each category.

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.

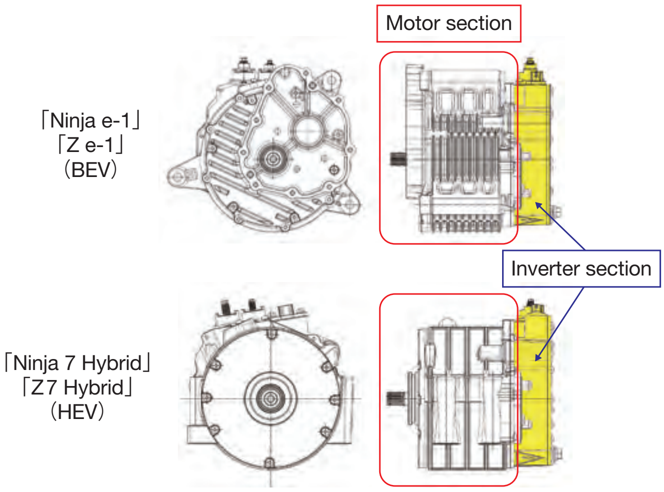

Fig. 4 Traction motor

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

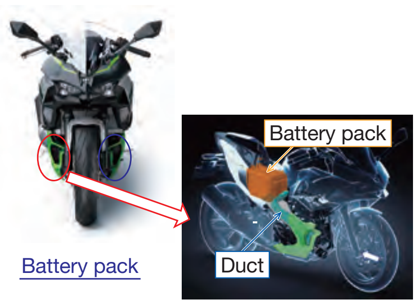

Fig. 6 Battery cooling

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

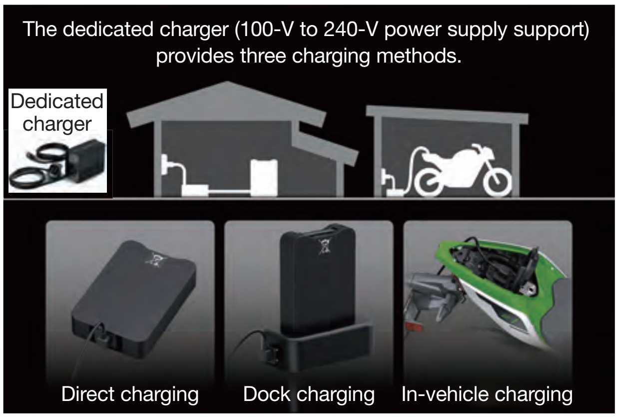

Fig. 7 Battery pack for the BEV & Charging system

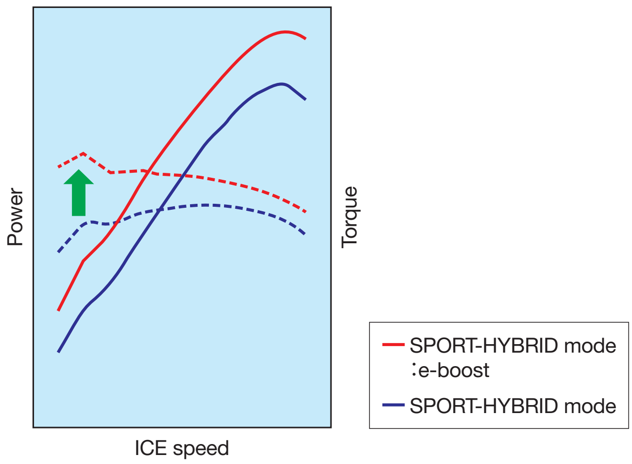

Fig. 8 e-boost function (performance curve) the intended time when the rider wants to speed up. In ECO-HYBRID mode, only the motor is used to start the motorcycle, which can run with lower emissions using the function to automatically switch between the motor and the ICE and the function to stop idling. 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

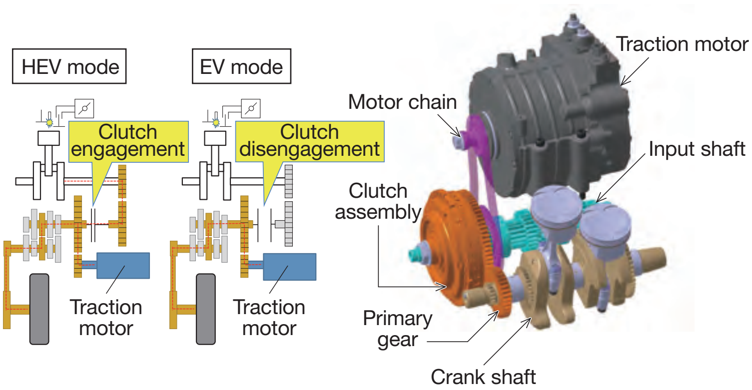

Fig. 9 Hybrid power delivery system

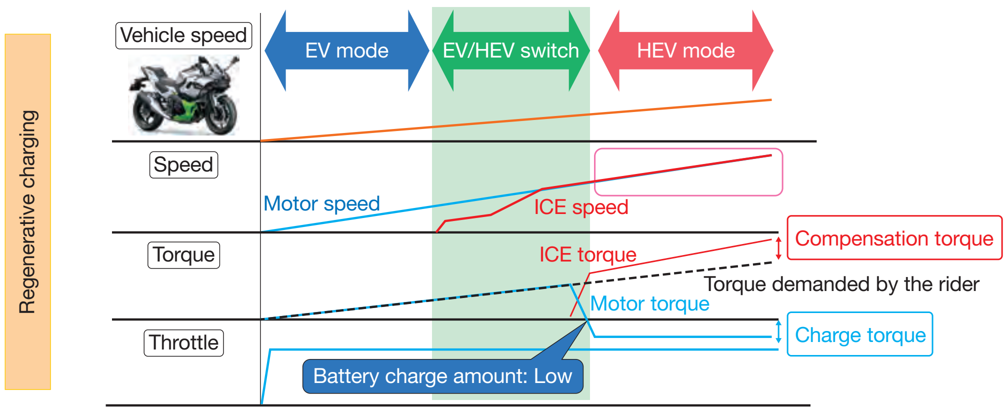

Fig. 10 Torque-based control

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.

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Study on Hydrogen Engines for Carbon Neutrality

Kawasaki Heavy Industries Group is developing a hydrogen supply chain in response to the accelerating worldwide movement toward carbon neutrality to prevent global warming. Within the Group, Kawasaki Motors is conducting experiments and simulations to analyze hydrogen jet flows within engines, with the aim of commercializing new mobility solutions based on hydrogen-fueled combustion engines. The research engine has also been mounted on four-wheeled and two-wheeled vehicles to explore practical applications.

Introduction

To prevent global warming, the worldwide movement toward carbon neutrality is accelerating and expectations for mobility solutions are also rising. One way considered necessary for promptly reducing CO_2 emissions is a multi-pathway approach in which various types of systems that each have different advantages, such as battery vehicles, fuel cell vehicles, and alternative fuel engine vehicles (e.g., alcohol-, synthetic fuel-, or hydrogen-fueled), are combined in an optimal way based on the application purpose. Among such vehicles, vehicles with hydrogen-fueled engines (hereinafter, "hydrogen vehicles") are gaining attention as a means to achieving carbon neutrality while further utilizing the advantages of conventional small power-sport vehicles.

1 Background

The Kawasaki Heavy Industries Group is working to establish a supply chain throughout the processes of production, storage, transportation, and use of hydrogen. Focusing on the use of hydrogen, Kawasaki Motors, Ltd. is working to commercialize small vehicles with hydrogen-fueled engines to make them carbon-neutral.

(1) Characteristics and problems of hydrogen engines

The by-product of hydrogen combustion is water, and thereby hydrogen combustion releases no CO_2. In addition, compared with gasoline, hydrogen has the characteristics of a faster combustion rate and wider combustion range. Therefore, because hydrogen engines can offer the quick response required in small power-sport vehicles, they are expected to both achieve carbon neutrality and provide a new driving feel. Furthermore, the combustion period is shortened and is closer to the theoretical cycle, which is expected to deliver higher efficiency.

Meanwhile, although the ignition temperature is high, the ignition energy is low. Consequently, there are concerns that minute hot spots may ignite, causing abnormal combustion (preignition and engine knocking) and backfires, where flames flow back to the intake pipes, may occur. There are also concerns of an increase in the heat loss and burning of engine oil due to the short quenching distance, as well as generation of nitrogen oxides caused by high-temperature combustion gas; however, the mechanisms of such phenomena have not been clarified in detail.

In addition, because the hydrogen fuel is gas at room temperature, various technologies are required for filling small vehicles with gas and to prevent, detect, and stop fuel leaks.

(2) Hydrogen Small Mobility & Engine Technology Association (HySE)

Although the issues described in the previous section need to be resolved in order to commercialize hydrogen engines, various companies studying basic technologies to control the physical properties of hydrogen at the same time is an inefficient way to do it. Accordingly, a technology association was set up for member organizations to work together to solve the problems. Regular members of HySE, which was established in May 2023, are Kawasaki Motors, Ltd., Suzuki Motor Corporation, Honda Motor Co., Ltd., and Yamaha Motor Co., Ltd., while special members are Kawasaki Heavy Industries, Ltd. and Toyota Motor Corporation. HySE's main tasks are to research and discuss common problems related to hydrogen engines (establishment of a hydrogen engine model based on element research and studies using actual engines/vehicles) and storage (tanks and peripheral equipment). In addition, as another major policy, HySE is working to make hydrogen engines a world-standard technology in cooperation with companies around the world, instead of allowing the technology to be peculiar to Japan.

2 Study of hydrogen engines

(1) Deciding on the fuel supply system

There are two fuel supply systems: the port injection (PI) system, in which fuel is injected into intake ports to produce an air-fuel mixture so as to supply it into the cylinders; and the in-cylinder direct injection (DI) system, where fuel is directly injected into cylinders to produce an air-fuel mixture.

Regarding the PI system, the volume of fuel in an air-fuel mixture in a state with the theoretical air fuel ratio is approximately 2% for gasoline, while it is approximately 30% for hydrogen. Because the volume of air that can be taken in decreases for the volume of hydrogen, the calorific value per cylinder capacity decreases by approximately 16%. In addition, at high loads, a backfire (where a flame that ignites in the cylinder during the intake process reaches the intake port) may occur, which poses a problem in high-load operations.

With regard to the DI system, the intake air volume does not decrease and backfires can be avoided, so this system is optimal for small engines requiring high power. Accordingly, this study targeted the DI system.

(2) Deciding on the air-supply system

It is known that when the combustion temperature in hydrogen combustion is high, nitrogen oxides (NOx) form and lean-burn is effective to suppress this. However, lean-burn reduces the output, and adopting a supercharging system is an effective way to supplement the power loss. To expand the air volume selection range, in this study we selected a supercharging system. The test engine was prepared based on supercharging engines for the Ninja H2[1),2)]. **Table 1** lists the main specifications.

Table 1 Specifications

Engine type	Inline 4
Displacement [cm^3]	998
Bore × stroke [mm]	76. 0 × 55. 0
Stroke/bore	0. 72
Compression ratio	8. 5

(3) Deciding on the fuel supply pressure

For the DI system, to secure a sufficient intake air volume and prevent hydrogen from flowing back to intake ports, the hydrogen supply start (SOI) timing was determined to be after intake valve closure (IVC). In addition, injection needs to finish by the ignition timing (IgT). The crank angle is approximately 100CA, so when the engine speed is 6,000 min^{-1}, the actual time is approximately 4 ms while when the engine speed is 12,000 min^{-1}, the actual time is only approximately 2 ms. To achieve the theoretical mixture ratio, hydrogen of approximately 100 Ncm^3 needs to be supplied into cylinders within this time period, so the fuel supply pressure needs to be set to high at 2 to 10 MPa or higher.

(4) Optimizing the air-fuel mixture formation

Regarding the supply of hydrogen, in addition to the appropriate volume, it is necessary to form an air-fuel mixture in optimal concentration distribution and guide the flammable air-fuel mixture close to the ignition plug at the ignition timing. We performed 3D CFD simulation to understand the phenomenon and discussed the design of improved engines. **Figure 1** illustrates the simulation results. When the injection directions are as shown in the figure on the lower left, the simulation results indicate imbalance in the fuel concentration, etc., and in evaluations using actual engines, abnormal combustion, such as preignition and engine knocking, was observed. After the fuel injection directions were changed to downward as shown in the figure on the lower right, the air-fuel mixture distribution was improved and in operations using actual engines, less abnormal combustion was seen. As described above, it is crucial to understand the behavior of hydrogen gas in the cylinders of hydrogen engines[3)].

3 Understanding the behavior of hydrogen jet flows

(1) Experiments

As the molecular weight of hydrogen (2) greatly differs from that of air (30), understanding the phenomenon of

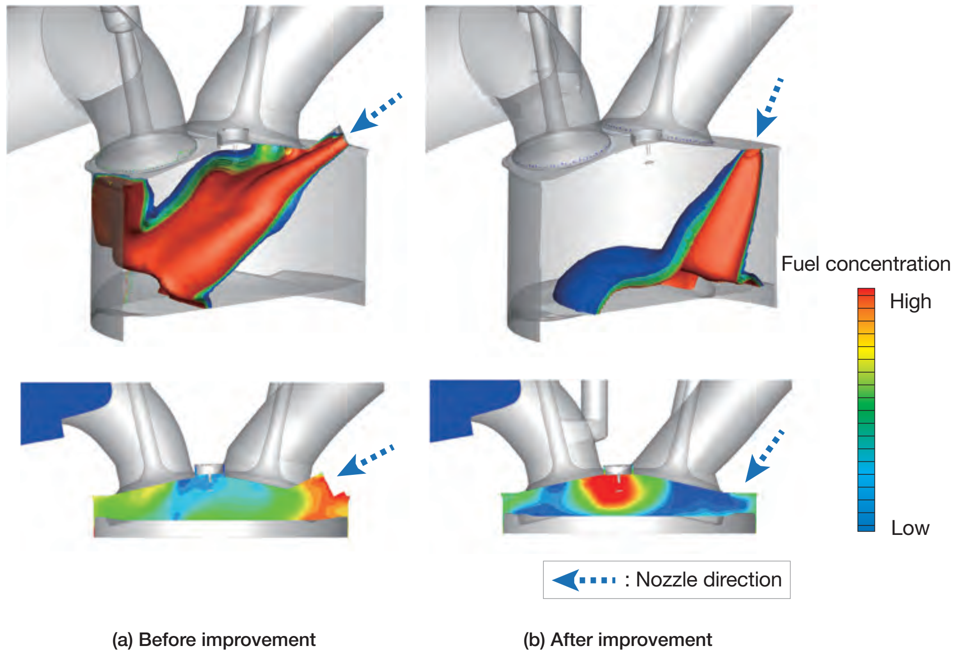


Fig. 1 Improved mixture through simulation of mixed air and fuel (Upper figures: After injection; lower figures: before ignition)

their mixing is crucial when considering abnormal combustion and the generation of nitrogen oxides. This chapter introduces cases in which hydrogen was injected into constant-volume vessels to measure the mixing of the hydrogen and air.

Regarding the DI system, to supply hydrogen into engine cylinders, hydrogen needs to be injected at pressure sufficiently higher than the in-cylinder pressure. If the pressure close to the injector nozzle outlet is two times or more of the back pressure (in-cylinder pressure), an under-expansion jet flow involving a shock wave occurs and the jet flow structure becomes complicated.

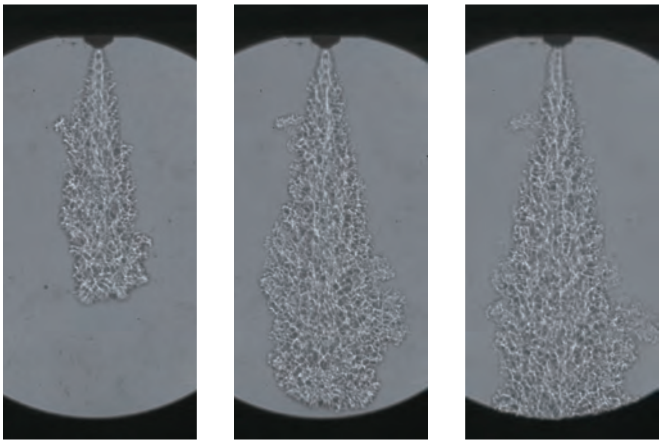
Accordingly, to understand the behavior of hydrogen jet flows and their spreading phenomena, the behavior of hydrogen jet flows when the pressure in constant-volume vessels and the hydrogen injection pressure were changed was photographed using the Schlieren method. In the injection tests, hydrogen was jetted from the injectors into constant-volume vessels for predetermined times and a high-speed camera (Phantom V2512 manufactured by Vision Research Inc.) was used to photograph the behavior of the hydrogen jet flows through a glass window installed in each vessel.

Table 2 lists the test conditions. Assuming injection in the compression process, the pressure in the vessels was set to 0.2 to 1.0 MPa and changes in the behavior of hydrogen jet flows according to the changes in the injection pressure were observed. **Figure 2(a)** shows the behavior of a hydrogen jet flow assuming injection in the first period of the compression process (near the IVC). The pressure in the vessel was set to be equivalent to in-cylinder pressure in a low-pressure atmosphere (0.2 MPa) and the hydrogen was injected at the injection pressure of 2 MPa. The photographs show that the hydrogen in the vessel starts spreading within 2.0 ms after injection,.

Figures 2(b) and **2(c)** show the behavior of hydrogen jet flows when the injection pressure was changed, assuming injection in the middle of the compression process. When the injection pressure is high, the jet flow distance at the front end increases and the hydrogen starts spreading after injection. The photographs also show that when compared with injection in a low-pressure atmosphere, the hydrogen jet flow gathers and remains at

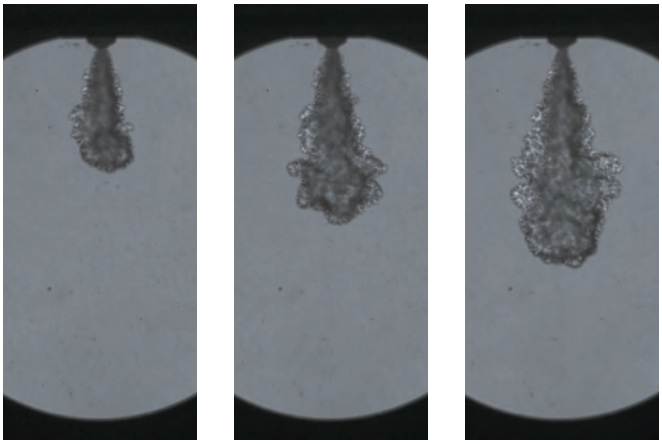
Table 2 Conditions for Schlieren photography of hydrogen jet flows

Fuel	Hydrogen
Fuel injection pressure [MPa]	2. 0–10. 0
Fuel temperature [K]	300
Injection time [ms]	1. 0
In-vessel pressure [MPa]	0. 2–1. 0
Gas in the vessel	Nitrogen
Frame rate [fps]	39000



In 1.0 ms In 1.5 ms In 2.0 ms

(a) Injection pressure of 2 MPa and in-vessel pressure of 0.2 MPa



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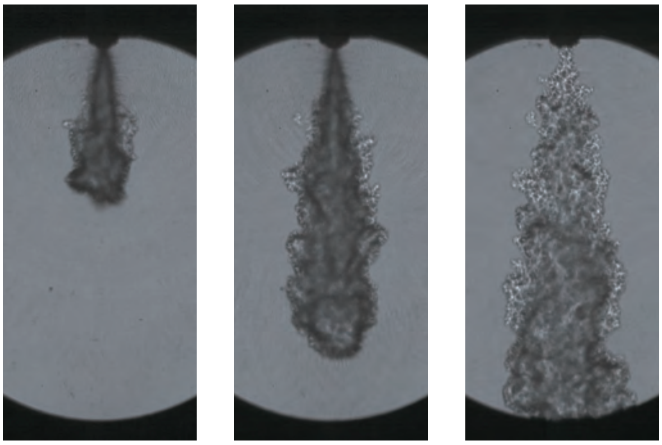
(b) Injection pressure of 2 MPa and in-vessel pressure of 1 MPa



In 1.0 ms In 1.5 ms In 2.0 ms

(c) Injection pressure of 10 MPa and in-vessel pressure of 1 MPa

Fig. 2 Schlieren images of hydrogen jet flows that place. Through such characteristic results from observing the hydrogen jet flows, we will gain a clearer understanding of the behavior of hydrogen jet flows and hydrogen mixing phenomena, which will contribute to optimizing the air-fuel mixture concentration distribution in engine cylinders.

(2) Numerical simulations

Understanding the process of forming an air-fuel mixture as a result of a hydrogen jet flow is important, so CFD numerical simulation is considered to be effective for ① considering hydrogen injection on a parametric basis and, ② evaluating the state in the mixing process.

As described above, high-pressure hydrogen jet flows generally become supersonic flows, causing very high-turbulence flows. Accordingly, spreading phenomena of turbulent flows of hydrogen and air are important to know, so a turbulent flow model needs to be selected for conducting numerical simulations. There are two simulation types: Reynolds averaged numerical simulation (RANS), in which turbulent flows are smoothed to create a model, and large eddy simulation (LES), in which eddy scales equal to or larger than the designated mesh size are directly subjected to numerical calculation and eddy scales smaller than the designated size are subjected to modeling.

In addition, as the hydrogen injection modeling method, the motions of the lifting parts in an injector were simulated and an injection pressure boundary was given to the upstream side of the lifting parts. The pressure in the cylinders of direct-injection hydrogen engines changes moment by moment, so establishing an injection model that includes the motion of the lifting parts was determined to be necessary. However, the details inside injectors are not known, so the approximate diameter of the resting position was tentatively determined from the appearance of the injector, and the time history of the injector curtain area (opening) was adjusted such that it matches the state of the injection signal history and hydrogen injection volume per cycle.

Figure 3 compares the numerical simulation results with the test results of the visualization of hydrogen jet flows in constant-volume vessels within 1 ms after injection starts when the injection pressure was set to 6 MPa and the in-vessel pressure was set to 1 MPa under the testing conditions listed in **Table 2**. The images of the Schlieren test and LES show projections and depressions of the eddy structures of the turbulent flows at the jet flow interfaces, while the RANS image shows the jet flow in a teardrop shape without projections and depressions at the jet flow interface because the turbulent flow is smoothed. In other words, these results show that the area of the jet flow interface varies from the turbulent flow model to the model, which may make the degree of mixed diffusion different to some extent. Next, **Fig. 4** compares the jet flow distances and injection angles between the test and simulation models. The jet flow distance is an important index for observing the momentum of jet flows and mixing behavior after collision in cylinders. The jet flow distance obtained in the test closely matches the numerical simulation (LES/RANS) results, and these results show that all turbulent flow models can reproduce the test results. Meanwhile, the injection angle is an important index for evaluating the spread of jet flows; although the injection angles in the latter half of the injection differ slightly between the test and simulations, the LES angles are almost the same as the RANS angles. Note that the calculation time varies greatly between RANS and LES; it is approximately 1.5 days for RANS but around 14 days for LES.

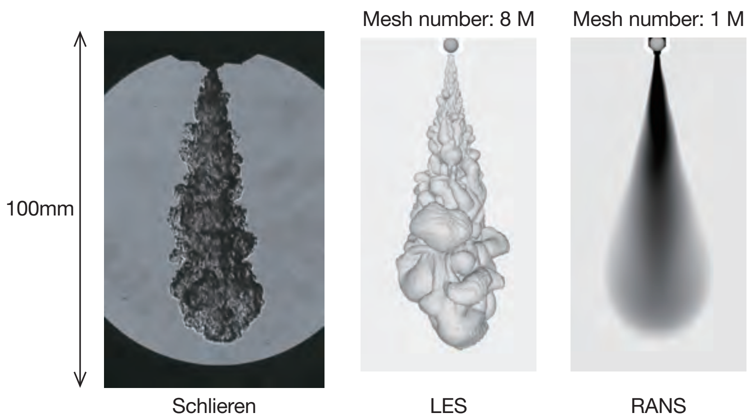


Fig. 3 Comparison of visualized hydrogen jet flow within a constant-volume vessel with simulated images (Within 1 ms after injection start, injection pressure of 6 MPa and in-vessel pressure of 1 MPa)

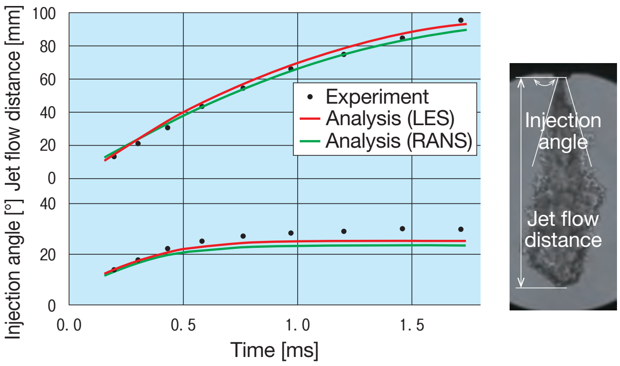


Fig. 4 Comparison of jet flow distances and angles in tests and simulations

Through verification with the test results above, a technology for numerically simulating hydrogen jet flows has been successfully established. It may be appropriate to use optimal turbulent flow models for different situations: LES to evaluate phenomena in the mixing process of hydrogen and air in detail, and RANS for globally discussing many design parameters (e.g., injection positions, directions, and pressure).

