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KAWASAKI TECHNICAL REVIEW

Special Issue on Motorcycle & Engine

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Kawasaki
A Class Apart
Kawasaki

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The Present Situation of the Motorcycle & Engine Business and its Development Going Forward

Yuji Horiuchi
Managing Executive Officer
President, Motorcycle & Engine Company

How do you feel about the business environment and conditions of the Motorcycle & Engine Company?

The Motorcycle & Engine Company is doing business in the fields of motorcycles, four-wheel vehicles, personal watercrafts (PWC), and general-purpose engines.

The motorcycle market had been shrinking since the global financial crisis in 2008, or the so-called Lehman Shock, but is currently recovering gradually in Europe and Japan, shows signs of bottoming out in Thailand and Indonesia, and has been growing steadily in the Philippines. We can say this market is enjoying strong growth. In 2017, we released the Z900RS, Ninja H2 SX, and other new models in succession, attracting a lot of attention from home and abroad, so we would like to take this opportunity to further increase sales.

As for four-wheel vehicles, the U.S. Side × Side market has more than doubled in the past ten years and is expected to see stable growth. As for general-purpose engines, with the growing housing market in the U.S., the mower market is enjoying very strong growth. Under such a situation, we expect that the four-wheel vehicles and general-purpose engines business will become a core revenue source.

At the same time, motorcycle manufacturers are now moving toward industry reorganization. Especially Indian and Chinese manufacturers are growing rapidly, and those manufacturers who lack competitiveness in research & development are forced out of the market or taken over. With increasingly strict emissions regulations and the advancement of electrification, autonomous driving, and driving assistance technologies, the motorcycle, four-wheel vehicle, PWC, and general-purpose engine markets are undergoing a once-in-a-century paradigm shift, and so, research and development are becoming more important than ever.

What is your future business strategy?

First, we will continue to work on the three reforms in the 2016 mid-term plan: demand chain reform, product competitiveness improvement reform, and supply chain reform. For the demand chain reform, we aim to establish a brand clearly distinct from competitors' brands with "A Class Apart" as the keyword. For the product competitiveness improvement reform, we aim to establish a framework for developing products ahead of competitors with "Fun to ride" and "Ease of riding" as the keywords. For the supply chain reform, we aim to enhance capital efficiency through efficient operation of the entire supply chain system.

As for motorcycles, we are paying close attention to the Indian market. In India, the motorcycle market is expected to grow with the active economy, so we established a new factory in July 2017, and in addition, we are promoting local parts procurement and have established a local R&D base for active business expansion.

In the U.S. four-wheel vehicle market, we will continue to enhance our model lineup, including accessories. For general-purpose engines, we will strengthen the cooperation with the local R&D bases in the U.S. to increase the market share.

What's the brand strategy?

The Motorcycle & Engine Company is the only company among Kawasaki Heavy Industries, Ltd. that deals with B-to-C (business-to-customer) products, and I believe that the Motorcycle & Engine Company is leading the Kawasaki brand. Therefore, the Motorcycle & Engine Company is placing particular emphasis on enhancing brand value. With a good brand image, customers will think that Kawasaki products are worth the price. We are aiming to win the price competition with our Ninja and Z product brands.

Closing comments

The Motorcycle & Engine Company has a vision of continuing to grow mainly in the motorcycle, four-wheel vehicle, PWC, and other powersports markets as well as in the high value-added categories of the general-purpose engine market. These markets are undergoing radical changes. Amid such a situation, we would like to offer Kawasaki's unique, innovative products, clearly distinct from its competitors.

Product Development and Technology Deployment in Motorcycle & Engine Business

Hideto Yoshitake
Associate Officer
General Manager, Research & Development Division, Motorcycle & Engine Company

Introduction

In developing competing products in the Motorcycle & Engine business, which handles motorcycles and four-wheel vehicles (side-by-side and other off-road vehicles), and PWCs (personal watercrafts) as its core products, Kawasaki is aiming to establish demands, free from price competition, through the creation of brand value quite different from competitors. And it is doing so under the slogan "A Class Apart."

Today, Kawasaki is undergoing a so-called once-in-a-century transformation of transportation devices, amid which, for example, realizing a low-carbon society is required due to increasing demands for environmental regulations, and is working to develop technologies incorporating new technologies, such as electrification, communication, and advanced assistance systems, as well as existing technologies.

For general-purpose engines that are traded business-to-business, Kawasaki has achieved a share of over 50% in the commercial mower market in North America, and has achieved its unique position with the highly reliable brand image that Kawasaki has been developing for a long time.

1 Kawasaki brand

Since 2010, the Motorcycle & Engine Company has been researching brand images with affective engineering. This research revealed that the customers use "Reliability," "Activity," and "Desirability" as psychological scales in their recognition of a brand. With this understanding of the psychological position of each brand on the brand impression map drawn based on these three psychological scales, Kawasaki has set "achieving a higher rank" as its goal. This gave birth to the brand slogan, "A Class Apart," which serves as a policy for our brand value creation.

2 Products free from price competition

Motorcycles are categorized into various types including the supersport type, which is close to racing models, the naked type, which is a street model with a casual atmosphere, the touring type, which is for enjoying a long ride, and the off-road type, which is for riding through untamed terrain, but customer preferences change every moment. In recent years, with an aging customer base, customers tend to prefer the touring type and classic style, which are more comfortable to ride. Taking this tendency into account, we released the Z900RS (**Fig. 1**) and Z900RS Cafe, which enjoy popularity as products that evoke the brand image at a glance and suit the times. We also released the Ninja H2 SX, which is expensive but enjoys a good reputation from many customers as a product for enjoying high-quality and comfortable touring.

For four-wheel vehicles, we have a brand lineup called MULE, which is used for a very wide range of applications, including workplace patrolling, trail riding, and camping. In particular, the MULE PRO has enjoyed a good reputation for a long time. It is equipped with our unique transformation mechanism that enables the vehicle to be used as both a three-passenger vehicle and a six-passenger vehicle according to the application and has an increased cruising speed (**Fig. 2**).

3 Engine technology

Kawasaki has developed supercharged engines for motorcycles and has been continuously working to improve their performance. For the Ninja H2 SX (**Fig. 3**), we pursued high power, excellent acceleration, and fuel economy, and successfully improved both the running performance and environmental performance. Moreover, we equipped the Ninja H2 SX with traction control, thereby achieving high reliability even for long-distance touring involving staying overnight with heavy loads, riding double, and riding on various road surfaces.

4 Chassis technology

For the Ninja 250 and Ninja 400 (**Fig. 4**), we achieved

Fig. 1 Z900RS

Fig. 2 MULE PRO

Fig. 3 Ninja H2 SX

† The Ninja H2 SX has high power and powerful acceleration which are features of the supercharged models, and at the same time has higher fuel economy than other Kawasaki models that have the same level of power.

Fig. 4 Ninja 400

light riding and significant weight reduction, thereby allowing more customers to enjoy "Fun to Ride" and "Ease of Riding" securely and safely. These models enjoy a good reputation even from first-time motorcycle riders and female riders, leading to the creation of new customer segments.

5 Various analyses supporting added value

One of our efforts to increase customer confidence is introducing the latest analytical technologies for accurate development. Structure, strength, heat, fluid, vibration, sound, and material are analyzed, each of which has a great influence on engine and chassis design. For example, sound is an important factor for motorcycles, from which value is created through the five senses. Creating attractive sounds contributes to adding value to products, so we have been developing the sounds of intakes, and have recently begun developing the sounds of exhaust systems (**Fig. 5**).

6 Exterior design

The technologies supporting exterior design include three-dimensional design, computer graphics, virtual reality, and surface treatment. Recently, exterior surface treatment technology has made significant progress, which has made silver mirror painting possible, which offers a metal-like appearance, and paints with a self-repairing function. This has enabled the sense of high-quality to last longer, thereby offering an enhanced feeling of attachment. We developed the technologies necessary to apply these technologies to mass production and have adopted them

Fig. 5 Z900RS Cafe

†† The Ninja 400 is over 20% lighter than the base model, and has improved fuel economy, reduced power weight ratio, and significantly reduced emissions.