4 Evaluating actual hydrogen engines

(1) Study of hydrogen engines in environments involving actual machines

Before applying hydrogen engines to two-wheeled vehicles and other small vehicles, as well as conducting desktop tests, we need to extract problems that may arise during actual driving and develop measures against them. In actual driving, engines need to have transient characteristics to cope with changes in conditions, such as user-initiated acceleration and deceleration, road gradients, slippery surfaces, and influences from surrounding vehicles. In addition, influences on abnormal combustion, exhaust gas, driving feel, and other factors also need to be considered.

Furthermore, a fuel supply system is required and the vehicles need to be equipped with various other systems: a hydrogen storage system (e.g., hydrogen tanks, filling ports, and pressure regulating valves), a hydrogen storage control system that recognizes the state of the storage system and controls it, and a hydrogen safety system that prevents, detects, and stops hydrogen leaks.

We produced a test hydrogen vehicle based on Kawasaki Motors' TERYX KRX1000 off-road four-wheeled vehicle as a mobile laboratory equipped with the aforementioned systems and is in use for research. A driver and a vehicle status monitor ride the test vehicle, and control adaptations can be done in real-time. For the engine, a four-cylinder DI system was adopted.

Because we worked in cooperation with the other HySE members to build the laboratory vehicle, driving tests could be done in a short period of time with safety secured. In pursuing the common goal of carbon neutrality, we have been able to build an inter-company friendship that we could never have imagined in the past (**Fig. 5**).

(2) Study of hydrogen engines in harsh environments

To accelerate the establishment of fundamental technologies for hydrogen engines, the HySE team participated in the Dakar Rally, one of the world's toughest motorsport events, as part of our study of hydrogen engines so we could promptly extract unknown problems we could not easily foresee. The 2024 Dakar Rally's Mission 1000 (from January 3 to 19, 2024 in Saudi Arabia) is a new category established in 2024 to encourage the development of next-generation power trains, such as hydrogen vehicles, bio-fuel vehicles, fuel-cell electric vehicles, electric motor vehicles, and hybrids of them, toward carbon neutrality. The machines travel approximately 1,000 km in total within 11 days. The route consists of 11 stages that include desert terrain, sandhills, and wastelands, so the road conditions vary; the elevation height is 0 to 1,700 m or so and the difference in temperature between daytime and nighttime is drastic. These conditions make it possible to test machines in various harsh environments in a short time. The organizer provided a mobile hydrogen station, which made it possible for our team to participate in the rally. In addition, it is said that the number of TV viewers of the Dakar Rally is the second largest in the world, so HySE aimed to showcase our work and hydrogen engines as an option to the world, and spread awareness of us beyond Japan.

The HySE team used an all-terrain vehicle (HySE-X1) to participate in Mission 1000 (**Fig. 6**), and the engine was a four-cylinder DI system. The engine adaptation was carried

Fig. 5 The unveiling of the hydrogen vehicle at a racetrack

Fig. 6 HySE members with the HySE-X1

out near the stoichiometry (theoretical air fuel ratio) for the entire range by prioritizing the output, and the team's policy was, by enhancing the driving characteristics on various road surfaces and elevation heights, to travel as far as possible to collect data.

Although the preparatory period was short at just four months, thanks to the experience described in the previous section and the support of people with a rally background, the team could travel 830 km of the 11 stages' 922 km. In the stages whose distance exceeded 100 km, the team drove the machine with a focus on fuel economy while in the stages whose distance was 50 km or so, they drove it at high loads. Therefore, by changing the load conditions during driving (**Fig. 7**), the team could observe multiple abnormal combustion occurrences during the event. In addition, many media (TV and online news and live streaming during the 2024 Dakar Rally) picked up on our team and machine, so HySE could present its efforts to the world and contribute to attracting partners in the future. HySE will use the outcomes and experience gained through the rally to develop hydrogen engine technologies from now on.

(3) Study of hydrogen engines for two-wheeled vehicles

The space for installing components in two-wheeled vehicles is limited compared with four-wheeled vehicles, and because two-wheeled vehicles need to be picked up and pushed, there is a strict limit on the weight as well. In addition, there is a risk of two-wheeled vehicles falling, we need to extract problems specific to these vehicles (e.g., protection of equipment in case of a fall) promptly to solve them. Furthermore, at present the legal framework for these vehicles is not well developed, so test vehicles for technological demonstration are needed to bring the law up to date with the technology. If test driving on public roads is allowed, studies can be done across a wider scope, such as checking the relationship with existing vehicles in actual environments and extract problems associated with using hydrogen stations in urban environments.

With these factors as the background, we decided to produce and study a two-wheeled vehicle with a hydrogen engine (**Fig. 8**). The engine is a four-cylinder DI system. The machine is equipped with two hydrogen tanks on both sides at the rear. The tanks are surrounded with piping materials to protect them, they are fixed in place with suitable fasteners, and the outsides are covered with CFRP (carbon-fiber reinforced plastic) covers. This structure prevents third parties from directly touching the hydrogen tanks even when the vehicle falls over or is involved in a collision. This structure was subjected to FEM analysis to check the behavior of the hydrogen tanks when the machine experiences a crash. The tank capacity was set to 50 L (2 kg) because this is the minimum size that can be filled at urban hydrogen stations that have been set up according to the JPEC-S0003 Compressed hydrogen filling technical standard. However, regarding the

Fig. 7 HySE-X1 racing across sandy terrain

Fig. 8 Hydrogen-powered motorcycle

size of tanks for two-wheeled vehicles, UN Regulation 146 (UNR146) specifies up to 23 L, so we will use this test vehicle to appeal to related organizations to expand the tank size according to the vehicle category.

With regard to exhaust gas, NOx emissions could be reduced by adopting the lean-burn method.

To promote the appeal of hydrogen engines, we ran a public driving event at the Suzuka Circuit during the Suzuka 8 Hours Endurance Race held on July 20 and 21, 2024. We also hosted a public driving event in France, which highlighted the potential for hydrogen engines to the world.

Conclusion

In addition to technological development, related laws and regulations and the supply infrastructure need to be developed in order to popularize hydrogen vehicles. In addition, the Japan Automobile Manufacturers Association is proposing a multi-pathway approach, and public activities are important for raising awareness of hydrogen engines among the general public. We drove the test hydrogen vehicle during an event at the racetrack and at an exhibition of zero-emission vehicles held by the Tokyo metropolitan government and asked the Governor of Tokyo to test-ride it, which has helped make hydrogen vehicles better known to society at large.

Although hydrogen engines have been studied since long ago, they are now nearing commercialization due to rapid advances in equipment, such as storages and injectors, in recent years and gaining attention worldwide as a way to achieve carbon neutrality. We are focus on small vehicles in particular, and will work to commercialize them through various measures such as demonstration, the spread of our association, appeal to public opinion, and helping with the development of laws and regulations, in addition to research.

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Simulation Technologies for Efficiently Developing Off-road four-wheelers

In our Vision 2030 statement, we at Kawasaki Motors set a sales target of one trillion yen, primarily through our off-road four-wheelers. Achieving this target requires us to launch new, attractive models on the market for time to time. To streamline the development process we are employing simulation technologies, including measurement technology for tire forces, virtual durability testing, and virtual test driving.

Introduction

In North America, off-road four-wheelers (Side × Side) are used for various applications, including agriculture, forestry, hunting, and recreation. Recently, the off-road four-wheelers market has been expanding exponentially as shown in **Fig. 1**. Because many manufacturers have entered this market as a result, leading to fierce market competition, we need to differentiate from competitors and explore new market segments.

1 Background

In our Vision 2030, Kawasaki Motors set a goal of achieving a sales of one trillion yen in FY2030, primarily through our off-road four-wheelers.

Dramatic growth in the off-road four-wheelers business is required to achieve the vision.

2 Policy

The key to growing the off-road four-wheelers business is to develop attractive products ahead of competitors and

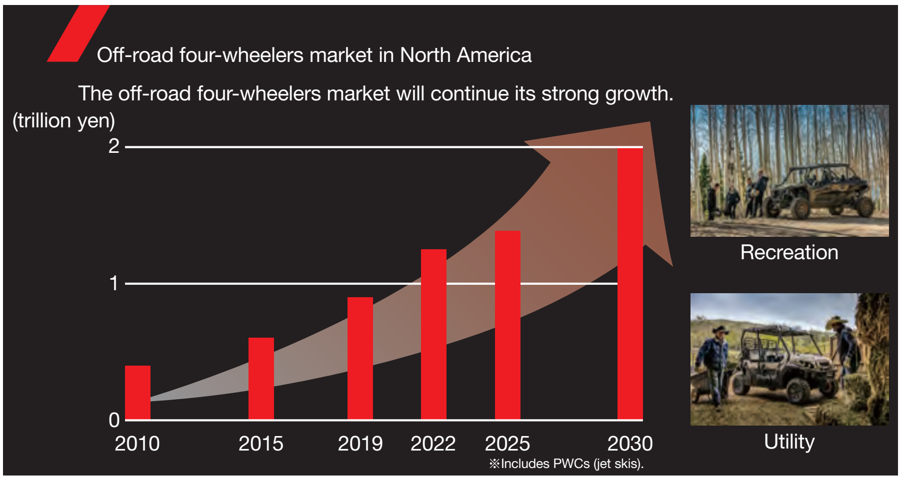


Fig. 1 North America Off-Road Four-Wheelers Market[1)]

launch them early. Therefore, to shorten the development period, we ensure vehicle performance and quality at the initial planning stage, where there is a high degree of design freedom, to reduce rework at the verification phase after vehicle prototyping and decrease development work as a whole (front-loading of development).

3 Issues

Figure 2 is a conceptual diagram of front-loading efforts during durability evaluation. Replacing the durability during real-vehicle evaluation at the verification phase with virtual simulation during detailed design at the design phase decreases rework at the verification phase, which, in turn, reduces the overall work.

Figure 3 is a conceptual diagram of work reduction through front-loading. Work for conceptual design and detailed design at the design phase increases because considerations increase at the initial design stage. However, this is expected to cut problems at the verification phase following prototyping and evaluation, to eventually reduce development work as a whole.

The current issue is to establish a method to achieve such front-loading.

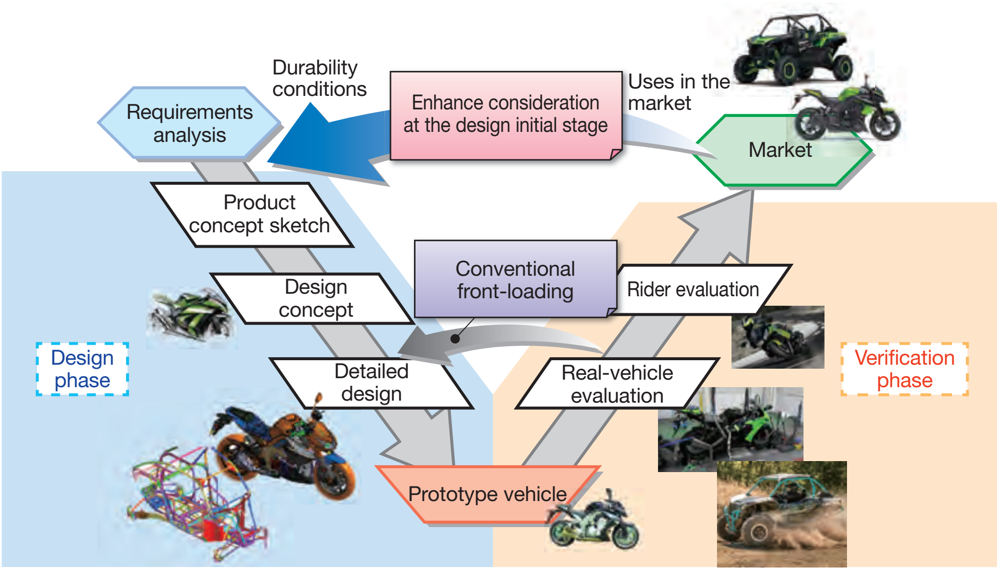


Fig. 2 Front-loading of durability evaluations

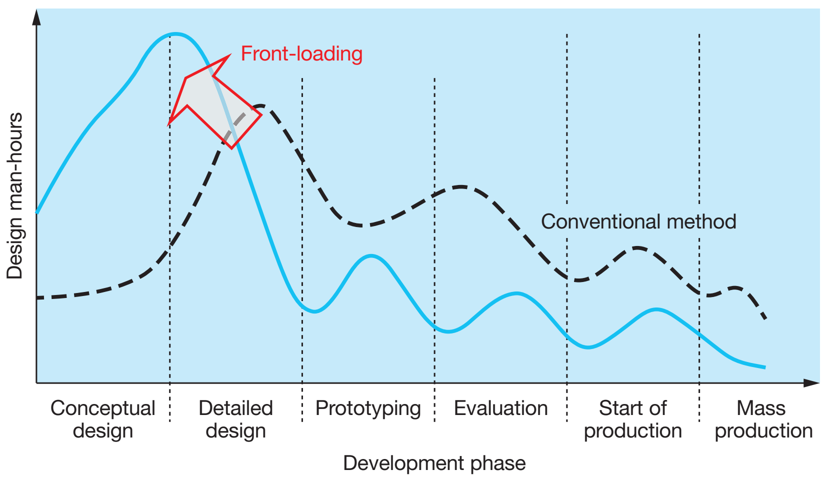


Fig. 3 Reduction in man-hours achieved by front-loading

4 Examples of endeavors

This section shows examples of current endeavors to solve problems toward achieving front-loading.

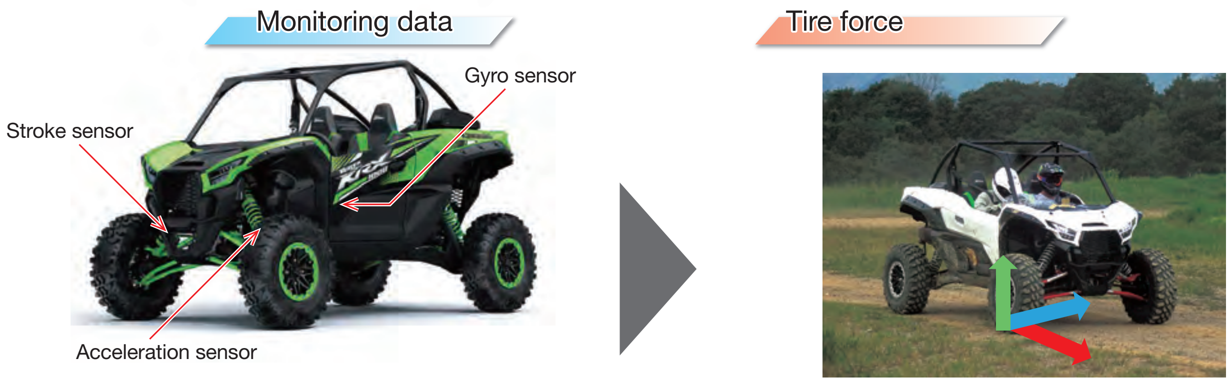
(1) Measurement technology for tire forces

Because external forces are applied to the body via the tires while the vehicle is moving, the body conditions for a durability test run are determined based on tire forces. If the tire forces are incorrectly estimated at the initial stage, rework such as frame repair may result due to insufficient body durability or other causes when the durability of prototype vehicles is checked. Therefore, highly accurate tire force estimation is essential when evaluating body durability.

The tire forces on motorcycles can be estimated relatively easily because they mainly run on flat, paved roads. In contrast, evaluating the tire forces acting on off-road four-wheelers has been more difficult than on-road vehicles because their driving conditions vary widely, from high-speed driving on rough ground or bumpy roads, climbing in rocky sections, and landing after jumps. Therefore, we established a technology to measure the tire forces acting on all four wheels in the off-road environment.

Figure 4 shows the tire force estimation method. We built a logic to estimate the tire forces based on information from the in-vehicle posture angle sensor and other sources.

Figure 5 is a conceptual diagram of tire force estimation. The established method can be used to estimate the tire forces of each element (front, back, right,



(a) Modeling data sample

(b) Conceptual diagram of tire forces

Fig. 4 Measurement method of the tire force [2)]

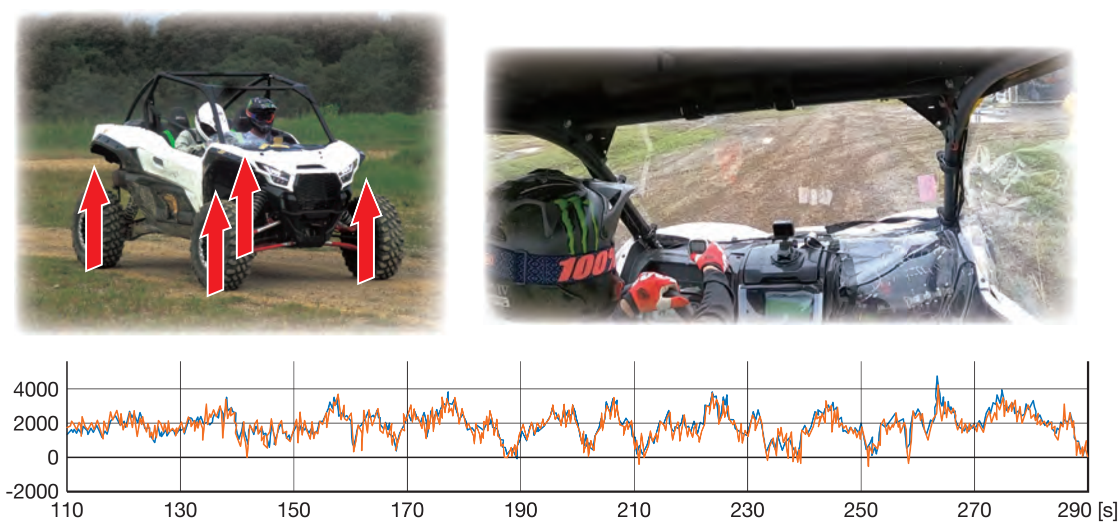


Fig. 5 Measurement of tire forces in action

left, top, and bottom) of four wheels even when the vehicle runs in a rough environment, such as along bumpy roads or landing after jumps.

(2) Virtual durability testing

We expect to prevent problems that may arise during real-vehicle evaluation by estimating the tire forces the vehicle is likely to encounter as it runs in an off-road environment. This will be done through virtual durability testing of the body using the estimated tire forces.

The procedure from the calculating stress on the body frame after tire force acquisition through service life estimation is described below. **Figure 6** shows a conceptual diagram of stress analysis. We can calculate the stress on the frame by applying inertia relief analysis when the tire forces are input. Because tire forces are time history data of when the vehicle runs on a rough road, the frame stress is also calculated as time history data. As the cumulative damage to each part is calculated after the stress time history is derived, the remaining service life of each part can eventually be estimated as shown in **Fig. 7**.

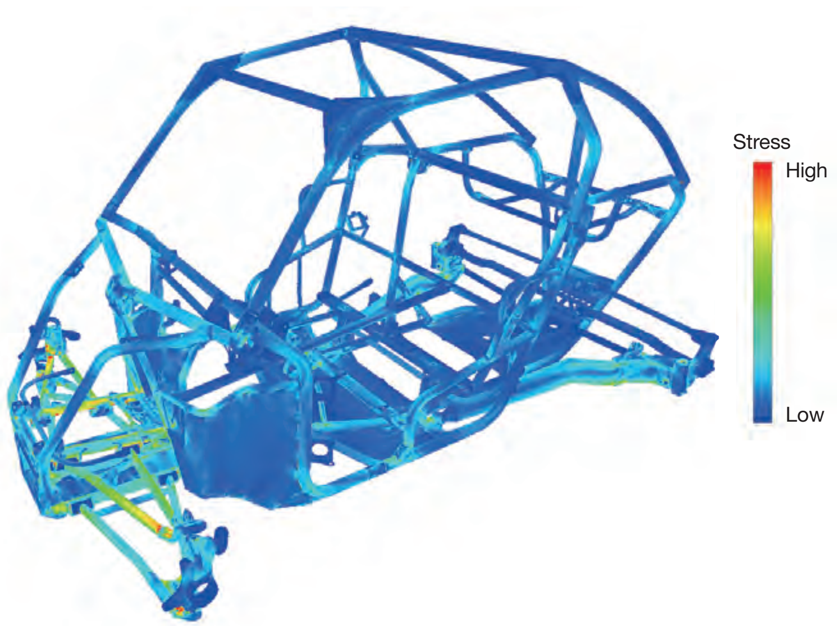


Fig. 6 Image of stress analysis

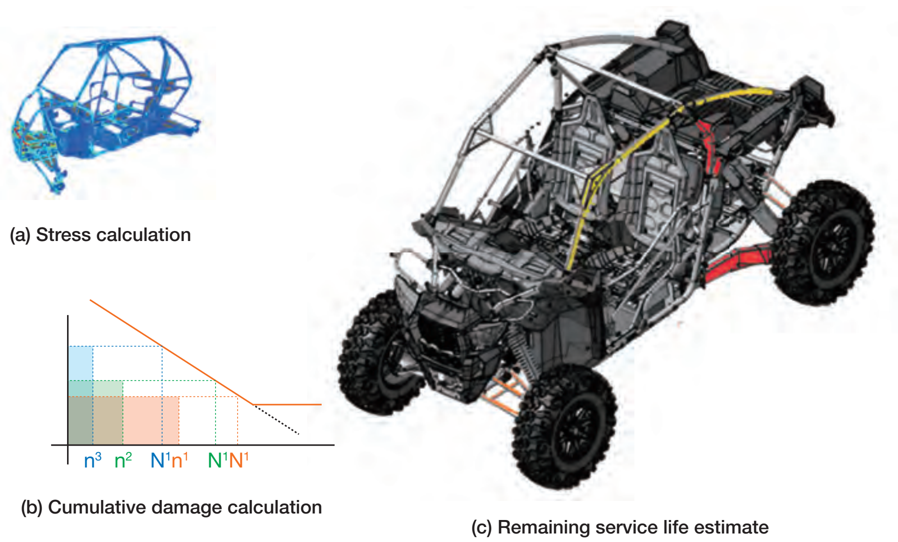


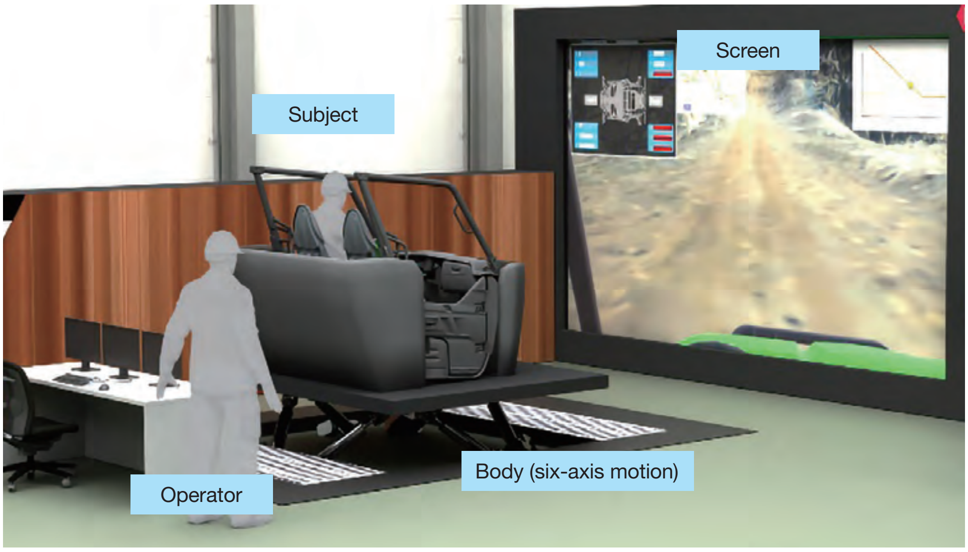
Fig. 7 Image of calculating frame damage

(3) Virtual testing

At the verification phase in **Fig. 2**, the vehicle body is finished based on driver sensory evaluation using a real vehicle. The driver evaluates many different items, including vibration, ride, maneuvering stability, seat positions, and switch operability. If a product fails at the driver evaluation stage, a lot of work and time are required to make the necessary changes. For this reason, we have worked on front-loading by replacing driver evaluation using real cars with virtual testing.