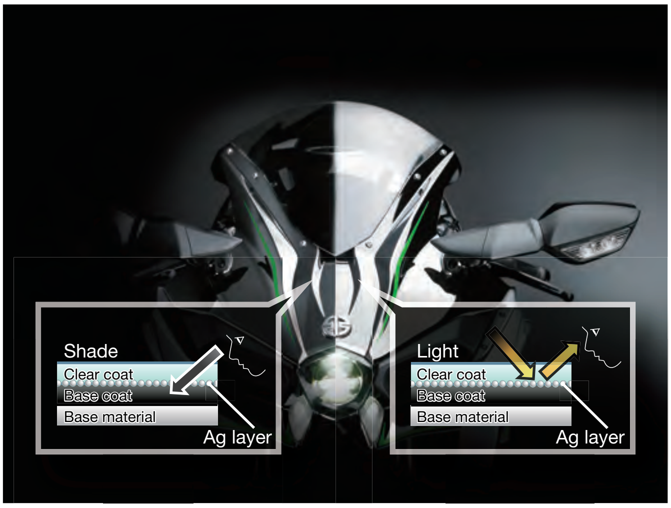


Fig. 6 Silver mirror Paint

for the Ninja H2 and other models (**Fig. 6**).

7 Efforts to expand brand recognition

(1) Efforts in dealers

In the Japanese market, we are developing Kawasaki brand shops and deploying them throughout the nation. This activity is intended to offer high-level hospitality as well as space that can be enjoyed with the five senses and to promote the creation of brand value free from price competition. The affective engineering we introduced about ten years ago has allowed for brand image integration with the five senses, shop design based on the objective analysis of a high-quality feel, and unique hospitality presentation. This also contributes to product demand creation (**Fig. 7**).

(2) Efforts in racing

Kawasaki has been participating in the World Superbike Championship (**Fig. 8**), motocross races in North America and Europe, and other races. Especially in the World Superbike Championship, Kawasaki won its fourth consecutive championship for the first time in its history. This success was the fruit of the technologies developed by our continuous efforts, and was only possible because we worked as a team.

Kawasaki also participated in the Asia Road Racing Championship (**Fig. 9**). Aside from the aim of winning, the race was also an important opportunity to improve local mechanics' and riders' skills in Asian countries. Moreover, in the new 300cm^3 class of the World Supersport Championship, Kawasaki's female rider won the first championship, shining brightly in the male-dominated

Fig. 7 Kawasaki Plaza

Fig. 8 World Superbike Championship

Fig. 9 Asia Road Racing Championship

motorcycle world (**Fig. 10**). I think that females will be both key customers and professional riders.

8 General-purpose engines

For general-purpose engines, we are doing business mainly in North America. The demand for engines for general households has been stagnant because the main customer base is aging and increasingly tend not to mow grass on their own. However, more people are hiring professionals to mow their grass instead of doing it on their own, boosting sales in the commercial market (market for professional use). Kawasaki is continuously developing reliable products in the commercial market, thereby maintaining a high market share.

In recent years, we are offering products equipped with electronic fuel injection systems, which enjoy a high reputation in the market (**Fig. 11**). The commercial market is expected to continue growing and become more competitive. We will strengthen our development system so that we can release optimal products to the market ahead of our competitors.

9 Future technologies

With Kawasaki's cooperate slogans, "realizing a low-carbon society," "realizing a recycling-oriented society," and "symbiotic society," the Motorcycle & Engine Company is working to further reduce fuel consumption, weight, noise, and chemical substances through technological development.

For electrification, advanced assistance, communication, and other technologies, we are maintaining a system that enables cutting-edge technical

Fig. 10 World Superbike Championship 300

Fig. 11 Kawasaki FT730V-EFI

research through not only market competition but also clarification of fields that we research to gain know-how on our own and fields in which we can collaborate with other companies regardless of industry type.

Conclusion

Motorcycles and four-wheel vehicles are globally traded products, and are recognized not only as a useful means of transportation, but also as a hobby. In this rapidly changing world, with the slogan "KAWA-ru SAKI-e," or "Changing forward" in English, we are developing products prior to competitors that can offer society a secure, safe, new lifestyle are as well as offering "Fun to Ride" and "Ease of Riding."

For general-purpose engines, we will reflect customers' demands in our products so that they continuously mature to make our products more reliable, convenient, and irreplaceable.

Development of Ninja H2 Series for Excellent Acceleration Performance

To achieve the excellent acceleration performance in response to various requests for motorcycles from customers, we developed the Ninja H2R and Ninja H2 in 2015, which are equipped with a supercharged engine. Moreover, we developed the Ninja H2 SX in 2018, which has enhanced daily usability. To develop these models, we combined Kawasaki Heavy Industries Group's supercharger with aerodynamic, combustion, robot and other technologies, while developing new technologies based on craftsmanship.

Introduction

Some riders of large motorcycles want to make their life more productive through extraordinary experiences. These people enjoy riding motorcycles in their own unique ways and are seeking not only high performance but also excitement from their motorcycles.

1 Background

In response to customer's diverse requests[1] for the kind of overwhelming acceleration that cannot be experienced in daily life, we decided to develop the Ninja H2 series and equip it with a supercharged engine[2]. To develop the Ninja H2 series, we applied Kawasaki's supercharger technology, aerodynamic technology for achieving stability, combustion technology for preventing abnormal combustion, and other technologies and at the same time developed new production technologies based on craftmanship with the aim of pursuing uniqueness and innovation and developing motorcycles incorporating first-class technologies.

2 Product concept

We decided to first develop the Ninja H2R in the pursuit of ultimate performance, and then offer the Ninja H2 and Ninja H2 SX, equipped with enhanced equipment for riding on public roads.

(1) Ninja H2R (photo above)

Ultimate motorcycle for experienced riders

- Engine displacement : 998 cm^3
- Engine power : 228 kW {310 PS}
- Riding stability : Stable even at speeds exceeding 300 km/h
- Design : Shape that pursues functional beauty
- Finished appearance : Elaborately finished appearance that makes its owner proud
- Riding environment : Closed course
- Riding capacity : 1 person

(2) Ninja H2 (Fig. 1)

Inheriting the design concept of the Ninja H2R, the Ninja H2 has additional equipment necessary for riding on public roads (e.g., headlight, rearview mirrors, turn signal lights, equipment necessary for compliance with noise and emissions regulations).

- Engine power : 147 kW {200 PS} (2015 year model)
  : 170 kW {231 PS} (2019 year model)

(3) Ninja H2 SX/Ninja H2 SX SE (Fig. 2)

More equipment has been added to the Ninja H2 for riding on public roads.

- Riding capacity : 2 people
- Ease of loading : Can be equipped with pannier cases
- Fuel economy : Improved from the Ninja H2 by 25%
- Riding posture : More upright position

3 Development policy

To achieve high engine power and riding stability, which are the product concepts of the Ninja H2 series, we decided to develop a new supercharger, supercharged

Movie

Fig. 1 Ninja H2

Movie

Fig. 2 Ninja H2 SX SE

engine, trellis frame (frame structure consisting of high-tensile steel pipes arranged in truss form), aerodynamic devices, and other components. In addition, we determined to offer the product expected of us by using total-vehicle computational fluid dynamics (CFD) analysis and manufacturing based on craftmanship.

Because technical elements not used in conventional motorcycle development were needed for this development, we adopted other companies' and the Corporate Technology Division's technologies early on in the development to harness the synergy of Kawasaki's technologies. These technologies include superchargers and supercharged engines, aerodynamic devices for improved stability during high-speed riding, and robot welding for a beautiful appearance.

4 Introduction of technologies

(1) Newly developed technologies

(i) Supercharger and supercharged engine

Motorcycles have an extremely wide engine speed range of 1,200 to 14,000 min^{-1} and extremely high specific power (power/mass), so they can accelerate and decelerate rapidly, which is accompanied by rapid changes in engine speed. In addition, motorcycles are required to respond precisely and instantaneously to the rider's commands. To satisfy these requirements, we designed and developed a centrifugal supercharger exclusively for motorcycles.

Moreover, we developed the engine and supercharger at the same time, thereby achieving high efficiency with advanced matching. This has allowed us to achieve a lightweight, compact motorcycle that has high power but does not require the use of an intercooler as shown in **Fig. 3**.

(ii) Trellis frame

Even with high engine power, the rider cannot ride with a sense of security if the vehicle does not have high stability. To ensure stability, the Ninja H2 series adopts a frame structure consisting of high-tensile steel pipes arranged in truss form (trellis frame) as shown in **Fig. 4**.

In general, the characteristic values for the vehicle frame are increased to ensure stability. The ZX-10R series uses aluminum materials with relatively low specific gravity, and in addition, adopts a frame made from hollow casting to achieve a lightweight, high rigid frame. A feature of this frame is that it can provide high stability in a high-speed range, but it may cause the vehicle to have high-frequency behavior if the vehicle is disturbed due mainly to bumps in the road and rapid road surface changes. For racing vehicles, emphasis is placed on weight reduction, but this high-frequency behavior causes general riders to feel uneasy. Therefore, for the Ninja H2 series, we adopted high-tensile steel pipes that have higher specific gravity than aluminum and high-strength materials to decrease the stiffness and characteristic values by bringing the thickness down to a minimum, thereby contributing greatly to developing a main frame with the concept of “avoiding disturbances with agility.”