An overview of virtual testing is shown in **Fig. 8**. This environment enables us to build four-wheel vehicle models during simulation and virtually reproduce the behavior of new vehicle models. The driver can virtually drive a new model using a console on the six-axis motion table. The console can be used to operate the accelerator, brakes, and steering, and through the feedback from the six-axis motion the driver can feel vehicle movement such as roll, pitch, and acceleration/deceleration. The driver can also virtually ride existing vehicles and new models for comparison. This virtual testing system has been leveraged, for example, to fine-tune the maneuvering sensation of new models.

Figure 9 illustrates a sensory evaluation result from



(a) Sensor evaluation simulator

(b) Conceptual diagram of driving simulation

Fig. 8 Virtual test driving[3,4]

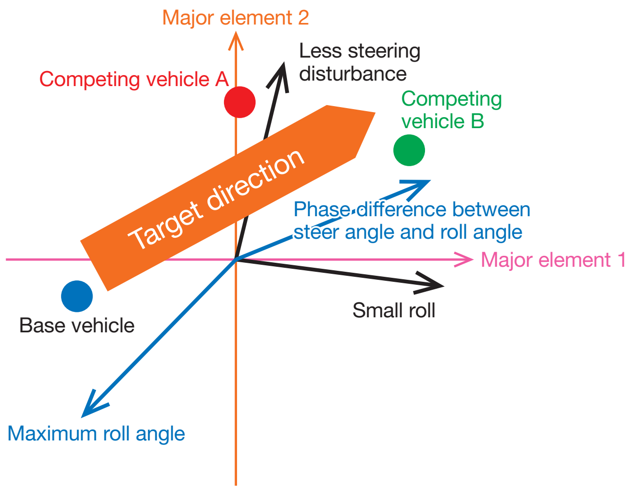


Fig. 9 Example of applying the sensory evaluation method

virtual testing. We expect to apply virtual testing to consider desirable body specifications when finishing a body receives high praise from drivers and passengers in terms of roll motion.

Conclusion

This article has introduced simulation technologies for efficient development of off-road four-wheelers and examples of initiatives to help achieve Kawasaki Motors' 2030 Vision.

We are currently refining the simulator's estimation accuracy for various situations.

In addition, we plan to improve the overall development process, adopting these initiatives, and continue our activities with the goal of significantly reducing development work and time per model as of 2030.

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Development of Autonomous Ride-on Mower Technologies

In North America's landscaping industry, chronic labor shortages and rising wages are boosting demand for labor-saving mowing solutions among professional gardeners.

To capture a larger share of the ride-on mower engine market, we are developing key technologies for autonomous models, focusing on supplying autonomous systems and suitable engines for professional ride-on mowers.

Introduction

In North America's landscaping industry, chronic labor shortages and rising wages are boosting demand for labor-saving mowing solutions among professional gardeners.

1 Background

With the ride-on mower market in North America recently expanding, we, like our competitors, are developing a variety of technologies to boost our sales volume and maintain the top market share. Thanks to our differentiating technologies, we currently hold the industry's top market share with an engine supply ratio of over 50% in the commercial ride-on mower market.

However, recent labor shortages and rising wages are driving increased demand for labor-saving mowing solutions among professional gardeners. In response to this, we believe that developing key technologies related to autonomous ride-on mowers and supplying autonomous systems and suitable engines will further expand our market share.

2 Overview of ride-on mowers

(1) Chassis overview

Figure 1 shows the chassis structure of a typical ride-on mower. **Table 1** lists its specifications. Its engine is

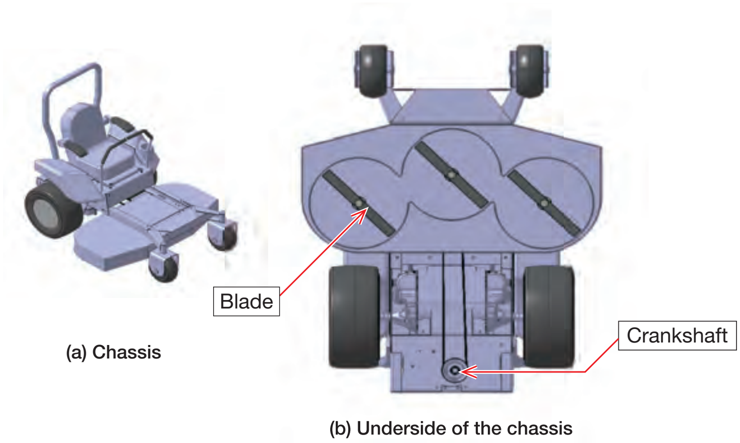


Fig. 1 Structure of a ride-on mower

Table 1 Specifications of a typical ride-on mower

Specifications of a typical ride-on mower	
Engine	Kawasaki FX820V
Displacement [cc]	822
Horsepower [hp] *Gross power	34. 5
Dimensions [mm]	2, 007 (L) ×1, 283 (W) ×1, 562 (H)
Mowing speed [km/h]	16

Fig. 2 Engine for lawn mowers: FX820V

shown in **Fig. 2**.

The ride-on mower cuts grass by rotating the blades attached to the underside of the chassis, as shown in **Fig. 1(b)**, via a belt connected directly to the engine's crankshaft pulley.

The engine is connected to hydraulic pumps, which move the mower by driving the right and left tires using generated oil pressure. The driving force to the tires can be controlled with the levers located to the right and left of the seat. The driver can move forward, backward, or turn the mower by manipulating these two levers with both hands. Tilting both levers forward moves the mower forward while tilting them backward moves it in reverse. You can change the orientation of the mower on the spot around its center (zero-turn) by pushing one lever forward and pulling the other back. This zero-turn capability is essential for ride-on mowers, which need to turn around with a small turning radius.

(2) Mowing procedure using ride-on mowers

Many families in North America have lawns, and since regular mowing is necessary to keep them looking beautiful, many homeowners hire professional gardeners for the job.

These gardeners typically arrive at the site in a truck loaded with a ride-on mower to mow the lawns.

Figure 3 shows conceptual images of mowing. Lawns are mowed to a consistent height in a uniform direction. In many cases, the mowing direction is maintained by turning the mower with a turning radius for a single mower once it reaches the end of the mowed area. Gardeners use ride-on mowers for wide, unobstructed areas and handheld mowers for trimming confined spaces, such as those between trees.

Since mowing a single location often takes less than one hour, professional gardeners can visit multiple sites each day to mow.

Fig. 3 Images of lawn mowing

3 Overview and benefits of autonomous operation

Mowing is usually done by a team of two or three gardeners. One or two gardeners mow the wide areas with ride-on mowers, while the other trims the edges.

The introduction of autonomous operation is expected to save labor for one gardener, because an autonomous mower can mow the wide areas while one gardener trims the edges and manages the autonomous mower, as shown in **Fig. 4**.

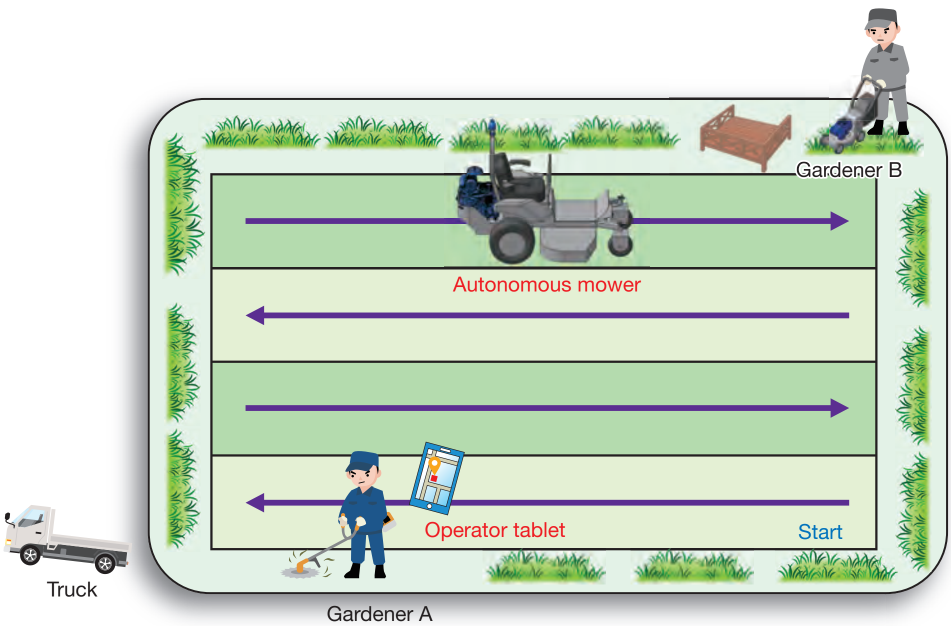


Fig. 4 Usage case for an autonomous lawn mower

4 Development of a chassis control technology specific to ride-on mowers

(1) Chassis modification for autonomous operation

Figure 5 shows an overview of the autonomous mower system. External commands from the autonomous driving control unit manage various operations, including engine start, acceleration, deceleration, turning, parking-brake setting, and engine stop. Additionally, the autonomous mower can switch between autonomous operation and manual driving[1, 2].

Before starting the autonomous operation, the mowing area and mowing direction must be specified remotely via a tablet computer. Once the tablet computer transfers the driving route information to the autonomous driving control unit, autonomous driving can begin. During autonomous driving, the mower follows the predetermined route while tracking its own location. The autonomous driving control unit calculates the mower's speed and turning direction based on it's current position and the target route information. GNSS antennas mounted on top of the mower gather satellite data for self-location and azimuth estimation. An inertial measurement unit (IMU) is also installed to calculate traction torque distribution according to the slope gradient and other factors, ensuring stable autonomous driving with little path deviation. The mower is also equipped with obstacle detection sensors, and is designed to pause, reroute, or perform other necessary actions to continue mowing once an obstacle is detected.

(2) Setting the driving accuracy

We collected driving data from professional gardeners while mowing to set the target driving accuracy for autonomous mowers.

Fig. 6 shows the driving track of a ride-on mower during mowing. The figure illustrates that the mower

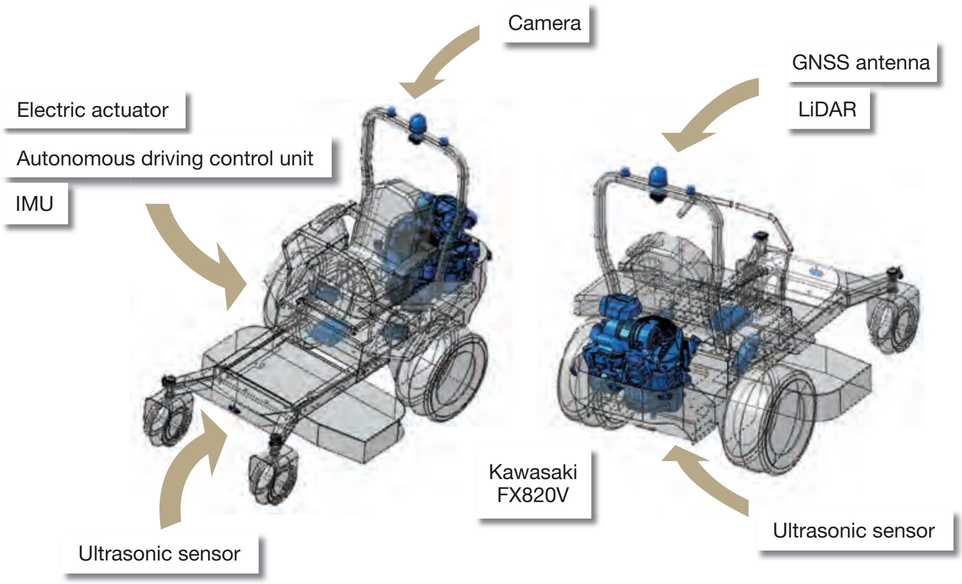
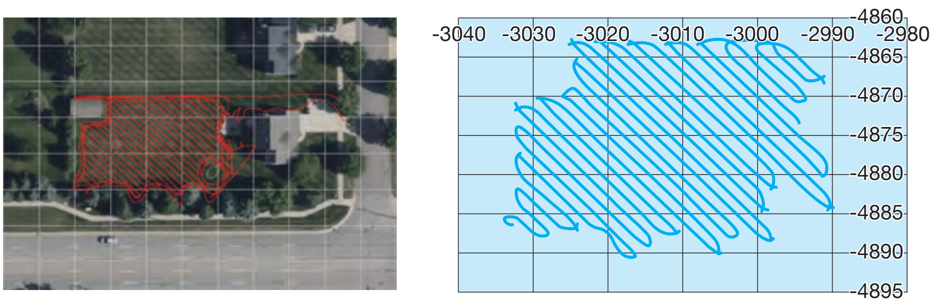


Fig. 5 Illustrated overview of the autonomous lawn mower



(a) Mower driving log

(b) GNSS coordinate data

Fig. 6 Logging manual driving data

thoroughly mowed the lawn by moving back and forth across the work area, repeatedly traveling from one end to the other. Stability during forward movement is crucial for achieving a beautifully finished lawn. Additionally, the mower must turn with a small turning radius of about 1.5 m to travel back and forth from one end to the other.

We set the mower's speed and tolerance for straight forward movement during autonomous driving based on manual driving to achieve a mowing accuracy and working speed equal to or higher than manual driving.

(3) Test drive

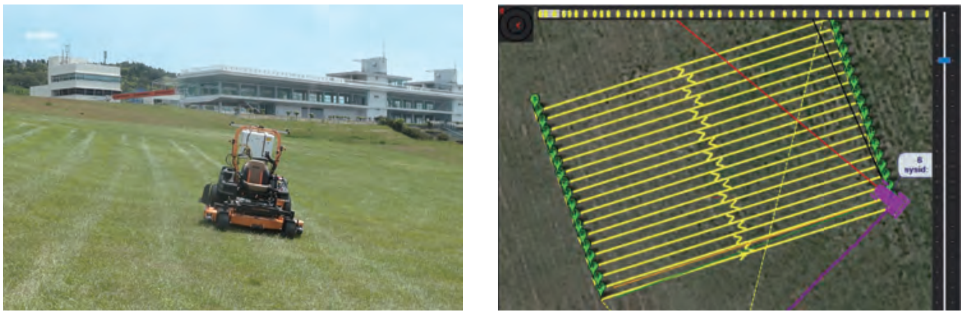
Figure 7 shows the autonomous lawn mower during a test drive. We conducted autonomous driving based on the same path plan as an actual mowing job on a lawn area to verify stability during straight forward movement, followability at the target mower's speed, stability on slopes, behavior during turn arounds, and operation in environments with obstacles.

5 Efforts to further enhance added value

(1) Synergy effects achieved through combination with our own engine

We are also working to enhance added value by integrating the autonomous system with our engine.

An autonomous system using our engine has a significant advantage: it can inherently utilize information from the engine control unit (ECU). For example, we believe that the fuel consumption rate during mowing can be calculated to set appropriate mowing prices, and the engine speed can be controlled to reduce work noise depending on the mowing environment. We are also



(a) Autonomous test drive (b) Mowing path plan

Fig. 7 View of the autonomous lawn mower during a test drive

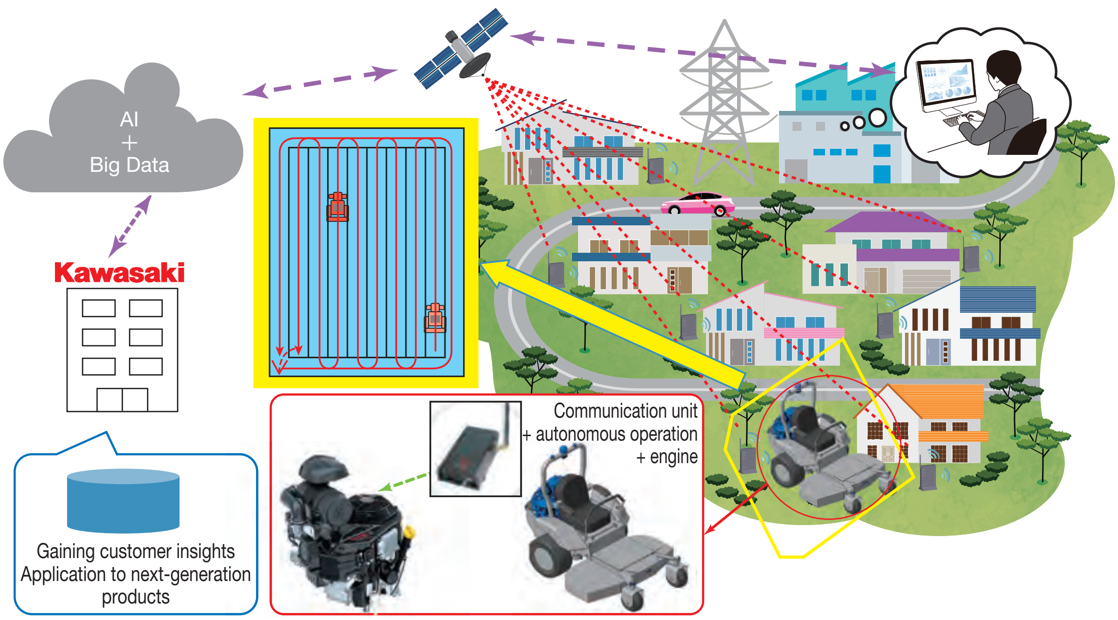


Fig. 8 Potential added value with our engine

Fig. 9 Beautiful lawn mowing patterns

considering incorporating a communication unit that supports external communication into our engine in the future, as shown in **Fig. 8**. This would allow us to consolidate operating data during autonomous driving in our cloud server, leveraging the data for business operations such as providing feedback for the development of next-generation products.

(2) Achieving well-designed lawn mowing patterns

Customers often request professional gardeners to create beautiful mowing patterns, as shown in **Fig. 9**. Creating these patterns requires tasks such as following complicated paths and varying the cutting height depending on position. In other words, it requires high skill levels to complete these patterns with manual driving.

In contrast, autonomous mowers can follow complicated paths if these are set in advance, allowing landscapers to create beautiful lawn mowing patterns easily and efficiently. Therefore, we are also developing key technologies to provide benefits to professional gardeners who adopt autonomous mowers.

Conclusion

We are developing autonomous technology for ride-on mowers to address chronic labor shortages in North America's landscaping industry. We will continue to focus on high-value development with the goal of maintaining our leading engine supply share in the commercial market.

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Connected Vehicles Delivering New Levels of Fun!

Recently, the automotive industry has experienced a surge in the development of CASE-focused products and services, leading to a rapid increase in connected vehicles. Amid this trend, we have been developing a "connected" app that integrates our flagship product, motorcycles, with smartphones.

The second generation of this app enhances bidirectional communication through our cloud service. This not only delivers new value to our customers but also facilitates product improvements and the introduction of new services through big data analysis and utilization.

Introduction

Recently, the automotive industry has experienced a surge in the development of CASE (Connected, Autonomous, Share & Service, and Electric)-focused products and services.

In the field of connectivity, a component of CASE, connected vehicles functioning as ICT (information and communication technology) devices are rapidly becoming widespread as ICT evolves. Connected vehicles provide unprecedented value and services through ICT.

1 RIDEOLOGY THE APP MOTORCYCLE

As companies in the motorcycle industry provide many different services, Kawasaki Motors has also researched and developed RIDEOLOGY THE APP MOTORCYCLE since 2017. This smartphone app connects to motorcycles via Bluetooth and is designed to help customers feel the enjoyment that can only be experienced through riding motorcycles and to provide new value.

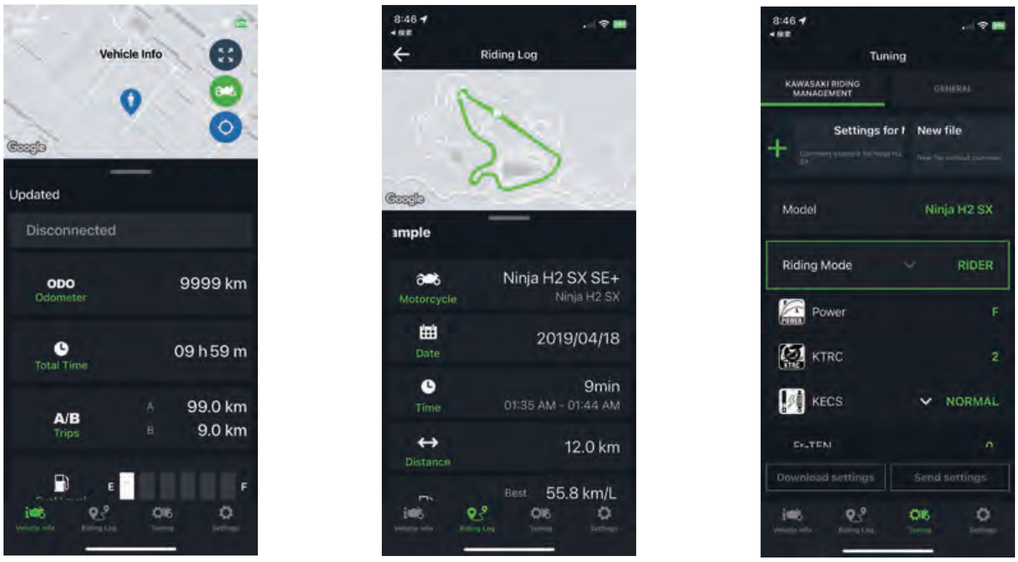
2 Development policy for the second-generation app

The first-generation app (**Fig. 1**) was launched in 2019 to enhance convenience and customer experience, and offers the following functions by connecting motorcycles with smartphones.

・Vehicle information (**Fig. 1 (b)**)

This is a function for viewing information such as remaining fuel amount and battery voltage when the

(a) Wireless communication interface



(b) Vehicle information (c) Riding log (d) Vehicle settings

Fig. 1 Features of 1st-generation app

engine is stopped (IG-OFF). This function can be leveraged to plan fueling on the next ride or to review data during maintenance.

- Riding log (**Fig. 1 (c)**)

  This is a function to display overview information on any riding section such as riding distance, time, and fuel efficiency, and show sensor values such as riding speed and gear information in graph form. This function can be leveraged to analyze your ride on a race track, etc.

- Vehicle settings (**Fig. 1 (d)**)

  This is a function to operate and configure various settings that determine the feeling of the ride, including vehicle riding modes (such as normal mode, sports mode, or rain mode) from the app. You can effortlessly configure the settings without the hassle of cumbersome switch operations.

The second-generation app (**Fig. 2**) launched in 2021 offers the following new functions that create more opportunities for riders or people with similar hobbies to meet.

- Sharing riding logs (**Fig. 2 (c)**)

  This is a function to share the above-mentioned riding logs with others. Users can benefit from others' logs when planning a motorcycle tour.

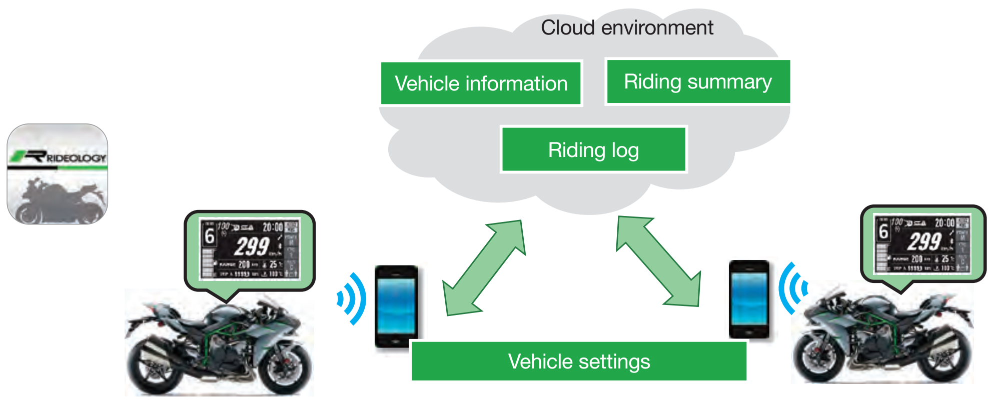
- RIDEOLOGY SCORE (**Fig. 2 (d)**)

  This is a function to indicate the fun levels of the ride in riding logs.

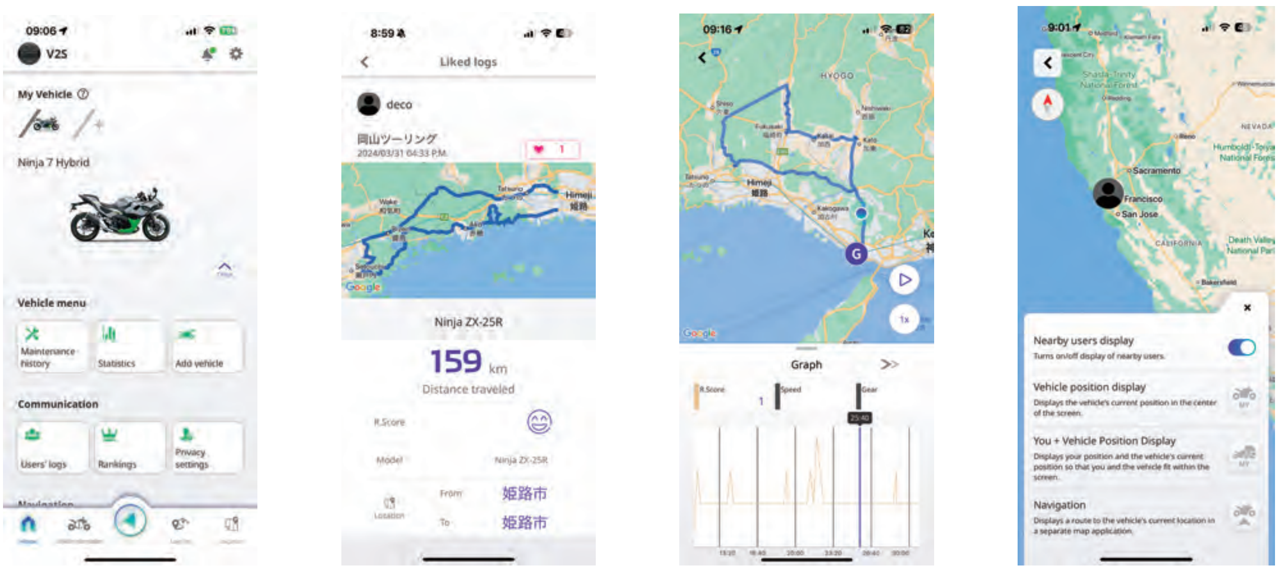
- Sharing the current location (**Fig. 2 (e)**)

  This function can be leveraged to send your current location to app users to invite them to join the ride.

Many functions of the second-generation app serve users by connecting them via the Internet. We also



(a) Wireless communication interface



(b) Home screen (c) Sharing riding logs (d) RIDEOLOGY SCORE (e) Sharing the current location

Fig. 2 Features of 2nd-generation app

focused on the benefits that arise from connecting us as the app provider and users. The benefits include identifying how the app and vehicle are used based on data obtained via the Internet, which can be utilized for future vehicle development, and immediately detecting functional defects.

3 Technical challenges

(1) Development of the app and cloud environment

(i) Creation of a cloud environment mechanism

Building the system requires not only a means of communication using the Internet but also a server to accumulate and calculate riding logs and other data. Users must select an on-premise environment to internally manage and operate the server or a cloud environment that simplifies management. Because we assumed international deployment and anticipated that the number of users would increase year by year, we decided to introduce a cloud environment. Doing so takes into account a system that has flexibly adjustable hardware specifications and can operate continuously for 24 hours a day. One technical challenge in building a cloud environment is establishing a mechanism to efficiently develop and operate the system with limited development resources.

(ii) Shorter response time

Because riding logs will be stored in the cloud environment, we need a system configuration with security measures to protect personal data that minimizes

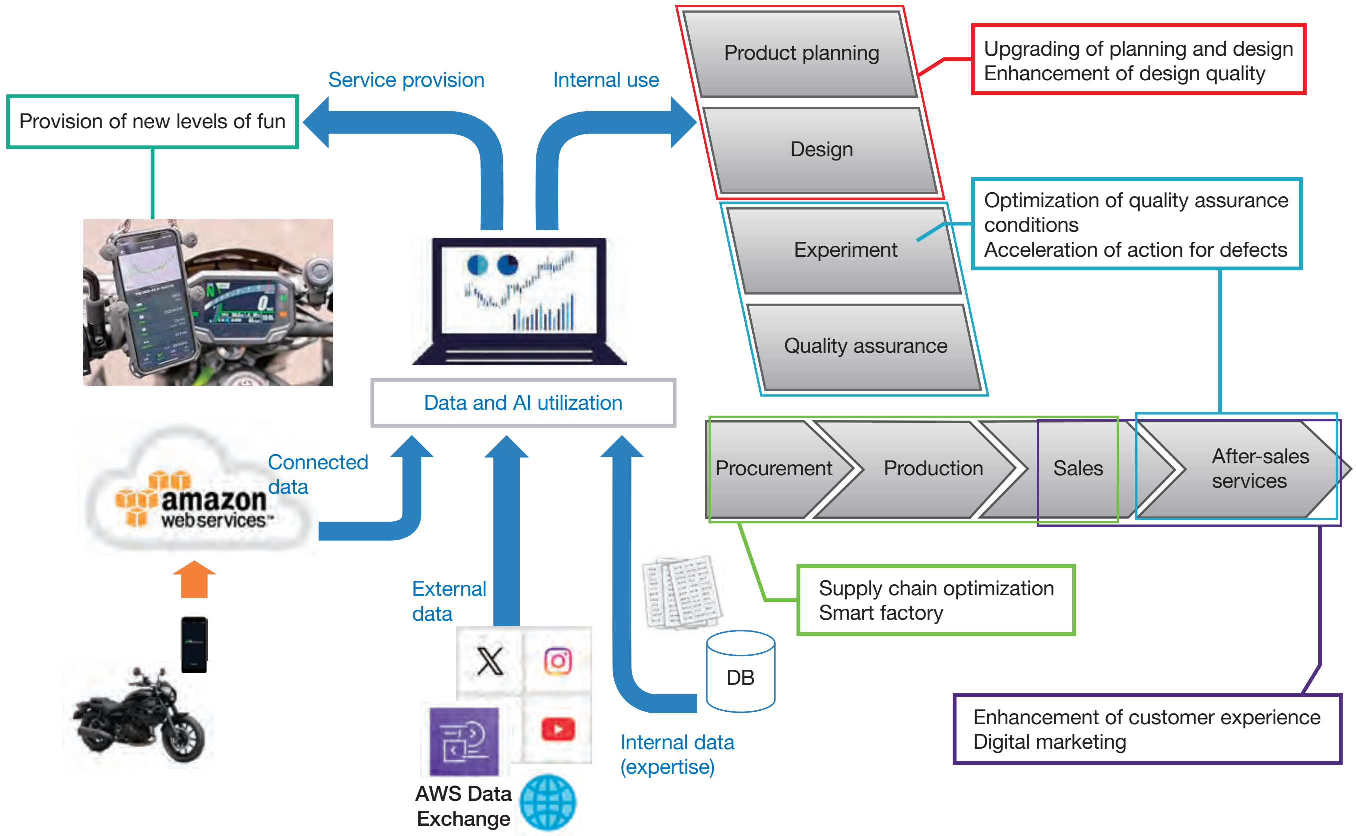


Fig. 3 Image of big data utilization

response delay due to communication between smartphones and the cloud.

(iii) Visualization of riding log sharing

Sharing riding logs means making riding data such as vehicle speed and fuel efficiency information available to the public. Because disclosing this numerical information to other users may encourage dangerous riding, we had to consider an alternative way of sharing riding logs with some visual information in place of numerical information.

(2) Data analysis and utilization

Components of motorcycles frequently exchange various data via CAN communication. We analyze this data during the vehicle development stage and use it for evaluation and improvement. In contrast, the circumstances of vehicles in the market largely depend on riders, riding environment, and other factors, which are very difficult to accurately identify and apply in the development phase. At present, information that can be collected from the market is limited to findings from user feedback sessions at the planning stage, defect information from dealers, and other sources.

We will leverage the “connected” app to overcome these challenges by collecting more accurate data, such as vehicle data and route information, on the cloud. Analyzing and leveraging this big data is expected to improve our products, enhance the quality of after-sales services, contribute to marketing, and promote the provision of new services as shown in **Fig. 3**.

A technical challenge here is the need to properly process and adjust a vast amount of data that will eventually be frequently sent every day from several hundred thousand vehicles around the planet and accumulate it in a secure but easily available method.

4 Initiatives to overcome the technological challenges

(1) Development of the app and cloud

(i) Creation of a cloud environment mechanism

To reduce the time taken to develop the app and cloud environment, we adopted Amazon Web Service (AWS) and the configuration shown in **Fig. 4**. AWS enables us to build the system by combining small-scale functions called microservices. We emphasized early defect detection during development and operation, performance

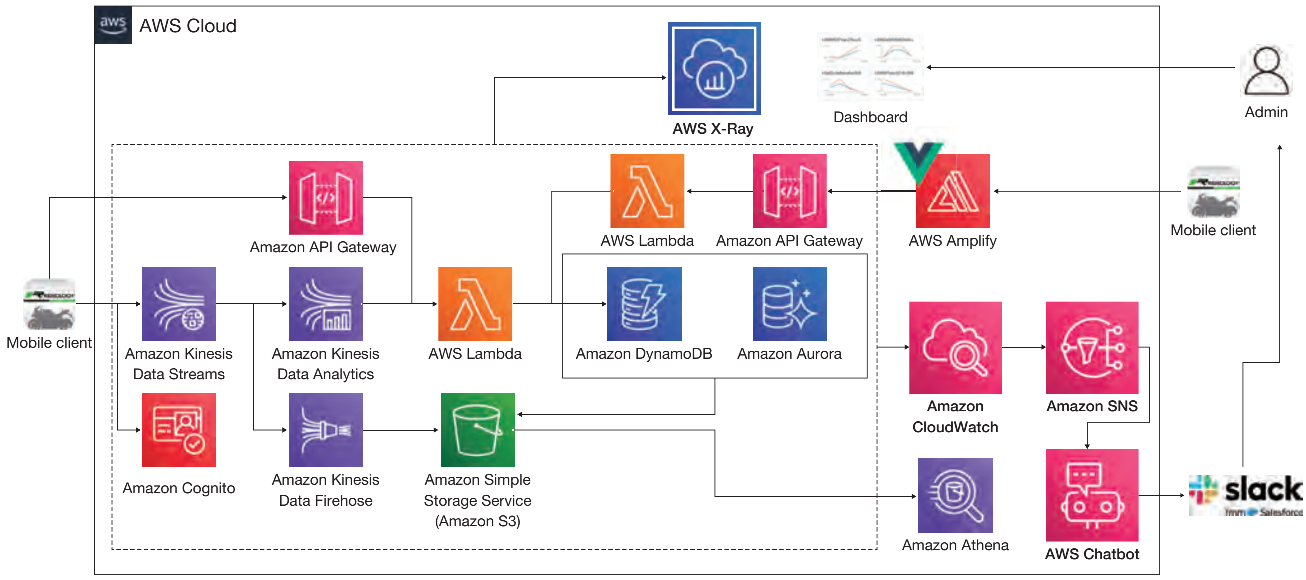


Fig. 4 AWS architecture diagram

Fig. 5 3D animation

Fig. 6 Business intelligence dashboard

monitoring, and other aspects, and introduced the following services.

- Amazon SNS and Amazon Chatbot

  These services form a mechanism to send arbitrary notices by microservice, including error information, to major social media services.

- AWS X-ray

  This service make it easy to locate performance bottlenecks and the root causes of errors across microservices.

- Amazon CloudWatch

  This standard log monitoring service in AWS enables you to create necessary dashboards.

(ii) Reduction in response time

The adoption of Amazon Kinesis Data Analytics made it possible to start continuously sending vehicle information as soon as the collection of riding logs starts, and to save and analyze them in real time. This service is enjoyable because users can view results in logs shortly after data collection ends.

(iii) Visualization of riding log sharing

To make riding log information available to the public, we adopted 3D animation as shown in **Fig. 5**, enabling users to visually enjoy viewing their riding status while avoiding showing vehicle speed and other numerical data.

(2) Data analysis and use

We adopted an architecture to store data in Amazon S3 via Amazon Kinesis, mentioned in the previous section, to stably and securely collect, process, and accumulate a huge amount of data sent at high frequency from several hundred thousand motorcycles. In addition, we separated the data analysis infrastructure above the app backend system to facilitate authority management and set a rule to avoid bringing sensitive data, including personal data in the data analysis infrastructure, to promote internal data utilization. This ensures security.

Regarding the data analysis infrastructure, data sent from the app through the backend system is processed to be visualized on BI dashboards according to usage as shown in **Fig. 6**. We have also leveraged AWS services to automatically extract, convert, and store data to reduce data processing work required for the app to operate.

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Conclusion

Over 100,000 motorcycles are now connected to our second-generation app for motorcycles, which was launched three years ago. We have continued to further improve quality and include new functions to satisfy customers' requests and expectations. We also launched a new app for off-road four-wheelers in June 2024, and plan to gradually support new models and expand this service to other products.

Future work will involve creating and providing new value with not only products but also connected services by supporting always-on connection, which is commonly used in passenger cars.

Developing a Flexible Production System: Transforming the Vehicle Production Process

The US market for off-road vehicles is projected to experience steady growth, and our Group Vision 2030 anticipates a sales increase of 20% to 50% for motorcycles and 40% to 60% for off-road vehicles. To implement this growth strategy and achieve our Group Vision, we are driving the reform of our production processes related to vehicle assembly. The aim of this transformation is to be flexible enough to adapt to customer demand while minimizing costs and maximizing productivity.

Introduction

The market environment around Kawasaki Motors is projected to experience steady growth due to the growth of the off-road four-wheel vehicle market in North America, a recent sales increase of supersport motorcycles, and other factors.

1 Background

To achieve our Group Vision 2030 and subsequent sustainable growth, we aim to develop into a company that surpasses competitors in the global market by continuing to promptly supply products to customers in order to ensure reliable income.

Essential to attaining this goal is developing a flexible production that can adapt to customer demand, while also reducing production costs at each production base and pursuing efficient production.

We believe that the role of the Akashi Works is to pioneer the promotion of DX as the true mother factory for each production base, and to lead other factories in developing production technologies and reforming production processes. Of the production processes at the Akashi Works, we selected the vehicle assembly, parts management, and parts transport processes, which are end-product production processes, as the initial targets, and started factory visualization that leverages digital technologies and enables us to reform production processes based on the visualization.

2 Challenges and action policies

The production processes related to vehicle assembly present the following challenges.

(1) Vehicle assembly line

The vehicle assembly process not only determines the final quality of products but also must flexibly deal with disturbances such as changes in market demand and issues related to parts supply. This is an important process in smoothly conducting all production activities, including those on the parts production line, which comprise casting, machining, welding, painting, and other steps. For the vehicle assembly process to play this important role, we must be able to quickly reorganize our production lines even in irregular circumstances to achieve the production plan.

Currently, each vehicle assembly line can only produce predetermined models. As a result, several months are required to implement a line shift for all manufacturing processes when items are produced in parallel with other lines to increase production or when problems occur on other lines. The same applies when shifting production to another line if one line has problems. This is partly because there is not enough room along the lineside space full of parts racks to put in parts racks for an additional model. Another reason is that rewiring work is required to add or reposition parts racks due to the part poka-yoke (fool-proofing) system installed for each part to prevent assembly errors.

To solve these problems, we are considering discontinuing the parts racks and poka-yoke system along the lineside by synchronizing the parts supply so that only those parts required at a given moment are supplied to the line as production progresses (**Fig. 1**).

(2) Parts management process

We must store parts currently kept along the lineside somewhere else so that only those parts required at a given moment are supplied to the line as production progresses. In addition, the globalization of our supply chain has increased the number of imported parts, which, in turn, has increased the frequency of carrying parts from third-party warehouses dedicated to imported parts into the Akashi Works. We have also experienced other incidents such as the suspension of just-in-time (JIT) supply due to contingencies at domestic part suppliers. Under these circumstances, we need a radical transformation of the parts management method to build the following:

- An environment to centrally manage domestically and internationally procured parts at the Akashi Works' parts warehouse
- An environment to only supply parts from the parts warehouse to the production line at the moment they are needed.

(3) Parts transport process

Turret trucks and bicycles are used to transport parts on the Akashi Works premises, and trucks are used between factories. In both cases, humans are involved in transport.

However, the recently shrinking workforce resulting from the falling birthrate and the aging population is making it increasingly difficult to secure enough people to do the work. This is likely to disrupt production activities in proportion to the number of processes that require human intervention.

Therefore, we must prioritize coming up with methods that do not need human resources for processes where added value is not created, such as carrying tasks.

3 Current progress

We are working to solve the problems in the production processes related to vehicle assembly as follows.

(1) Production-synchronized parts supply system

To supply parts in synchrony with the progress of the assembly line and discontinue the parts racks equipped with the parts poka-yoke system, we will develop an automated delivery system (ADS) that calculates which parts are needed and when as products move along he assembly line.

The ADS will be designed to obtain progress information about each product on the assembly line

Fig. 1　Lineside parts racks and the poka-yoke system

based on BOM information, which is necessary part information by model, and assembly order information by vehicle assembly line.

The ADS creates the following instructions as shown in **Fig. 2**.

- Instructions to the warehouse to pick parts in synchrony with the progress of production
- Instructions to transport picked parts to the lineside

These instructions are linked with each parts warehouse management and automatic parts transport function described later. In response to them, parts needed for each assembly section are prepared on a dolly to be supplied to the lineside at an appropriate time.

(2) Warehouse management

To establish a parts supply system as shown in **Fig. 2**, we will build a new parts warehouse at the Akashi Works and create an environment to manage every part in bulk.

For parts management at the warehouse, we will adopt a free location method with which storage locations change fluidly to efficiently manage several tens of thousands of parts in a limited space. Furthermore, we will introduce a warehouse management system (WMS) to manage all processes from parts warehousing through delivery in it. Regarding delivery instructions for parts, the above-mentioned ADS outputs parts picking instructions for each dolly cyclically in a timely fashion and links them to manage a series of processes.

We are also eying the use of an automated multistory warehouse that makes effective use of the vertical direction and considering its introduction, taking the cost versus the benefits into account, to reduce the size and workload of the parts warehouse.

(3) Automated parts transport system in the factory

We investigated transport vehicles and systems from each manufacturer commercially available in the market to automate parts transport, and found that systems suitable for the environment and use at the Akashi Works are limited and expensive. Therefore, we decided to develop an autonomous mobile robot (AMR) in house that employs autonomous traveling technology. This is a state-of-the-art technology in the logistics industry.

(i) Autonomous traveling technology

Figure 3 shows the appearance of the in-house AMR and **Table 1** lists its specifications. The autonomous traveling mechanism employs the simultaneous localization and mapping (SLAM) method. With this method, the AMR travels, collating distance data positioned using its LiDARs against environmental data prepared in advance to estimate self-location. Moreover, this method is combined with the odometry technology to feed back the travel distance of the AMR calculated from the number of wheel rotations, and for advanced self-location estimation the nine-axis IMU sensor is used to correct the traveling posture and minute slips.

(ii) Flexible travel route setting

All AMR settings, such as travel routes, stop points, and travel rules, are configured in software. **Figure 4** shows map data and travel routes created on a vehicle assembly line. The motor, as well as the front and rear wheels and related components, are combined into the

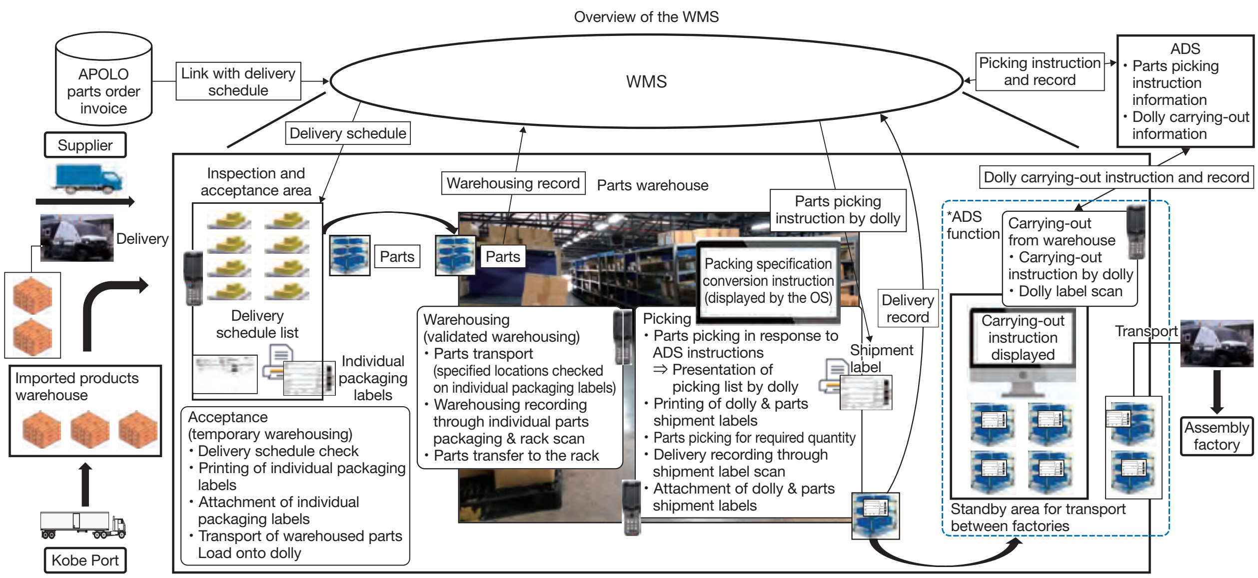

Fig. 2 Overview of the WMS and its peripheral systems

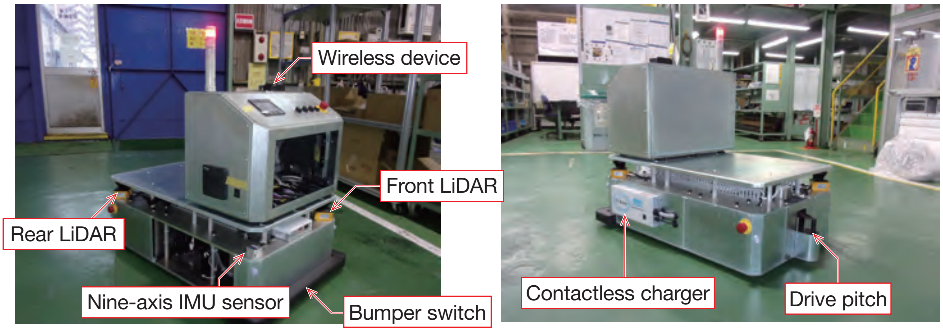

Fig. 3 Appearance of the AMR developed in-house

Table 1 Specifications of the AMR

Vehicle size [mm]		D1, 200×W750×H1, 130
Weight [kg]		200
Drive system		Differential two-wheel drive
Rated speed [km/h]		4. 7
Drive weight [kg]		300
Stopping accuracy	Distance [±mm]	10
	Angle [±°]	1
Battery capacity [Ah]		23
Charging method		Contactless quick charging
Charging current [A]		30

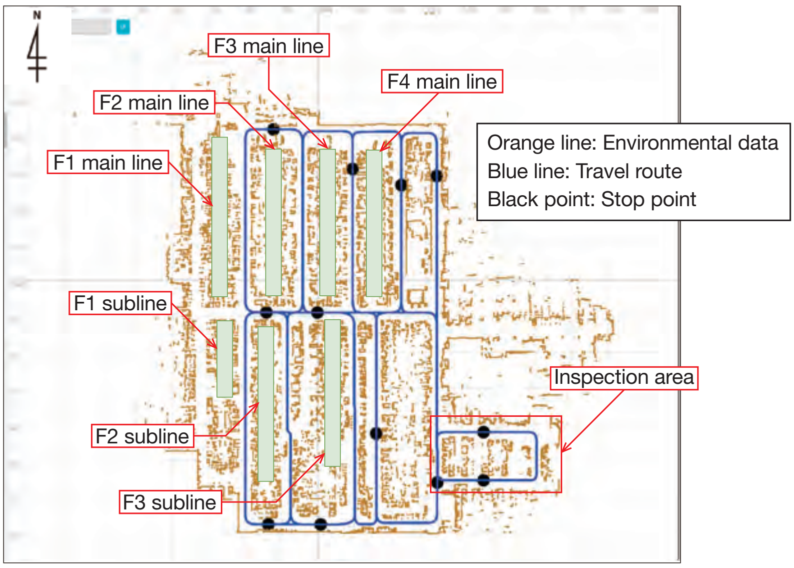

Fig. 4 Map data and travel route

frame on the sublines in the figure. These sublines are connected to the main lines across passages. On the main lines, peripheral components are assembled onto the body to finish the vehicle. First, the AMR is manually operated to obtain wall and column information as 2D point-cloud data. The obtained information is then edited to create map data. Afterward, travel routes, stop points, and other details are set. Because you can also divide and create map data, the map for even a vast area is easy to create and edit. Likewise, you can flexibly and immediately address changes in the internal layout, travel routes, and stop locations.

(iii) Coexistence with people and goods

When traveling toward people or goods, the AMR can avoid these obstacles without requiring guides installed on the floor. The AGV, whose travel route is determined, must stop if there are obstacles. In contrast, the AMR we developed here can avoid obstacles while traveling. This function is indispensable for delivering parts when needed.

(iv) Link with the host system

We developed a group control system for the AMR to link multiple AMRs with the ADS. The group control system properly allocates each AMR and gives transport instructions based on information from the ADS. The group control management screen can be used to monitor the travel positions, device status, and transport status of each AMR, obtain logs in case of problems, and provide feedback such as transport records.

(v) Safety function

The developed AMR has its safety function standardized according to JIS D 6802[1)], the Japanese standard for the safety of unmanned transport systems. A safety system controller is prepared in a system separate from the travel controller and PLC to configure a circuit that immediately stops travel if the safety system is activated. The system consists of an emergency stop button, a bumper switch to detect collisions by the AMR, a laser scanner that creates a protected area around the AMR, as well as a virtual bumper that varies its area depending on the speed, curves, and other conditions. Safety certification has been obtained for all of these devices.

(4) Automated inter-factory parts transport system

Parts picked in a parts warehouse in response to ADS instructions are automatically transported between factories using the multi-use unmanned ground vehicle (MUGV) (**Fig. 5**).

Fig. 5 Appearance of the MUGV

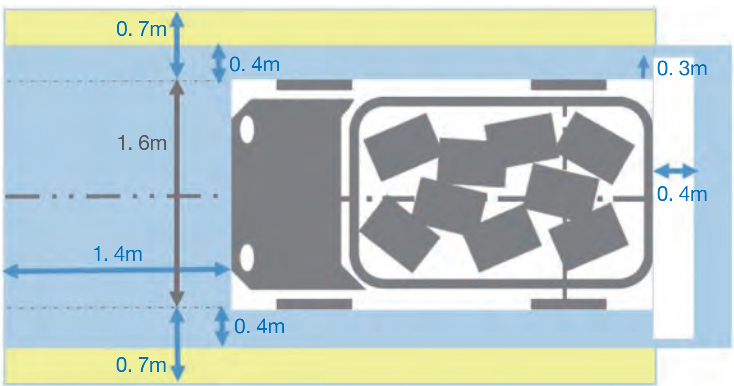

Fig. 6 Surrounding detection range

The MUGV is an automated parts transport vehicle used between factories (outdoors). This vehicle can also be operated by a driver. Autonomous operation requires the travel controller to automatically control speed, steering, and other factors in response to manual input of operations from the steering wheel, accelerator, brakes, or other device, and the autonomous controller to identify the current vehicle position and surrounding obstacles from data obtained with LiDAR sensors and control autonomous travel on determined travel routes. We prioritize safety during operation by requesting risk assessment from an insurance company, considering autonomous control specifications, and incorporating a safety system, particularly when developing the autonomous controller, so that unmanned vehicles can safely travel in factories where pedestrians, bicycles, trucks, and other delivery vehicles move back and forth in a complex manner. Although its autonomous travel method is basically the same as the AMR's, the MUGV conducts more advanced self-location estimation and environment identification using 3D LiDAR sensors and map data to which information on speed limits, crossings, intersections and other elements is added.

The autonomous controller software is Autoware, an open-source autonomous traveling OS. We repeatedly verified its operation and implemented the following functions to address obstacles during travel.

① Function to detect obstacles in front of the vehicle and follow them or stop

The MUGV can slow down and stop 5 m in front of obstacles. If obstacles move, the vehicle can follow them, maintaining a distance of at least 4 m.

② Function to detect obstacles to the right or left of or behind the vehicle

The MUGV can also detect obstacles around it and slow down or stop, as shown in **Fig. 6.** (The MUGV slows down in the yellow areas and stops in the blue area.)

③ Operation with moving object prediction

The MUGV can predict the movement of moving objects at crossings and intersections using AI, and decide whether to continue operation, slow down, stop, or perform other operations based on the prediction.

Conclusion

We will contribute to implementing the growth strategy in our Group Vision 2030 by refining vehicle assembly production processes at actual production sites. We will also lead other bases as the true mother factory and pursue lower production costs and higher production efficiency for the whole group to secure reliable profits and help the company surpasses competitors in the global market.

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1) JIS D 6802:2022 Automatic guided vehicles and systems − Safety requirements and verification

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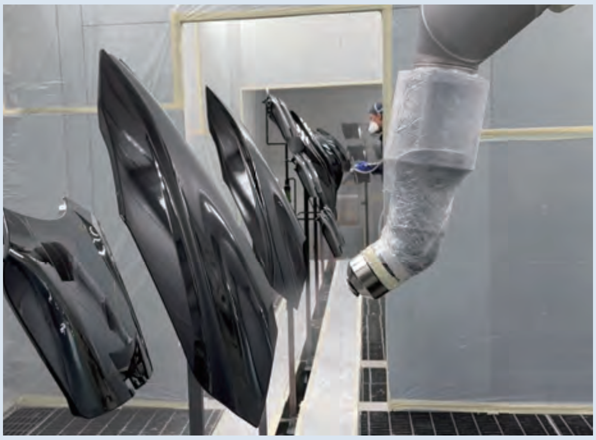
Innovative Coating Technology to Reduce Environmental Impact



The Kawasaki Heavy Industries Group is committed to achieving carbon neutrality, targeting Scope 1 and 2 emissions by 2030 and Scope 3 by 2040. Given the significant CO_2 emissions from our coating processes during product manufacture and the production and logistics of coatings, minimizing coating waste is essential. To achieve this objective as part of our efforts to reduce our environmental impact, we have developed an innovative coating technology. This includes a two-pack coating machine that is easy to clean and a virtual reality system that simplifies the teaching of complex operations to painting robots for highly efficient coating.

Introduction

Many types of energy, including water, steam, mains gas, and electricity, are used for production in the coating division. Reducing the consumption of these energy sources important for achieving carbon neutrality. Moreover, reducing the consumption of coatings used in the coating division is also a critical effort toward carbon neutrality with an eye to the overall lifecycle, including the production and logistics of coatings. As the Kawasaki Heavy Industries Group is committed to achieving carbon neutrality, targeting Scope 1 and 2 emissions by 2030 and Scope 3 by 2040, we aim to reduce coating waste.

1 Problems with the coating process

Disposal loss from coating is largely broken down into two types as shown in **Fig. 1**. The first loss is the disposal of blended coatings. Two-pack curable coatings are used for the resin cowlings and fuel tanks of motorcycles. This type of coating is designed to blend the base coat and the hardener, and cure the mixture in a low-temperature drying oven. The disadvantage is that curing the reaction progresses even at room temperature. This disadvantage means that large amounts of coating are disposed of every day in the coating division, which must change coating colors about 20 times a day. The second loss is the

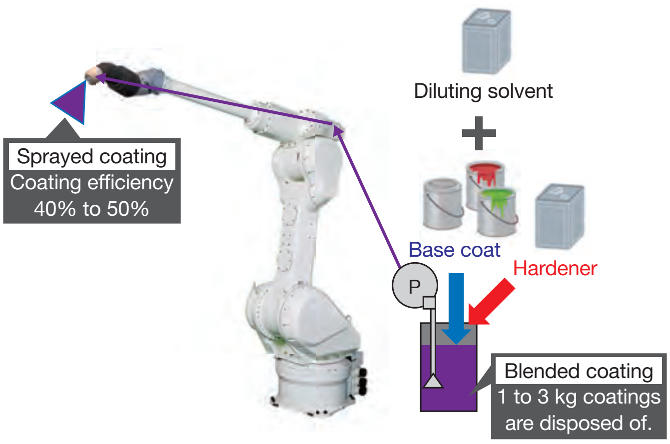


Fig. 1 Waste from a coating process

disposal of sprayed coatings. Coating efficiency, which indicates how much of the coating sprayed from the coating machine adheres to the object to be coated, is about 40% to 50% for electrostatic coating with a painting robot and as low as around 10% for manual non-electrostatic coating. Coating materials that do not adhere to a target surface are disposed of without going through any process.

2 Development of a two-pack coating machine to reduce coating waste

Once blended, two-pack curable coatings cannot be used on the following day even if some of them remain unused. Daily washing and disposal are required, so in general, two-pack coating machines are used. However, businesses such as Kawasaki Motors that handle various coatings find it difficult to ensure stable coating quality with conventional two-pack coating machines.

(1) Problems with conventional two-pack coating machines

(i) Problem of washability

Figure 2 shows a sectional view of an electrostatic rotary atomization bell, which is a conventional two-pack coating machine. The paint feed tube in the diagram supplies a coating and the bell cup that rotates at high speed atomizes it. The base coat and the hardener go through the static mixer shown in **Fig. 3**, which is built into the coating machine's paint feed tube, where they are blended and churned. However, because it has multiple blades of complicated shape, the static mixer is difficult to wash, which leads to a higher probability of coating defects due to an increase in the consumption of cleaning solvent and accumulation of coating residues that result from insufficient washing.

(ii) Problem of blendability

Figure 4 shows the feeding paths for the base coat and hardener. The base coat path connects to the

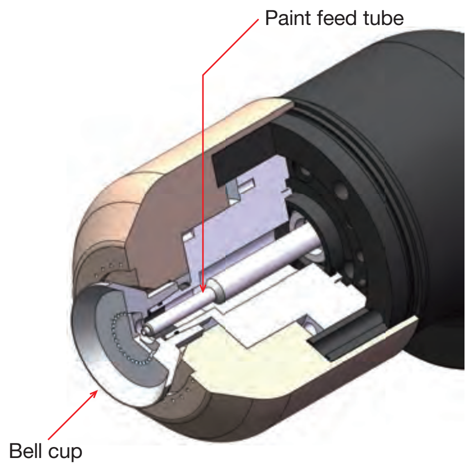


Fig. 2 Section of an electrostatic rotary atomization bell

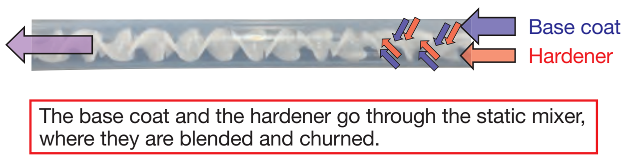


Fig. 3 Built-in static mixer in a coating machine

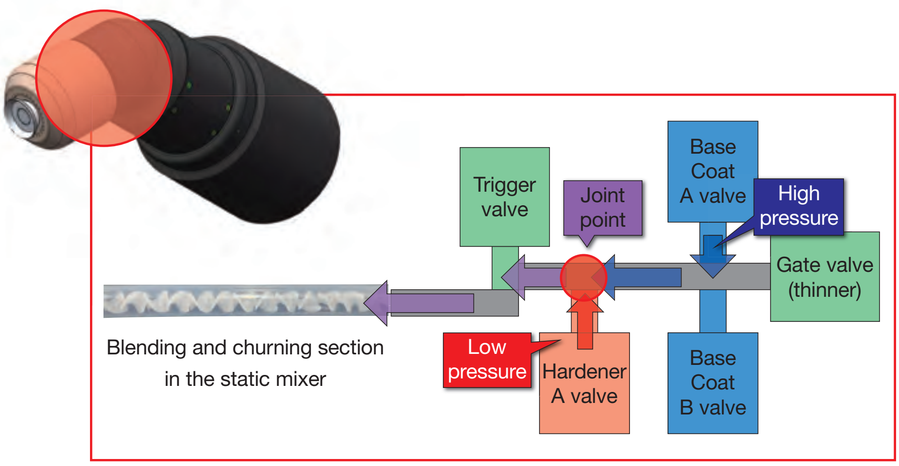


Fig. 4 Feeding paths for the base coat and hardener inside a coating machine

hardener path midway. As long as the supply pressures of the base coat and the hardener are comparable, no problem occurs. However, if the hardener's supply pressure drops it cannot be added, causing insufficient curing.This does not cause a problem as long as the ratio of base coat to hardener is fixed to 3:1 like they are for coatings in the automobile industry. However, the coatings we work with have varying base coat-to-hardener ratios, ranging from 3:1 to 11:1. Especially when the hardener ratio is small, supplying a tiny amount of hardener and keeping a constant supply pressure is difficult, so insufficient curing can happen.

(2) Development of a coating machine that blends two-pack at the tip

We overcame conventional problems by developing a new two-pack coating machine with an innovative blending function based on an unprecedented hydrodynamic idea.

The interior of the electrostatic rotary atomization bell contains a paint feed tube that has a double-tube structure. A coating is supplied to the central section and a cleaning solvent is supplied to the outer part. **Figure 5** shows the paint feed tube Kawasaki Motors developed through focusing on this double tube structure. This paint feed tube has a simple structure, with the tapered nozzle cap fitted onto double tubes. We anticipated that, in this structure, the hardener input through the central section of the double tube and the base coat input through the outer section would merge in the nozzle cap, with the sectional area of the nozzle cap gradually decreasing. This would accelerate the flow speed and mutually blend the base coat and the hardener.

To validate this structure, we carried out two patterns of computational fluid dynamics (CFD) analysis. In verification 1, the hardener and the base coat were input through the central section and outer section of the paint feed tube with the double tube structure, respectively. In verification 2, we attached the nozzle cap to the tip of the paint feed tube under the same conditions as verification 1. The analysis result is shown in **Fig. 6**. Red, blue, and white indicate hardener, base coat, and good blended state, respectively. The base coat and hardener began to blend when they hit the rapidly rotating bell cup in verification 1 as shown in **Fig. 6(a)**. In verification 2, blending started inside the nozzle, and the base coat and hardener sufficiently blended at the nozzle outlet as shown in **Fig. 6(b)**. This result suggests that a shear force occurs due to the flow speed difference at the interface between the base coat and the hardener and that the nozzle further accelerates the flow to promote blending.

We jointly developed a coating machine with a coating machine manufacturer based on this analysis result. **Figure 7** shows a sectional view of the developed coating machine.

This machine is easy to wash because it does not require a static mixer and has an extremely simple structure with a nozzle cap added to the tip of the paint feed tube. This means no risk of coating defects. In addition, because the point where the base coat path and the hardener path merge is inside the nozzle, two-pack with different flow speeds are blended due to their shear force. This means that unlike in the past, their supply pressures do not have to be exactly the same.

(3) Introduction cases

We have defined this coating machine as our Group's global standard coating machine and plan to gradually deploy it to our bases in Japan and overseas. We are already operating this coating machine at our resin coating factories in Japan and Mexico (**Fig. 8**), which is helping to reduce blended coating waste.

In addition, because we jointly developed this coating machine with a coating machine manufacturer, it is now

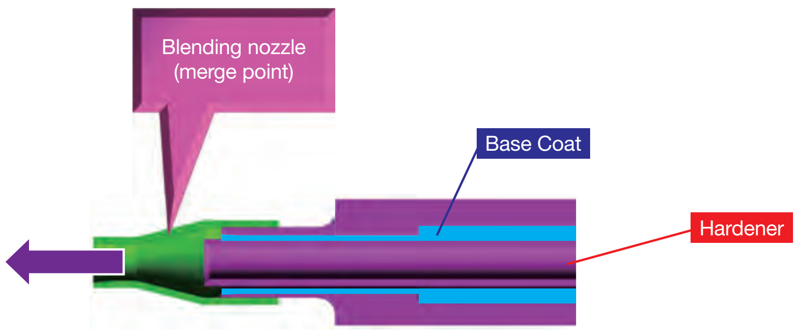


Fig. 5 Paint feed tube developed by Kawasaki Motors

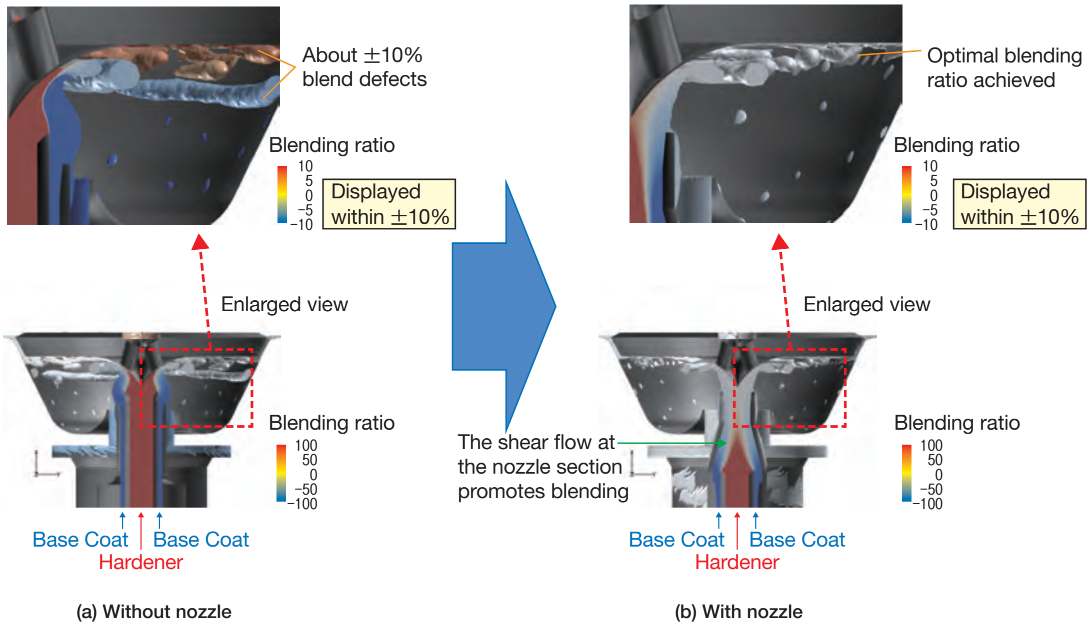


Fig. 6 CFD analysis results

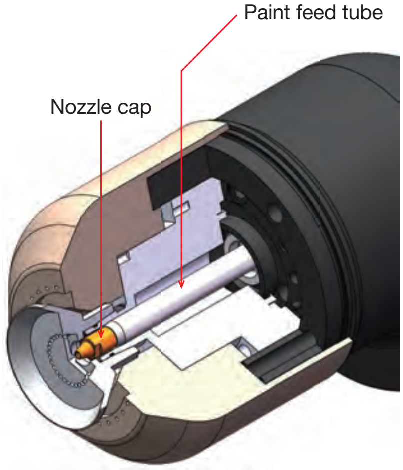


Fig. 7 Section of the coating machine that blends two-pack at the tip

Fig. 8 Installation at a factory in Mexico

also commercially available. This technology will contribute to reducing coating waste across the coating industry and help to create a future of sustainable manufacturing.

3 Teaching a robot to reduce coating waste during coating

(1) Creating of a painting robot teaching program

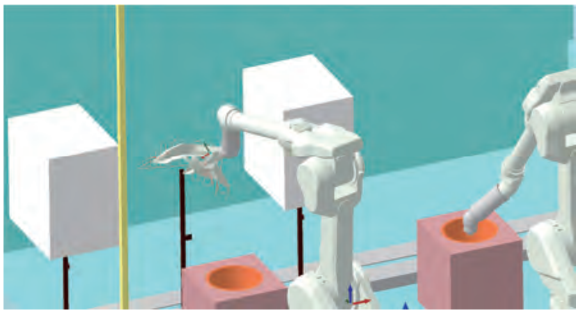
Improving coating efficiency is the most effective way to reduce coating waste during coating. As proximity coating using an electrostatic rotary atomization bell with a high coating efficiency has recently become mainstream, we have also started introducing it. However, for proximity coating with a good coating efficiency the distance between the coating machine and the object to be coated must be 100 mm, which is closer than that in the past by 150 mm. The key is robot movement, because the collision risk rises as the coating machine is placed closer to the object to be coated as shown in **Fig. 9**. Moreover, a large amount of coating adheres to the object to be coated, which may cause the coating to accumulate at the edge of the object to be coated, which could lead to coating failures. Therefore, we had to create a robot teaching program to move the robot along a new track (**Fig. 10**). In other words, robot coating is more important than ever for achieving high-efficient coating, so teaching

(a) Conventional coating

(b) Proximity coating

Fig. 9 Bell-type coating: distance between a coating machine and an object to be coated

(a) Robot teaching using a teach pendant



(b) Robot teaching using OLP

Fig. 10 Method for teaching coating robots

a pain robot requires the programmer to have a high degree of skill.

There are two methods available for teaching the painting robot how to operate the coating machine, as shown in **Fig. 10**. Specifically, you can teach the robot using a teach pendant in the field or offline programming (OLP). If you opt to teach the robot in the field, the workload on production engineers increases because they must work from evening into night after production ends at the factory. In contrast, OLP using a PC enables robot teaching regardless of the production situation in the field but it may take about one day per part. Therefore, we need a new OLP tool to create robot teaching programs easily and efficiently.

(2) Problem of robot teaching using OLP

The OLP environment must be the same as the real-world environment (the positions of the painting robot and object to be coated) to make the most of painting robot teaching programs created using OLP. If there are differences between the OLP environment and the real environment, the robot operating tracks will also differ. In other words, the coating efficiency drops even if a coating machine with a high coating efficiency is used.

We have highly accurate 3D models for parts to be coated, such as resin cowlings and fuel tanks, because we use 3D CAD for product design. However, we lack highly accurate 3D models for coating booths and other equipment partly because they were built based on 2D drawings. Moreover, coating equipment is a large structure that differs from the drawings at the construction stage, making it difficult to create highly accurate 3D models from 2D drawings. Therefore, we scanned actual coating equipment with a LiDAR (light detection and ranging) instrument, built a point cloud model based on the scanned data, compared the built model with a 3D model created based on a 2D drawing, and checked for differences (**Fig. 11**).

(i) Differences regarding the painting robot

Figure 11(a) shows a comparison between the point cloud model and the 3D model. Because the installation position of the base plate for the painting robot differed slightly from that in the drawing when coating equipment was constructed, the painting robot's installation position shifted, changing the relative positions of the coating machine for the painting robot and the object to be coated.

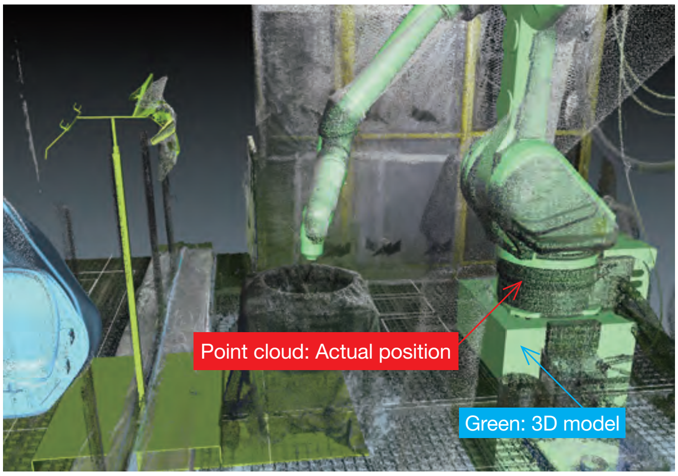
(ii) Difference regarding the coating jig

Figure 11(b) presents a comparison between the point cloud model and the 3D model. Although the coating jig was designed using 3D CAD, the inclination and sag due to its own weight and center of gravity of the object to be coated were not considered. Moreover, the coating jig used in the field had deformed due to aging and become different to that in the 3D model.

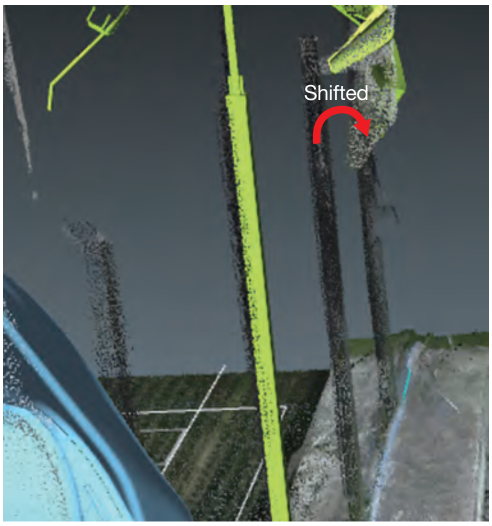
The key to improving the accuracy of the 3D model used during OLP is to build and compare a point cloud model for actual coating equipment. We succeeded in reducing differences from the real environment by correcting the 3D model based on the comparison result. This work enabled us to use the robot teaching program created with OLP without local adjustment on some coating lines, significantly reducing local work time.

(3) Development of the next-generation robot teaching system

We developed a next-generation robot teaching system by leveraging the technology of Successor Wizard (**Fig. 12**). Successor Wizard is a remote robot cooperative system developed by Kawasaki Heavy Industries. This system uses a technology to remotely operate the robot intuitively in line with the user's hand movement by moving a dedicated controller called Wizard in place of the teach pendant when operating the robot. We set a goal of creating robot teaching points with the user's hand



(a) Difference with respect to the painting robot



(b) Difference with respect to the coating jig

Fig. 11 Comparison of point-cloud and 3D models

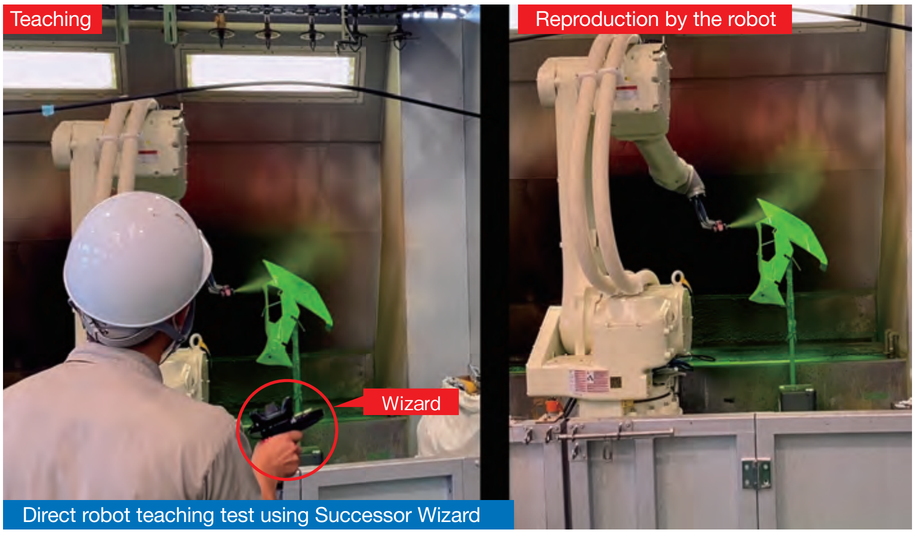


Fig. 12 Successor Wizard

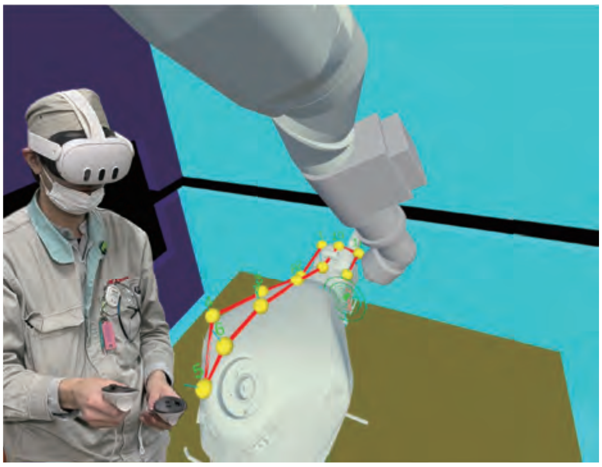
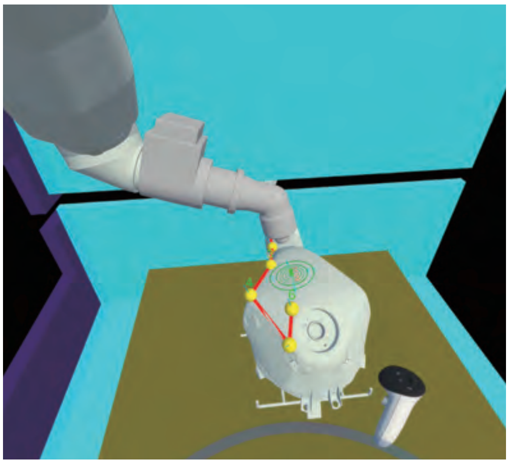


Fig. 13 Selected VR device

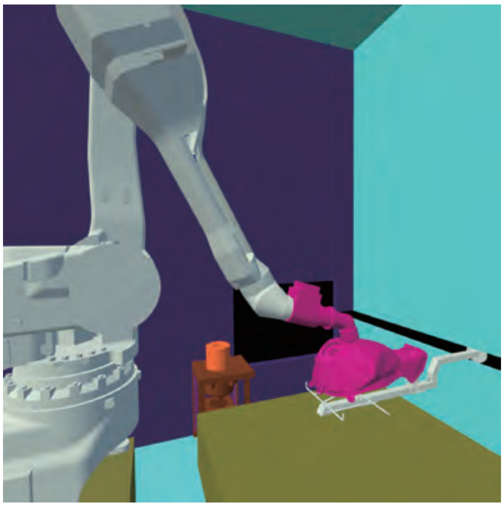
movement and placing teaching points at desired locations accurately and quickly by leveraging the controller tracking technology used in this technology. In addition, by combining this technology with VR technology, you can enter the environment created in OLP as if you are actually teaching a robot.

We selected Meta Quest 3, which has a see-through function, as the VR device used in this system so you can visually confirm the surrounding environment for safety even when you wear VR goggles. A special K-ROSET that supports the VR function is installed in the PC for OLP and is used for operations to replace 3D models. The K-ROSET simulates robot operation with high accuracy. As the controller attached to Meta Quest 3 is used to operate the robot, you can intuitively operate the robot by moving your hand as shown in **Fig. 13**. Furthermore, you can visually display teaching points and tracks in a way that is easy to understand (**Fig. 14(a)**), display the contact between the robot and the object to be coated (**Fig. 14(b)**), and perform other operations as VR-specific visual effects not available through robot teaching in the real world. We are still developing the robot teaching assistance function and plan to upgrade it as needed.

This system has become an OLP that anyone can easily handle because you can work in the 3D model at the same scale as actual factory equipment and intuitively operate the robot with your actions. Our mainly development target at the moment is painting robot teaching work, but in future we aim to apply this system to handling, welding, and other processes.



(a) VR display function (displaying teaching points and track)



(b) VR display function (contact with the robot)

Fig. 14 Example of VR display functionality

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Conclusion

We developed new coating technology and partially introduced it to verify its effect on reducing our environmental impact, and will gradually introduce it at domestic and overseas bases to reduce environmental impacts across the Kawasaki Heavy Industries Group.

The coating process consumes a lot of energy and generates much waste in reality, though it is intended to protect products and improve appearance. We will continue to reduce our impact on the global environment for the future of sustainable manufacturing.

New Lines of Off-Road 4-Wheelers: The RIDGE and RIDGE XR Series

RIDGE RANCH EDITION & RIDGE LIMITED shown

With the market for off-road four-wheel vehicles expanding in North America's power sports market, Kawasaki Motors has developed the RIDGE and RIDGE XR series to provide the versatility that supports both work and pleasure. These off-roaders are equipped with a Kawasaki 999-cm^3 water-cooled four-stroke parallel four-cylinder engine with high power and high torque and have a comfortable, quiet, and roomy cabin matched with high-quality finishing. We have gradually been launching the series into the market since February 2024, mainly in North America (U.S. and Canada).

Introduction

The market for off-road four-wheel vehicles is expanding in North America's power sports market. Off-road four-wheel vehicles have diverse uses closely related to lifestyle, such as for utility and recreation.

1 Background

Our MULE series launched in 1988 is known as a vehicle with high functionality and durability for everyday tasks. In 2008 we also launched the TERYX series, designed with a riding performance for recreational use. The RIDGE and RIDGE XR series have been developed to offer comfort and quality levels never seen before in conventional off-road four-wheel vehicles, and suit both everyday tasks and recreational use (**Fig. 1**).

2 Product overview

Both the RIDGE series for everyday tasks and the RIDGE XR series for recreational use feature many variants to meet a wide range of needs. Both series feature the engine and driving system that boast the performance and strength essential for off-road vehicles, long travel suspension, high minimum ground clearance, a platform with plenty of load capacity, and a robust chassis.

The RIDGE series uses small tires to lower the

Fig. 1 Variants of the RIDGE and RIDGE XR series

platform height, making it easy to load and unload during everyday tasks. In addition, we have reduced the engine exhaust sound, improving comfort when operating it for hours at a time.

The RIDGE XR series uses a high-power engine, a driving system with a front/rear differential lock mechanism, and large tires to improve off-road handling during recreational use.

3 Main features

(1) Engine

The RIDGE and RIDGE XR series are equipped with our newly developed 999-cm^3 four-stroke parallel four-cylinder DOHC engine, water cooled and with four valves per cylinder shown in **Fig. 2**. This provides a linear response and smooth power delivery, supporting a wide range of uses including everyday tasks and recreation. While the clear and exhilarating sound typical of four-cylinder engines adds to the thrill of the ride, this one is still quiet enough for conversation in the vehicle.

The power and torque of the RIDGE XR series engine has been further boosted from the RIDGE series to suit sport driving. The electronically controlled throttles allow you to choose from three power modes. In Work mode, the throttle response is softer and controllability in the low-speed region is improved. Sports mode features a more linear throttle response to suits sport driving. And Normal mode offers characteristics balanced between Sport and Work modes.

Moreover, reliable engine braking on downhill slopes by controlling the engagement and release of the continuously variable transmission (CVT) belt clutch ensures stability.

(2) Chassis

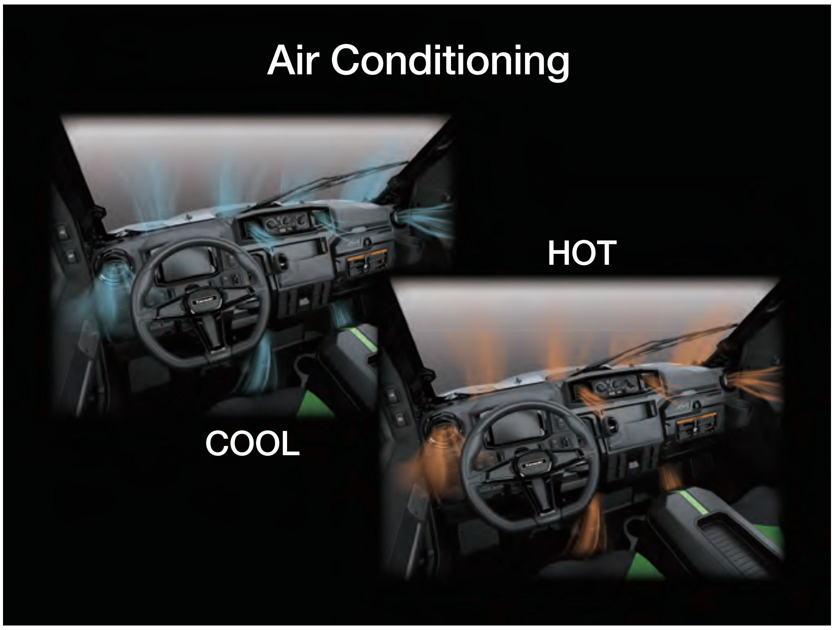
The steel tube ladder frame, developed with a focus on ride comfort, offers well-balanced rigidity and a highly comfortable ride. This design ensures enough flexibility to withstand the shocks endured in off-road driving while being extremely durable.

(3) Design and equipment

The entire range looks impressive, with line-type LED position lights complementing the high-intensity LED headlights.

High-grade fit and finish details, including the feel of the luxurious D-shaped steering wheel, dashboard design and controls with a built-in 7-inch TFT color instrument panel, flat door handles designed to make the most of the indoor space, non-slip foot rests with carefully selected texture and angle, floor lighting, backlit switches, and decorative touches in every section, result in a high-quality interior as seen in **Fig. 3**.

Fig. 2 Engine exterior



(a) Air Conditioning

(b) Interior lighting

Fig. 3 Vehicle interior

Fig. 4 Vehicle exterior

(4) Suspension

Double-wishbone suspension with long wheel travel for the front and rear wheels provide excellent ground-following performance and comfort.

(5) Full cabin and HVAC (heating, ventilation and air conditioning)

For the first time, Kawasaki's off-road four-wheelers have a fully enclosed cabin with front and rear windshields and full doors with electric power windows. This keeps out dirt and water during off-road driving for greater comfort, and the air conditioner offers and escape from summer heat and winter cold.

Conclusion

We have gradually been launching the RIDGE and RIDGE XR series since February 2024, mainly in North America. RIDGE represents Kawasaki's commitment to take on challenges to reach the pinnacle of excellence in this field, and we will keep striving to provide even better products and services.

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New Model with a Four-Cylinder Engine: Ninja ZX-4R

Targeting the increasingly competitive 400-cm³ class supersport motorcycle market, we have introduced a totally new four-cylinder model, the first since the ZXR400 debuted in 1989. Our new model comes with an engine that delivers a whopping 57 kW/14,500 min^{-1}, compared with a maximum output of 35 kW by our competitor's models.

Introduction

Although 400-cm³ class sport motorcycles were originally developed in line with the Japanese licensing system, because our Ninja 400 has sold well in the U.S., Europe, and China, the number of sales in the global market is expected to be large.

1 Background

Although the Ninja 400 is still a popular bike, many competing models have appeared over the years which is stiffening the competition. However, most of these models come with a one- or two-cylinder engine. To cement out position as the leader in this class, we developed the new four-cylinder Ninja ZX-4R as the model that sets the standard for others to follow.

This is our first 400-cm³ class four-cylinder model since the 2008 Zephyr400, and the first completely new design of a four-cylinder 400-cm³ engine for supersport motorcycles since the 1989 ZXR400 over 30 years ago.

2 Specifications

Table 1 compares the main specifications of the new Ninja ZX-4R and those of the Ninja 400 and ZXR400. The table shows that the Ninja ZX-4R outperforms the latest two-cylinder model Ninja 400 by more than 60% and the previous four-cylinder model ZXR400 by more than 30%.

Table 1 Main specifications of the ZX-4R, Ninja400, and ZXR400

	ZX-4R	Ninja 400	ZXR400
Engine type	In-line 4-cylinder	In-line 2-cylinder	In-line 4-cylinder
Displacement [cm³]	399	399	398
Bore stroke	57×39. 1	70×51. 8	57×39. 0
Max. power [kW]	57 / 14, 500 min^{-1}	35 / 10, 000 min^{-1}	43 / 12, 000 min^{-1}
Max. torque [N·m]	39 / 13, 000 min^{-1}	37 / 8, 000 min^{-1}	39 / 10, 000 min^{-1}
Compression ratio	12. 3	11. 5	12. 1

3 Features

The Ninja ZX-4R's four-cylinder engine offers a major advantage over competing models owing to its maximum engine speed equal to or higher than 15,000 min^{-1}, producing an exhilarating exhaust note inherent in four-cylinder motors. The new model also features the ram-air intake system (**Fig. 1**) similar to that on the higher-end ZX-6R and ZX-10R models, outputting 59 kW (80 hp) thanks to the ram pressure that improves charging efficiency.

(1) Engine

Figure 2 compares the performance curves of the Ninja ZX-4R and Ninja 400. Using four cylinders has reduced the weight of each piston and connecting rod, achieving higher revolutions. The performance is especially higher in the high-revolution range of 10,000 min^{-1} or above. Moreover, the Ninja ZX-4R delivers high output by increasing the compression ratio via reducing the clearance with the pistons, This is achieved by improving the precision in the shape of the combustion chamber squish area shown in **Fig. 3** through machining, and by adopting large-diameter throttle valves (ϕ34), which reduce the inhalation resistance, and by employing the same valve-seat section processing as for the ZX-10R.

(2) Frame

Based on the frame of the 250 cm^3 model ZX-25R, we applied FEM analysis to narrow down the sections related to improving the output, so the increase in the mass of the frame is within 1 kg. Other major changes were

Fig. 1 Ram-air system

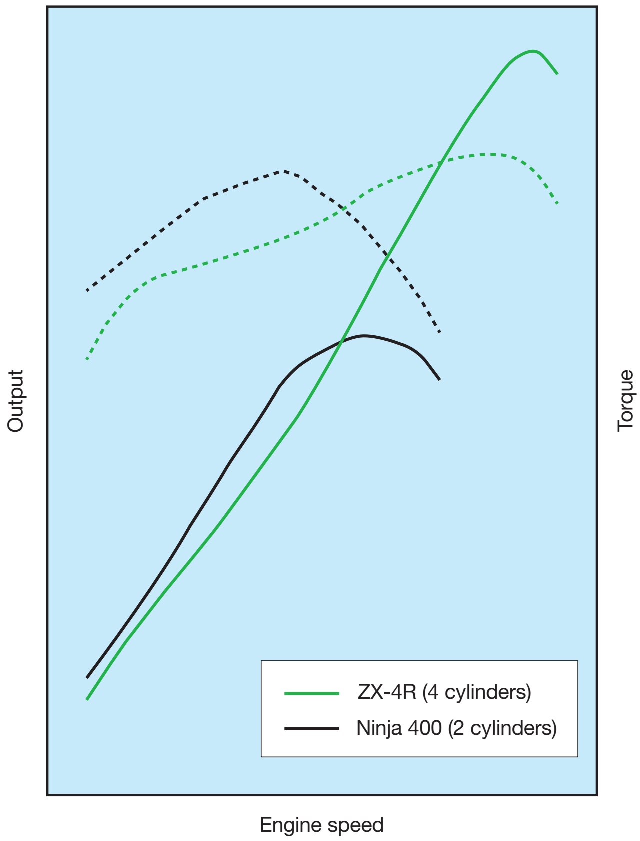

Fig. 2 Performance curves for the ZX-4R and Ninja400

confined to using double front brakes to enhance engine performance in place of the single brakes, and to changing the tire size from 110/70/17 to 120/70/17 for the front and from 150/60/17 to 160/60/17 for the rear to enhance stability at high speed. Keeping the changes minimal worked to suppress the increase of the bike's weight to 6 kg compared with the ZX-25R.

(3) Electronic accessories

For the ZX-4R we have adopted an electronic throttle for the first time in a four-cylinder 400-cm^3 model, giving it power mode and a quick up/down shifter. In addition, the full-color TFT meter display that supports Connected provides convenience to riders and can show information in a mode that makes riding circuit racecourses even more fun.

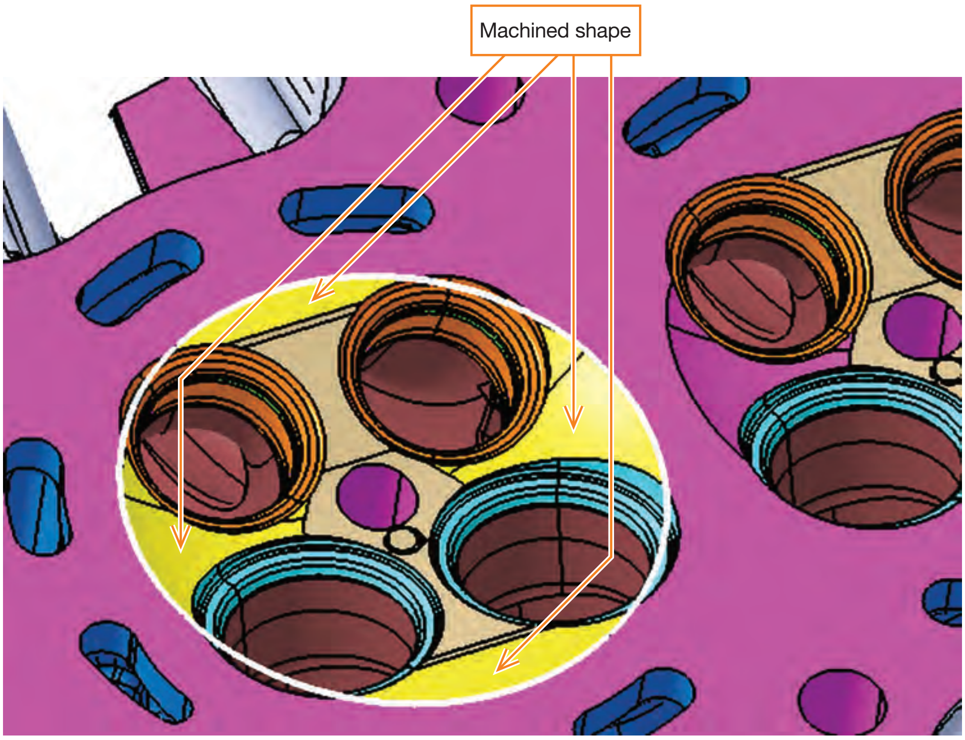

Fig. 3 Combustion chamber configuration

Conclusion

Motorcycles can be sold right around the world as long as they satisfy emission control standards EURO 5 and noise control standard R41-05. Our models satisfy the regulations of various countries and regions, such as China, Japan, the U.S., and Europe.

The release of this new model means a comeback for our 400-cm^3 four-cylinder model, which had been absent from our lineup for a long time. And as of 2024, the ZX-4R is the world's only mass-produced four-cylinder 400-cm^3 model. In addition, we have achieved a major increase in the ZX-4R's power output as various countries tighten their regulations, so this model is a showcase for our technical prowess as well.

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Merging High Performance with Easy Handling: Ninja 500 and Z500

The Ninja 400 and Z400 are already widely recognized in the market as models that combine easy handling with high performance. To further gain superiority in the category, we provide more values to customers by increasing the engine displacement and we make developments to enhance the products' marketability by upgrading the surface design and equipment. These developments are to enhance the products' marketability. We have improved engine performance by focusing on the low- to medium-speed range, and boosted marketability by incorporating a new full LCD meter display. On top of those upgrades, we have equipped the Z500, with a new LED headlight to reduce the light's physical size and so improve both surface design and nighttime visibility.

Introduction

Since the Ninja 250R entered the market in 2008 as our world model under this model series, we have been leading the market category while increasing the displacement. But rivals are also launching their own special new models into the market, heating up the battle for market share.

1 Purpose

The Ninja 400 and Z400 are already widely recognized in the market as models that combine easy handling with high performance. But to gain superiority in the category, we have upgraded the products through various improvements, such as increasing engine displacement and updating the surface design and equipment.

2 Specifications

We have increased engine displacement by increasing stroke length. There are two specifications: the full-power (FP) type with no power restriction, and the A2 license (A2) type for Europe with restricted output.

Table 1 compares the principal features of the new Ninja 500 and Z500 and the previous models Ninja 400 and Z400. The Ninja 500 and Z500 follow the frame-related specifications of the popular previous models.

3 Features

(1) Engine performance

To enable entry-level riders, who are the main customers, to further feel how easy these models are to ride, we made developments that focus on improving the sensation of power in the low- to medium-speed range from the perspective of increasing displacement while taking ease of handling into account, assuming acceleration when riding on general roads and freeways.

(i) FP specification

As shown in **Fig. 1(a)**, the output and torque of the Ninja 500 and Z500 exceed those of the Ninja 400 right across the range, showing improvement in their acceleration performance, yet their fuel economy has been kept as low as that of the Ninja 400.

(ii) A2 specification

While satisfying the output regulations, the Ninja 500 and Z500 have been developed to further enhance performance in the low- to medium-speed range. As shown in **Fig. 1(b)**, the performance of the Ninja 500 and Z500 exceeds that of the Z400 from the low-speed range to the output peak, so they are easier to handle in the

Table 1 Comparing principal specifications with previous models

Item \ Machine model	Ninja 500 with FP spec.	2023 Ninja 400 with FP spec.
Engine type	4 -stroke water-cooled Parallel 2 -cylinder DOHC 4 valves	←
Displacement [cm^3]	451	399
Bore × stroke [mm × mm]	70. 0 × 58. 6	70. 0 × 51. 8
Bench max. power [kW]	38. 3 / 10, 000 min^{-1}	35. 0 / 10, 000 min^{-1}
Bench max. torque [N · m]	42. 6 / 7, 500 min^{-1}	37. 0 / 8, 000 min^{-1}
Seat height [mm]	785	785
Machine mass [kg]	171	168

Item \ Machine model	Z500 with A 2 spec.	2023 Z400 with A 2 spec.
Engine type	4 -stroke water-cooled Parallel 2 -cylinder DOHC 4 valves	←
Displacement [cm^3]	451	399
Bore × stroke [mm × mm]	70. 0 × 58. 6	70. 0 × 51. 8
Bench max. power [kW]	33. 4 / 9, 000 min^{-1}	33. 4 / 10, 000 min^{-1}
Bench max. torque [N · m]	42. 6 / 6, 000 min^{-1}	37. 0 / 8, 000 min^{-1}
Seat height [mm]	785	785
Machine mass [kg]	167	167

normal range. The Z500's fuel economy has been improved to 26.2 km/L in WMTC mode from 25.5 km/L for the Z400.

(2) Meters and lighting devices

With "exciting and a step above" as the key phrase, we upgraded the exterior design, including the meters and lights.

The new models have a standard specification meter display (**Fig. 2(a)**) and lights. The Z500 has a new type of headlight that was developed for this model. In addition, bikes equipped with the special edition specification come with a TFT meter display (**Fig. 2(b)**) to enhance the products' marketability and visibility. Furthermore, the bikes have a new smartphone linkage function to increase user convenience.

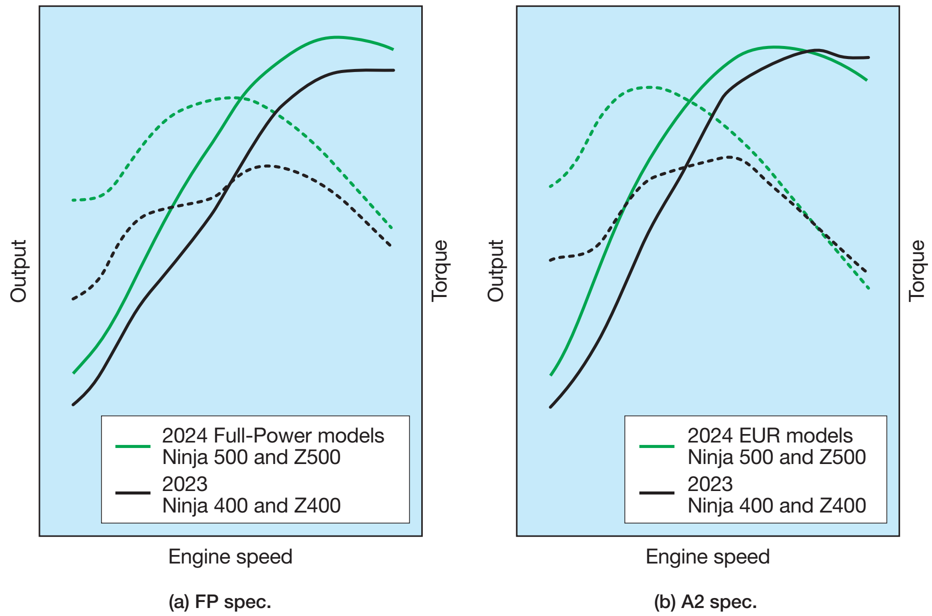

Fig. 1 Comparisons of performance curves

(i) Meters

For standard-specification meters, we developed a new model of high-resolution, high-contrast improved black nematic (IBN) liquid crystal meter display to enhance the products' marketability (first adopted for this model).

(ii) Headlight for the Z500

In the early stage of development, the design section, development riders, and suppliers set the goal of "balancing small size and brightness" and worked to achieve the goal under a common understanding. The result is a physically small headlight, which delivers an advantage in surface design and layout, with enhanced nighttime visibility compared to the previous models as shown in **Fig. 3**.

(3) Easy to handle

As with the engine characteristics, we have manufactured the frames by focusing on ease of handling.

(i) Lightweight frames

The frames of the Ninja 400 and Z400 are overwhelmingly light, which is their primary advantage. The Ninja 500 and Z500 follow those frames, and their weights have been kept to the level of previous 250-cc class machines, which leads to easy handling.

(a) STD

(b) SE

Fig. 2 Meter appearances

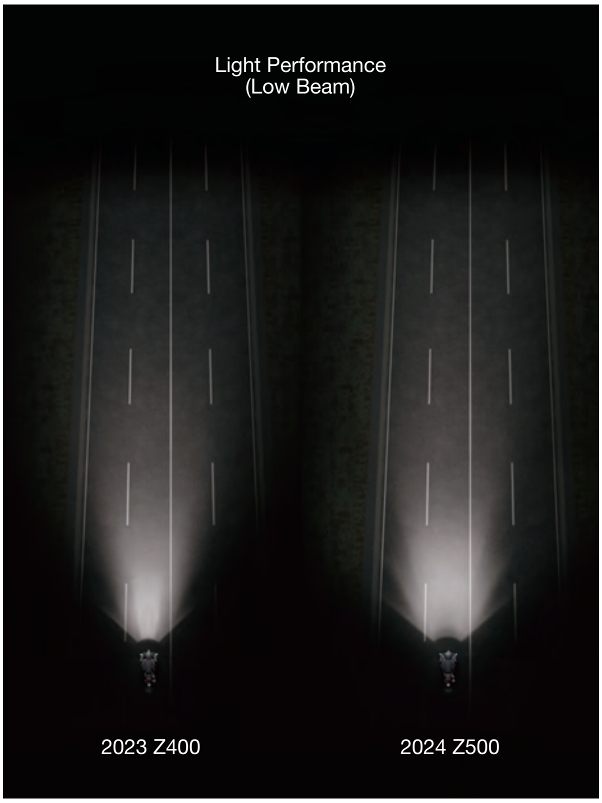

Fig. 3 Comparison of lighting performance

(ii) Riding position

Regarding the riding position, the Ninja 500 and Z500 avoid an excessively sporty leaning-forward form, instead adopting a comfortable position that works best in a variety of situations and that is optimal as an all-round position. This received wide praise when used for the previous models as well.

Conclusion

As with the previous models, we are sure these new high-performance, easy-to-handle models will satisfy a diverse range of riders including first-time bike owners, female riders, and riders who are jumping back onto the saddle after years away.

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New, Lightweight Cruisers with Enhanced Ground Reach: ELIMINATOR and ELIMINATOR SE

These days customers want models that suit their own lifestyles, s Accordingly, we have developed the ELIMINATOR as a modern cruiser model for which the riding position is comfortable and that users can easily enjoy.

The ELIMINATOR is the lightest cruiser model in the 400-cm³ class, and this lightness combined with the low seat means that even beginners can feel safe handling it.

Introduction

The influence of COVID-19, which began spreading all around the world in 2020, prompted people to rethink the role of motorcycles in their life, triggering stronger demand for them as a way to get around that avoids closed spaces, crowds, and close contact in their daily lives and offers leisure on weekends.

1 Background

Nowadays customers have more motives than ever before enrich their lives with motorcycles as a hobby or interest without placing motorcycles at the center of their lives, so there is demand for models that blend smoothly into those customers' lifestyles. To meet this need, we have developed the ELIMINATOR and ELIMINATOR SE as modern, fun cruiser models with a comfortable riding position under the concept of "a lightweight, easy commuter with enhanced ground reach."

2 Product specifications

We focused on ease of handling in various situations from daily travel to long tours, represented by the slim, low, and long style, low, comfortable seat, and light, smooth handling. The models are the lightest among the 400-cm³ class cruiser models, and this lightness combined with the low seat means that even beginners can feel safe handling it.

3 Product features

(1) Riding positions

To ensure that the rider is comfortable on the ELIMINATOR, the riding position is relaxing. As **Fig. 1** shows, the upper part of the body is relatively vertical compared with the riding position on the Z400. In addition, for the footrest position on the ELIMINATOR, we use mid control. This differs from many cruiser models that use forward control, so the riding position is natural with the knees moderately bent.

(2) Ease of handling

To enable even beginners to handle these bikes safely, we worked hard to reduce the weight by optimizing the frame with the engine as a stiffness/strength member and other measures.

In addition, as shown in **Fig. 2**, we have placed heavy objects, such as the battery and coolant reserve tank, under the seat to bring the gravity center closer to the rider comparing with the Z400. Moreover, the seat height is low at 735 mm. These improve the sense of safety when astride a bike, and make it easy to pick the bike up when it is parked. Furthermore, the ELIMINATOR delivers light, smooth handling expected from cruiser models

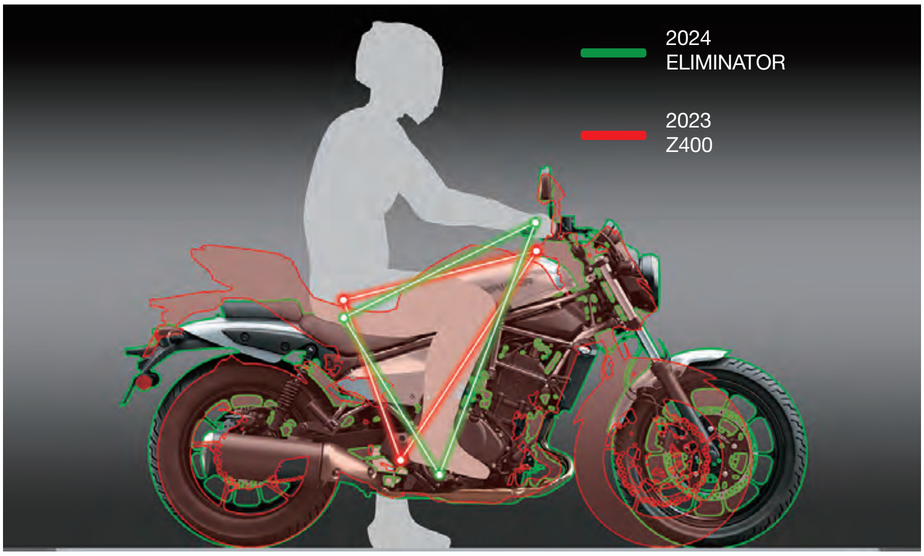


Fig. 1 Comparison of riding positions

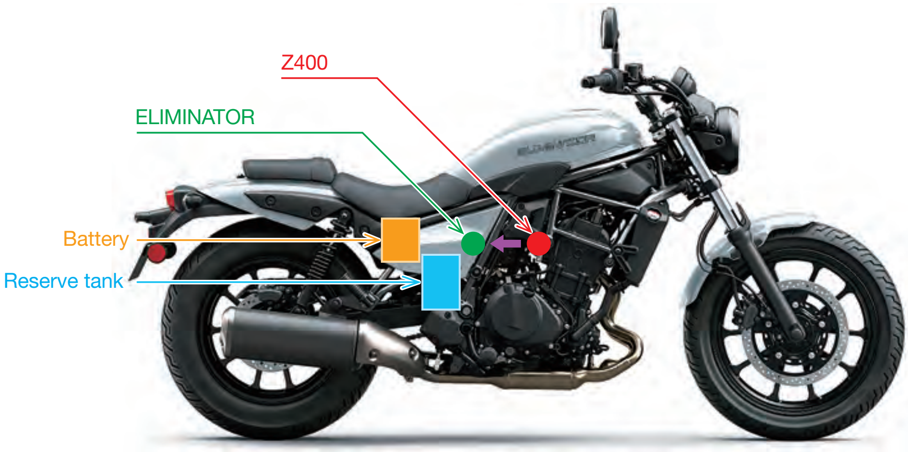


Fig. 2 Comparison of centers of gravity

thanks to the 1,520-mm long wheel base and 30° caster angle, while bringing the trail closer to that of sport models rather than general cruiser models as shown in **Fig. 3**.

(3) Ride comfort

For lasting comfort even during long rides, we secured sufficient urethane thickness in the seat by placing the locking mechanism at the front of the seat despite the low seat height. In addition, as **Fig. 4** shows, putting a cavity at the bottom of the urethane distributes the pressure across the seat surface when sitting astride the ELIMINATOR's seat compared with urethane without a cavity. This further improves the riding comfort. A high seat (seat height: 765 mm) and low seat (715 mm) are available as accessories, so riders with a wide variety of physiques can enjoy riding the ELIMINATOR in comfort.

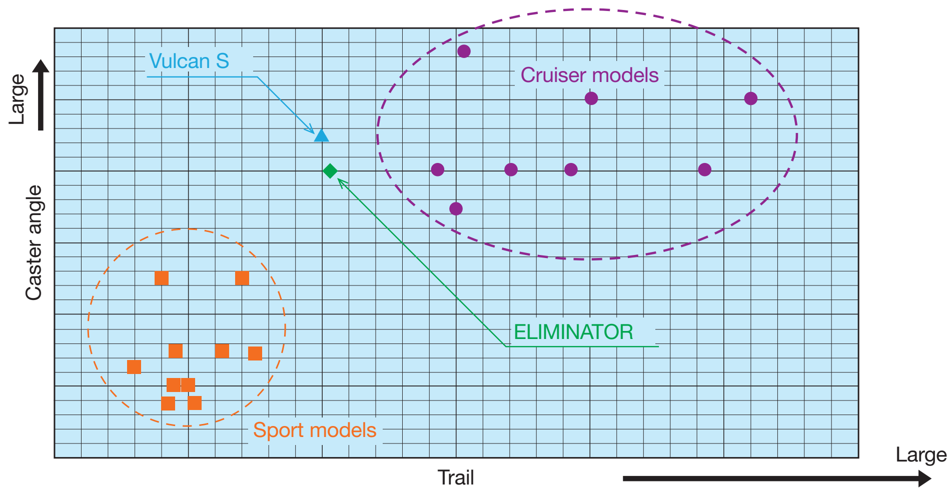
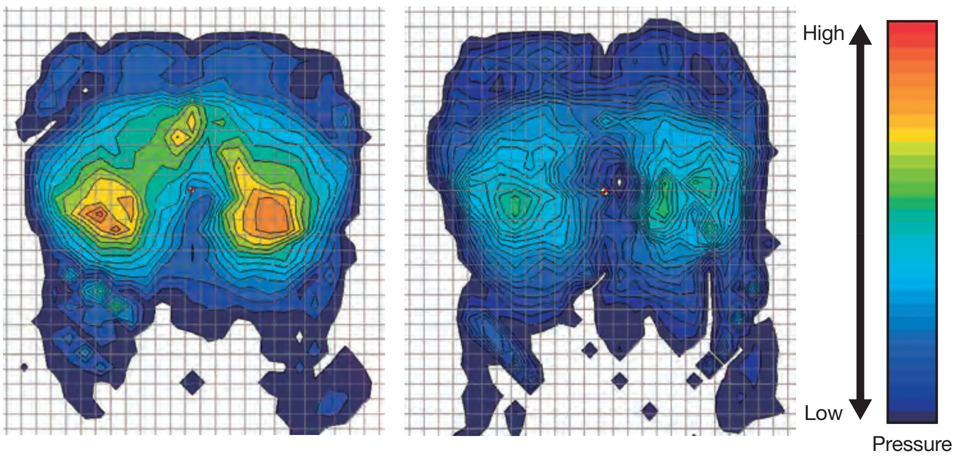


Fig. 3 Comparison of caster angles and trails



(a) Without a cavity (b) With a cavity

Fig. 4 Comparison of pressure distribution on seat surfaces

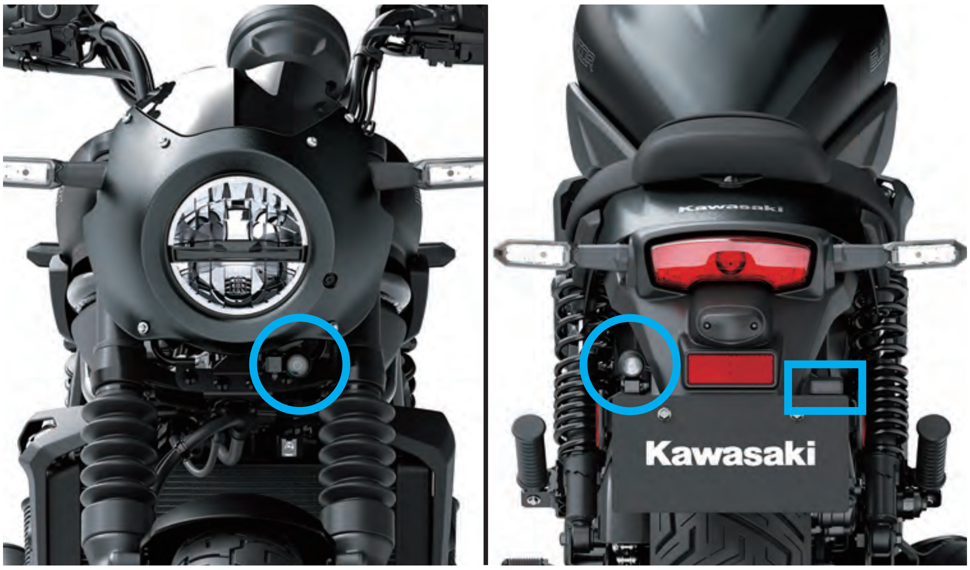


Fig. 5 GPS and both front and rear cameras

(4) Use of drive recorders

Although drive recorders for two-wheeled vehicles have not been widely adopted compared with those for four-wheeled vehicles because the installable locations are limited and installation is rather difficult for two-wheeled vehicles, demand is slowly increasing.

We designed a bracket and harness specially for the ELIMINATOR SE, blending in smoothly to the bike's form to keep them inconspicuous. The ELIMINATOR SE is the world's first commercially available motorcycle that has a drive recorder with the GPS and front/rear cameras shown in **Fig. 5** as a standard feature*.

*Only for the Japanese specification (surveyed by Kawasaki Motors, Ltd. in March 2023)

Conclusion

Since the ELIMINATOR went on sale it has earned high acclaim in the market, winning the gold award (first prize) in the Japan Bike of the Year 2023 small motorcycle segment. In a nutshell, we believe we have succeeded in creating a product that matches market needs. We will continue to develop user-oriented products while monitoring market trends in the future as well.

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New All-Round Motocross Bike: KX 450

Since its debut in 1973, the KX450 has consistently carried the philosophy of "Built to Win" for more than 50 years, and has evolved by incorporating advanced technologies that give riders the best chance of standing atop the podium.

The KX450 has won numerous races in the AMA Supercross Championship, which is the highest-profile off-road motorbike racing championship. We have developed its latest incarnation under the concept of "all-round," with the aim of achieving the highest levels in the industry for both machine performance and components, and it has received high praise in the market.

Introduction

People around the world are familiar with motocross through international racing championships, such as the AMA Supercross Championship and the FIM Motocross World Championship (MXGP). The AMA Supercross Championship races held in urban areas and large arenas in the US are very popular spectacles that excite large numbers of fans. Unpredictable developments, such as technical, high-impact jumps, fierce battles at corners involving contact between riders and bikes, and crashes following starts where everyone speeds away in a straight line, deliver tension and drama that captivate the spectators. All this and more has transformed motocross into a unique, appealing motorsport.

Recent years have seen many new manufacturers join the racing series and making the competition hotter, so we need to keep setting the benchmark.

1 Background

The KX's history began in 1973 when the first model debuted, and development has never ceased since then, even to one year ago today when the KX marked its 50th anniversary. As for racing victories, KX machines won AMA Supercross Championships for four years running from 2011 to 2014, in addition to many other titles — proof of their outstanding performance. The KX has been developed based on the philosophy of "Built to Win," where we aim at producing machines that win races. As a motocross bikes for experts, we have been evolving the KX450 by upgrading it for several decades with advanced technologies to give riders the best chance of stand on top of the podium every time.

2 Development concept

To embody this development philosophy, under the development concept of "all-rounder" we aimed to improve performance in every aspects so our rider can win races. With the goal of developing easy-to-handle machines, in particular, we set the goal at developing machines that would be able to be skillfully driven even in situations where the road conditions are bad and thereby controlling the machines is difficult.

In addition, we have upgraded components to the highest levels in the industry to support riders from various aspects, with the intent to that Kawasaki machines can win races throughout the season in the runup to the championship.

3 Features

Compared with the previous model, which earned itself a reputation for its responsive engine and agile chassis, the new one comes a new engine with better control and new a chassis with greater frontal stability.

(1) Frame performance

By focusing on the partial stiffness of the front part of the frame, separating the stiffness that contributes to nimbleness and stability, and optimizing the stiffness of the other parts while retaining the nimbleness that was highly valued in the previous model, as shown on **Fig. 1**. This significantly improves the stability of the front section when the bike corners. Achieving these mutually contradictory properties at high levels increase the speed when a bike enters a corner, making it possible to turn a corner faster and more stably, which helps to cut lap time. In addition, the stable frame reduces the risk of rollover and also mitigates rider fatigue.

(2) Engine performance

The new engine delivers brisk acceleration in the mid- to high-speed range and smooth handling due to the flat torque characteristic and higher output at high speed, as **Fig. 2** shows. Adopting a straightened intake and exhaust and taking advantage of the down draft shown in **Fig. 3** played a role in improving acceleration and handling because they boost charging and exhaust efficiency. To achieve this, we employed various layout techniques such as dramatically altering the layouts of components, altering the locations of the air intake duct and frame

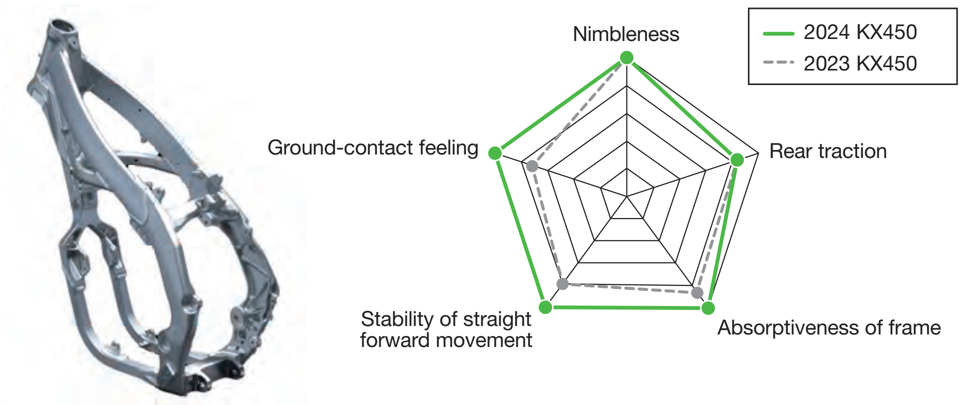

Fig. 1 Chassis performance radar chart

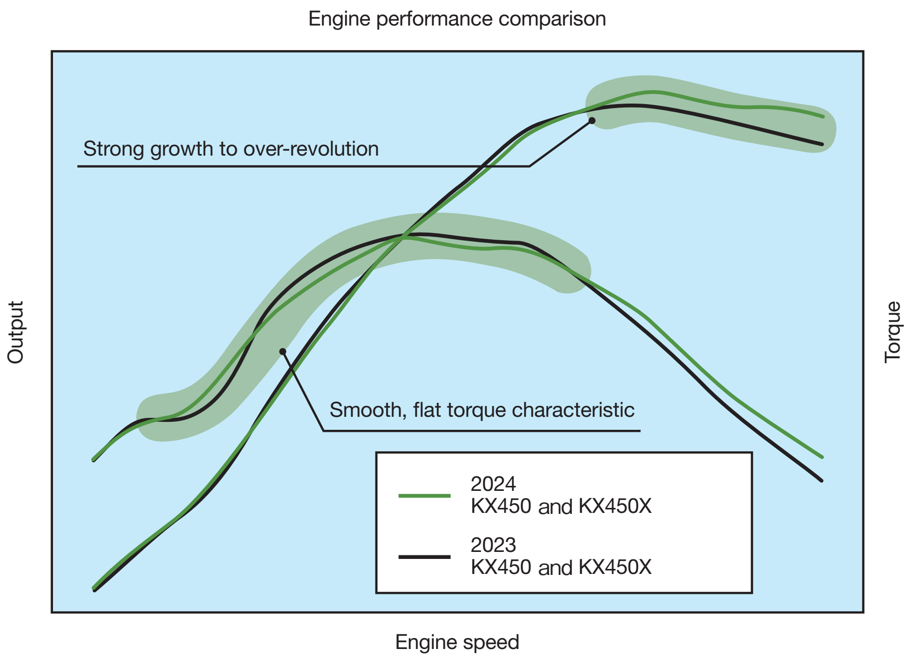

Fig. 2 Engine performance comparison

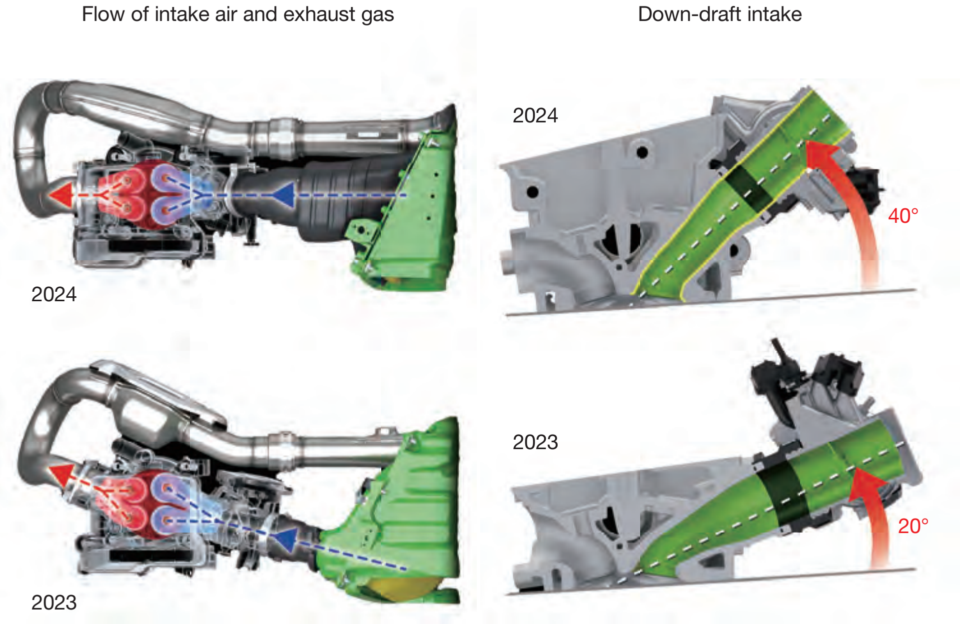

Fig. 3 Comparison of intake and exhaust layouts

parts, and adjusting the locations of the shocks.

(3) Smartphone connectivity

The smartphone application RIDEOLOGY THE APP KX enables riders to adjust the engine mapping (injection quantity and ignition timing) to change engine characteristics via smartphone. The KX FI calibration kit, which used to come as an optional accessory with the previous model, now comes as standard and can be operated by radio. This makes it easier and more convenient than ever before. Thanks to the simple, user-friendly interface, even users who have never made settings before can now match engine characteristics to their preferences and changes in road conditions.

In addition, the engine monitoring and maintenance and setup logs can be recorded.

Fig. 4 Other cutting-edge components

(4) Other

On top of boosting performance, we have added refinements that improve the riding experience and offer high market appeal as shown in **Fig. 4**.

- Brembo brakes with high control performance
- Quick-change ODI lock-on grips
- Traction control for stable acceleration

Conclusion

We are especially grateful to our business acquaintances who became involved in the development, and to related parties including Kawasaki Motors Corp., USA. Thanks to their efforts and cooperation, this development was completed with success.

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High-Power and Low Fuel Consumption Engine for Riding Mowers: FX820V EVO

In the US's commercial lawn-related market, the demand for engines with an electronic fuel injection (EFI) unit is increasing. Although we have released models fitted with an EFI system by using the same engine block as employed for existing carburetor specifications, competing manufacturers have also brought out their own product lineups. Against this background, we have developed the FX820V EVO—a new-generation engine with high power and low fuel consumption specially designed for EFI. It supersedes conventional models to increase the take-up rate of our engines among work machine manufacturers. Mass production of this model has already started, and it has appeared in the market as a component of riding mowers built by work machine manufacturers.

Introduction

In the commercial lawn-related market (for professionals) in the U.S., engines incorporating an electronic fuel injection (EFI) unit, which can accurately control the fuel injection amount and enables the improvement of fuel efficiency and good startability, have been adopted in riding mowers from operating machine manufacturers and higher performance models are demanded.

1 Background

In the US, professional gardeners (landscapers) are generally hired to mow lawns on large areas of land, such as general household gardens, in public places, and at supermarkets. To maximize their profits, landscapers look for mowers that are reliable (to avoid downtime), are powerful enough to quickly mow large areas of lawn, offer high fuel efficiency, and deliver a low lawn-mowing cost per unit area.

Kawasaki's products have long enjoyed a strong reputation for quality and reliability in commercial markets like the US's. However, competing engine manufacturers have also improved their lineups of models incorporating EFI, which offer better fuel efficiency than carburetor models. So to release a series ahead of the others with EFI specifications, we also developed and launched the FX850V-EFI, which uses the same engine block as that for conventional carburetor specifications.

However, work machine manufacturers demand higher added value for engines with EFI specifications. In response to this demand, we developed the FX820V EVO — the new-generation engine with EFI designed into it from the beginning to create an engine that delivers higher power and lower fuel consumption than before.

2 Specifications

Table 1 shows a comparison of the main specifications between the FX820V EVO, whose main parts were newly designed to incorporate EFI, and the FX850V-EFI — a conventional model that reuses the engine block with carburetor specifications. The FX820V EVO assumes highly accurate fuel injection control through EFI, employs three valves (two inlet valves and one exhaust valve) instead of the conventional two valves (one inlet valve and one exhaust valve), and has a higher compression ratio. In addition, the model is slightly smaller with a 30-cc reduction in displacement.

Table 1 Comparison of principal specifications: FX820V EVO vs. FX850V-EFI

Item	FX850V EVO	FX850V-EFI
Engine type	Air-cooled vertical shaft V-twin	
Valvetrain type	OH-3V	OH-2V
Displacement [cm^3]	822	852
Bore × stroke [mm]	83×76	84. 5×76
Compression ratio	9. 1	8. 2
Max. power [kW]	24. 1 / 3, 600 min^{-1}	19. 9 / 3, 600 min^{-1}
Max. torque [N·m]	65. 9 / 2, 600 min^{-1}	62. 0 / 2, 400 min^{-1}
Total length × total width × total height [mm]	519×521×624	524×515×620

3 Features

The engine specially designed for EFI has increased power and improved fuel efficiency by optimizing particular parts in the inlet, exhaust, and combustion systems. It also offers the reliability of conventional models by enhancing cooling performance and improving the durability of each section. We have done this to address the increase in the amount of heat generated by the engine that comes from the power increase. Moreover, since maintainability has been improved, landscapers who manage multiple work machines can inspect and maintain more quickly than in the past.

(1) Power increase

A higher compression ratio and two inlet valves enhance the heat efficiency and charging efficiency of air-fuel mixture. The power at a regular engine speed of 3,600 min^{-1} is about 20% higher than conventional models as shown in **Fig. 1**.

(2) Better fuel efficiency

By optimizing the layout of parts in the inlet system to lower the resistance along the inlet passage and then reducing the air-fuel ratio (the mixing ratio of fuel and air), we have reduced the fuel consumption rate in the regular power region by about 20% compared with conventional models.

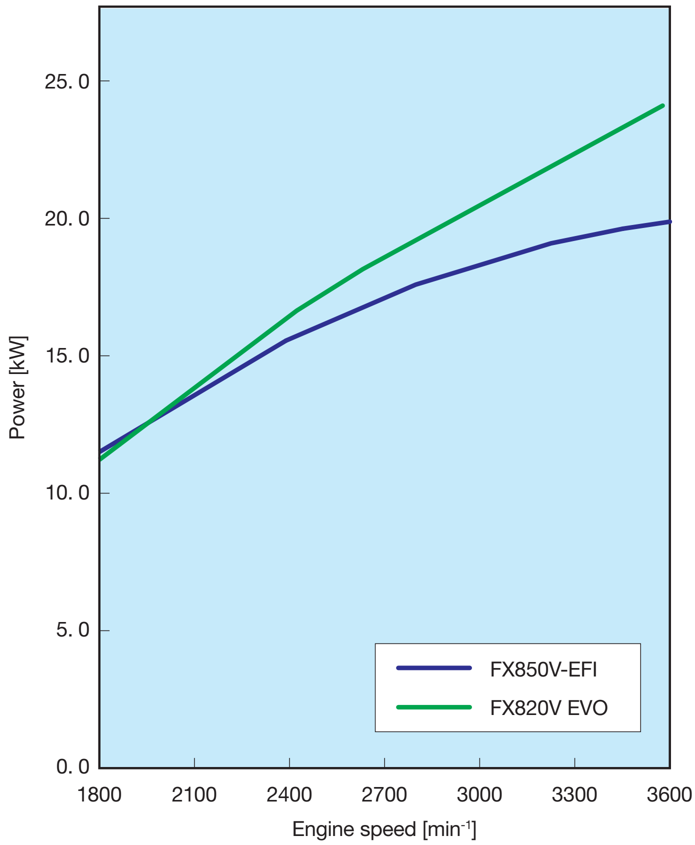

Fig. 1　Performance curves of FX820V EVO and FX850V-EFI

(3) Durability

The cylinder head is now manufactured using low-pressure casting, which offers high durability at high temperature, instead of conventional diecasting.

We also reviewed the cooling air guiding structure to concentrate cooling air onto hot portions.

This constrains the temperature rise associated with the power increase and ensures higher durability than conventional models even at high temperature.

(4) Maintainability

A wide opening for maintenance is located in one part of the engine cover. This makes it easy to clear away lawn clippings that accumulate around the cylinder and cylinder head, which causes overheating. In addition, a larger oil filler, serving as the oil inlet, is located in a high position for quick oil changes and inspections.


Fig. 2 Riding mower equipped with FX820V EVO

4 Delivery example

Mass production of this model for the US market started at the KMM factory at Maryville in January 2023. This model is mainly launched as a component of a type of ride-on mower called the zero-turn radius design shown in **Fig. 2**. This mower design can efficiently turn on a dime and is steered by applying speed differences to the right and left rear wheels.

Conclusion

The FX820V EVO has also been well received in the market because it has a power close to 1,000-cc class engines but needs fewer fuel refills. We will meet market needs by deploying this engine to other displacement classes as the EVO series.

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JET SKI with Naturally Aspirated Engines: ULTRA 160LX and ULTRA 160LX-S

Categories with high functionality and enhanced equipment are expanding in the personal watercraft market. We developed the ULTRA 160LX and ULTRA 160LX-S—JET SKI equipped with a naturally aspirated engine and featuring unprecedented innovative style, equipment, and functions in 2023 and launched them across the world. These models have been well received in the market thanks to their new equipment and high functionality that surpasses what competitors offer. Benefits include the bow structure that guides water flow to the right and left for a drier ride and the motor-driven jet that directs the jet blast forward and backward.

Introduction

The runabout type that can be operated while seated is the leading product in the personal watercraft (PWC) market because it is stable and easy to ride, making it ideal for recreational purposes like towing wakeboards and the like. As the number of models with high functionality and upgraded equipment have exploded in this category, each manufacturer also has rapidly updated their model lineups.

1 Background

We also launched the ULTRA 310LX, ULTRA 310LX-S, and ULTRA 310X—high-performance supercharged engines with new innovative equipment and functions—as the 2022 models, which received high praise from the market.

In addition, we developed the ULTRA 160LX and ULTRA 160LX-S equipped with a naturally aspirated engine, which is in high demand in the market, to boost our model lineup in this category.

2 Specifications

The ULTRA 160LX and ULTRA 160LX-S are equipped with a naturally aspirated 1,498-cm^3 environment-responsive, four-stroke/four-cylinder engine high in power, which is used in our runabout type STX 160. For the hull, the jet pump is optimized based on the ULTRA 310LX. **Table 1** lays out the main specifications of the ULTRA 160LX and ULTRA 160LX-S. These models boast new functions and equipment, including our proprietary technologies as shown in **Table 2**.

3 Features

We incorporated our proprietary style, functions, and equipment to satisfy market needs in this category.

(1) Innovative design

The ULTRA 160LX and ULTRA 160LX-S showcase a dynamic, shapely style. LED accent lights are placed on the front for the first time in PWCs to achieve a sharp look. The newly designed bumper and front hatch lid guide the water flow splashed on the bow during piloting to the right and left as shown in **Fig. 1**. This reduces the amount of water splashing over the rider and improves comfort.

(2) Kawasaki Smart Reverse with Deceleration (KSRD)

PWCs move backward by directing the jet blast released behind to the front using the reversing bucket. Although in the past the bucket was moved with manual levers, we have developed the proprietary Kawasaki Smart Reverse with Deceleration (KSRD) as a motor-driven mechanism as shown in **Fig. 2**.

Table 1 Principal specifications

Item		
Overall length [mm]		3, 580
Overall width [mm]		1, 195
Overall height [mm]	ULTRA 160LX	1, 240
	ULTRA 160LX-S	1, 180
Fuel capacity [liters]		80
Engine type		Four-stroke/Four-cylinder
Bore × Stroke [mm]		83×69. 2
Displacement [cm^3]		1, 498
Max. power [kW]		112 / 7, 500 min^{-1}
Max. torque [N · m]		144 / 5, 750 min^{-1}

Table 2 Comparison of features

	ULTRA 160LX	ULTRA 160LX-S
Kawasaki Smart Reverse with Deceleration（KSRD）	🔴	🔴
7 ” full-color TFT instrumentation	🔴	🔴
Adjustable LXury seat	🔴	-
Sport seat	-	●
Easy side-access storage	🔴	🔴
Cleat	●	●
Multi-mount system	●	●
Cup holder	●	●
Extended platform	●	●
Rearview camera	🔴	🔴
LED accent light	🔴	🔴
Meter visor	●	-
JETSOUND 4 s audio system	🔴	-

🔴 A red circle indicates our proprietary function or equipment.

The KSRD is operated with a thumb lever integrated with the throttle lever, which enables switching between forward and backward movement with just one hand. This makes it easy to slow down and move backward when piloting and on arrival at the shore, dramatically improving operability. This system also includes the following functions.

- Neutral mode: In the past, PWCs moved forward even when idling. To solve this problem, we optimized the bucket position to keep the thrust at zero, making it possible to stay in a fixed position.
- Reverse assist mode: If the reverse thrust is insufficient, you may not be able to lower the PWC from the trailer into the water. To solve this problem, we made it possible to temporarily increase the engine thrust.

Fig. 1 Water flow along bow

Fig. 2 Image of KSRD system

(3) 7-inch full-color TFT instrumentation and JETSOUND 4s audio system

The ULTRA 160LX and ULTRA 160LX-S have instrumentation equipped with a large 7-inch TFT screen. They also come equipped with GPS as standard to display the direction and distance to the registered destination. In addition, the ULTRA 160LX has the JETSOUND 4s audio system, so users can enjoy their favorite music while zipping across the water. All these functions add up to enable users to indulge in comfortable cruises and fun rides that were impossible until now.

Fig. 3 Image of ULTRA 160LX-S Angler

Conclusion

The ULTRA 160LX and ULTRA 160LX-S were launched across the world in 2023 and have been well received in each market. On top of these, we released the ULTRA 160LX-S ANGLER with equipment specially designed for fishing (**Fig. 3**) at various trade shows, to high acclaim.

We will continue to enhance the model lineup and develop products the market wants.

Toshio Araki

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New Personal Means of Mobility: The noslisu

Recently, electric vehicles (EVs) such as power-assisted bicycles and electric scooters have been attracting attention. They solve social issues and bring health and enjoyment but pose challenges such as stability, controllability, and loading capacity. To solve these problems, we have developed the noslisu—a three-wheel EV. The noslisu is a new type of EV developed by leveraging our motorcycle design technologies and long-term experience. The noslisu employs our proprietary two-wheel steering mechanism to combine the stability unique to three-wheel vehicles and natural controllability close to that of bicycles. It has been well received in the market since its launch in May 2023, and we expect to boost sales further with new specifications from around spring 2025.

Introduction

Recently, small electric vehicles (EVs) such as power-assisted bicycles and electric scooters have been gaining attention. These vehicles offer the benefits of being environmentally friendly, solving problems related to traffic congestion and parking lots, and delivering health and enjoyment. However, they pose challenges such as stability, controllability, and loading capacity. For example, small two-wheel EVs vehicles may be difficult to balance or inconvenient for carrying baggage. Four-wheel EVs, on the other hand, are large so may be difficult to maneuver or drive on narrow roads or sidewalks.

1 Development goals

We developed the noslisu — a three-wheel EV, to solve problems surrounding conventional electric vehicles. This three-wheel EV is intended to provide comfortable and easy transportation to a wide range of users by combining the stability unique to three-wheel vehicles and natural controllability close to that of bicycles.

Table 1 noslisu series specifications

Model	The noslisu	The noslisu e
Type	Power-assisted bicycle	All-electric vehicle
Driver's license	Not required	Regular driver's license
Vehicle weight [kg]	40. 0	41. 0
Maximum speed [km/h]	25	60
Riding distance [km]	47. 4	40. 0
Battery capacity [Wh]	504	504
Motor output [W]	250	4. 0k
Loading capacity [kg]	20	20
Recommended retail price	363, 000 yen	431, 000 yen

2 Specifications

The noslisu is a new type of EV developed by leveraging our motorcycle design technologies and experiences accumulated for a long time. This EV employs Kawasaki's proprietary two-wheel steering mechanism to combine the stability unique to three-wheel vehicles and natural controllability close to that of bicycles.

Table 1 lists the specifications of the noslisu series. The series offers two vehicle models: the noslisu with power-assisted bicycle specifications, and the noslisu e with all-electric specifications. For the power-assisted bicycle model, we will update the motor and battery specifications around spring 2025.

3 Features

One key feature of the noslisu series is Kawasaki's proprietary two-wheel steering mechanism*. This provides natural controllability that enables the vehicle body to move in synchronization with moving the handlebars, and delivers a stable ride less affected by road inclines and uneven surfaces.

*Patent application 2020-129765, patent application 2020-129766, etc.

(a) Link structure in which the wheels tilt in line with the body's lean

(b) Video of vehicle behavior (social media link)

Fig. 1 Two-wheel steering mechanism

4 Voices in the market

The noslisu series was sold exclusively through a crowdfunding service in 2021 and attracted tremendous interest. All fifty units of both the noslisu with power-assisted bicycle specifications and the noslisu e with all-electric specifications sold out by the evening of the launch day. They received high praise from supporters. Owing to such popularity, Kawasaki Motors Corporation Japan launched the series as regular products in May 2023.

We received the following feedback from crowdfunding supporters.

- Not only is the noslisu a fun bicycle to ride, but its power assist is strong and comfortable. The two-wheel steering mechanism allows me to turn corners more naturally and smoothly than I expected.

- The noslisu e is nimble and easy to maneuver even though it is all-electric. The maximum speed is sufficient and the battery lasts a long time. The three wheels make the vehicle stable and reliable.

We also received many reactions after launching the series as regular products in 2023. We realize that they are gradually growing in popularity, as we hear that some users have bought them for transportation after surrendering their driver's license.

5 Specifications of the next-generation model

We will significantly update the specifications as early as around spring 2025, based on more feedback and improvement proposals received since the launch in 2023. Major changes are as follows.

・Replacement of the rear hub motor with a center motor
・Increase in the battery capacity
・Repositioning of handlebar grips for a more comfortable riding posture
・Accessory enhancement

Fig. 2 Photo of all project members

Conclusion

The noslisu series is a new form of mobility from Kawasaki. The development concept is to deliver a comfortable and easy way to get around by combining the stability unique to three-wheel vehicles and natural controllability close to that of bicycles. We expect to boost sales further with the new models coming around spring 2025 for even better comfort, convenience, and performance. This project started when it was chosen in the Business Idea Challenge hosted by Kawasaki Heavy Industries' Innovation Department in the Corporate Planning Division at Head Office. It was then transferred to Kawasaki Motors, Ltd., where it was successfully commercialized and continues to be developed. Minor changes are planned around spring 2025. We have developed the project thanks to the cooperation, acceptance, and advice of many people who supported its promotion, and once again we would like to express our gratitude for this opportunity.

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Kawasaki Heavy Industries Group

Main Products and Production Bases by Business Segment

Business Segment	Main Products	Main Production Bases
Aerospace Systems	• Aircraft (fixed-wing aircraft and helicopters), missiles, electronic equipment, space systems and peripheral equipment, simulators	Gifu Works (Kakamigahara, Gifu Prefecture) Nagoya Works 1 (Yatomi, Aichi Prefecture) Nagoya Works 2 (Tobishima-mura, Aichi Prefecture) Kawasaki Motors Manufacturing Corp., U.S.A. (U.S.A.)
	• Aircraft components, target systems, rocket components, space equipment • Aircraft servicing and remodeling	NIPPI Corporation • Yokohama Plant (Yokohama, Kanagawa Prefecture) • Atsugi Plant (Yamato, Kanagawa Prefecture)
	• Aircraft engines, Aircraft gear boxes	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe, Hyogo Prefecture)
Rolling Stock (Kawasaki Railcar Manufacturing Co., Ltd.)	• Train cars, integrated transit systems, freight cars	Head Office & Works (Kobe, Hyogo Prefecture) Harima Works (Harima-cho, Hyogo Prefecture) Kawasaki Motors Manufacturing Corp., U.S.A. (U.S.A.) Kawasaki Rail Car, Inc. (U.S.A.)
	• Rotary snowplows, deicing material spreaders • Railway motor cars, heavy-lift cars	NICHIJO CORPORATION. • Akebono Plant (Sapporo, Hokkaido) • Inaho Plant (Sapporo, Hokkaido)
Energy Solution & Marine Engineering	• Cement, chemical, conveyers, and other industrial plant systems • Industrial boilers, power generation business boilers, etc., for land and marine use • Waste treatment facility • LNG tank and other low temperature storage facilities	Harima Works (Harima-cho, Hyogo Prefecture) Anhui Conch Kawasaki Energy Conservation Equipment Manufacturing Co., Ltd. (China)* Anhui Conch Kawasaki Equipment Manufacturing Co., Ltd. (China)* Shanghai Conch Kawasaki Engineering Co., Ltd. (China)*
	• Industrial gas turbines (for cogeneration, emergency power generators), gas engines for power generation, industrial steam turbines • Centrifugal compressors, air blowers and other aerodynamic machinery • Main engines, propulsion systems and other marine machinery	Kobe Works (Kobe, Hyogo Prefecture) Akashi Works (Akashi, Hyogo Prefecture) Harima Works (Harima-cho, Hyogo Prefecture) Wuhan Kawasaki Marine Machinery Co., Ltd. (China)
	• Air conditioning equipment, general-purpose boilers	Kawasaki Thermal Engineering Co., Ltd. • Shiga Works (Kusatsu, Shiga Prefecture)
	• Crushers, recycling equipment and plant	EARTHTECHNICA Co., Ltd. • Yachiyo Works (Yachiyo, Chiba Prefecture)
	• LNG carriers, LPG carriers, crude oil carriers, bulk carriers, container ships, car carriers, high-speed vessels, submarines, ships for government and municipal offices	Kobe Works (Kobe, Hyogo Prefecture) Sakaide Works (Sakaide, Kagawa Prefecture) Nantong COSCO KHI Ship Engineering Co., Ltd. (China)* Dalian COSCO KHI Ship Engineering Co., Ltd. (China)*
Precision Machinery & Robot	• Hydraulic equipment for construction machines, hydraulic equipment and systems for industrial machines • Marine application machines, gear and other marine deck equipment • Industrial robots • Medical and pharmaceutical robots	Akashi Works (Akashi, Hyogo Prefecture) Nishi-Kobe Works (Kobe, Hyogo Prefecture) Kawasaki Precision Machinery (U.K.) Ltd. (U.K.) Kawasaki Precision Machinery (U.S.A.), Inc. (U.S.A.) Wipro Kawasaki Precision Machinery Private Limited (India) Kawasaki Precision Machinery (Suzhou) Ltd. (China) Kawasaki Chunhui Precision Machinery (Zhejiang) Ltd. (China)* Kawasaki (Chongqing) Robotics Engineering Co., Ltd. (China) Flutek, Ltd. (Korea)
	• Hydraulic presses	Kawasaki Hydromechanics Corporation (Akashi, Hyogo Prefecture)
Powersports & Engine (Kawasaki Motors, Ltd.)	• Motorcycles, off-road four-wheelers (Side × Sides, ATVs), Jet Ski® personal watercraft • General-purpose gasoline engines	Head Works (Akashi, Hyogo Prefecture) Kakogawa Works (Kakogawa, Hyogo Prefecture) Kawasaki Motors Manufacturing Corp., U.S.A. (U.S.A.) Kawasaki Motores do Brasil Ltda. (Brazil) India Kawasaki Motors Pvt. Ltd. (India) Kawasaki Motors Enterprise (Thailand) Co., Ltd. (Thailand) PT. Kawasaki Motor Indonesia (Indonesia) Kawasaki Motors (Phils.) Corporation (Philippines) Kawasaki Motores de Mexico S.A. de C.V. (Mexico) Changzhou Kawasaki Engine Co., Ltd. (China)

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