In addition, the Ninja H2 series has a bolted swing arm

Movie

Fig. 3 Supercharged engine for Ninja H2 series

Fig. 4 Trellis frame

support at the rear of the engine crankcase as shown in **Fig. 5**. This has made it possible to efficiently absorb the reaction force from the drivetrain, thereby making it possible to reduce the weight of the main frame. This has also made it possible to optimize the stiffness around the swing arm pivot, greatly contributing to our ability to "parry disturbances lithely."

(iii) Aerodynamic devices

The Ninja H2R is required to run stably even at high speeds exceeding 300 km/h. In general, as motorcycles run faster the sense of contact between the front wheel and the ground decreases as lift increases. To prevent this and achieve high stability, we adopted aerodynamic devices that generate a downforce with wings.

Dog teeth, strakes, and other devices used on airplanes as shown in **Fig. 6** are aerodynamic devices that can satisfy the requirement that a downforce be generated with a minimum increase in air resistance. As shown in **Fig. 7**, the Ninja H2R has slotted flaps on its sides and wings that have strakes and dog teeth designed taking the cowl shape of the Ninja H2R at the upper front of the vehicle into consideration. When designing them, we used the automatic optimization technology with multi-objective genetic algorithm developed by the Aerospace Systems Company to increase the downforce through optimization.

(2) Total-vehicle CFD analysis

In the development of the Ninja H2 series, we conducted total-vehicle CFD analysis many times to enhance the engine cooling performance, reduce the running resistances and the lift, and ensure the rider's comfort. This analysis is intended to simulate with a computer how air or heat flows in and around all components during running, including the engine and chassis, and the rider.

In the past, conducting these measurements required making prototypes but today, with this analysis, we can conduct these measurements with 3D models created based on the drawings, enabling specifications to be selected in the conceptual stage.

(i) Study on engine cooling performance

The amount of air that passes through the radiator is an important factor in ensuring engine cooling performance, and it depends greatly on the cowl shape. We conducted total-vehicle CFD analysis as shown in **Fig. 8** to study the cowl shape, thereby successfully ensuring the required cooling performance without increasing the radiator size from the previous models.

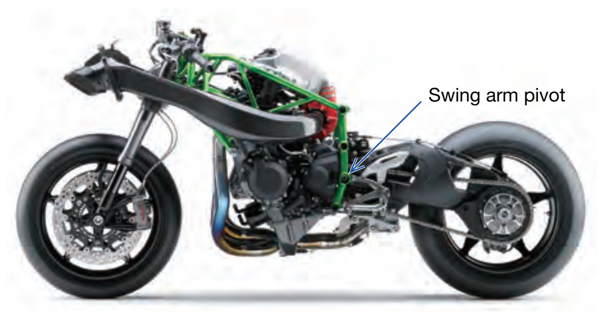
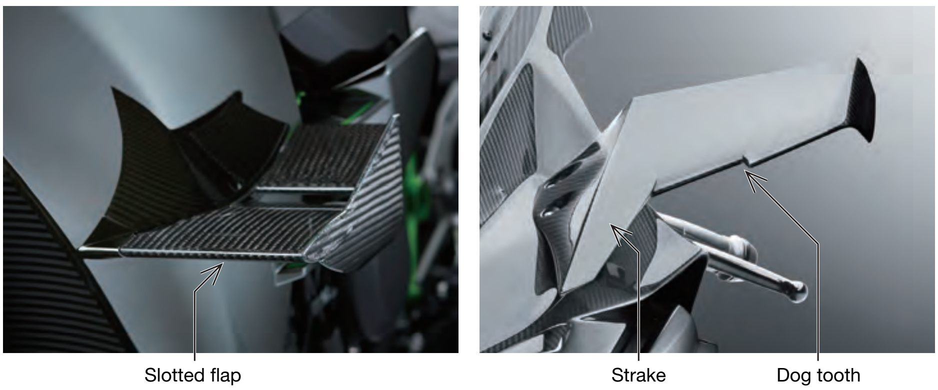


Fig. 5 Frame for Ninja H2R

Fig. 6 Aerodynamic devices used for aircraft



(a) Side

(b) Upper front

Fig. 7 Aerodynamic device shape of Ninja H2R

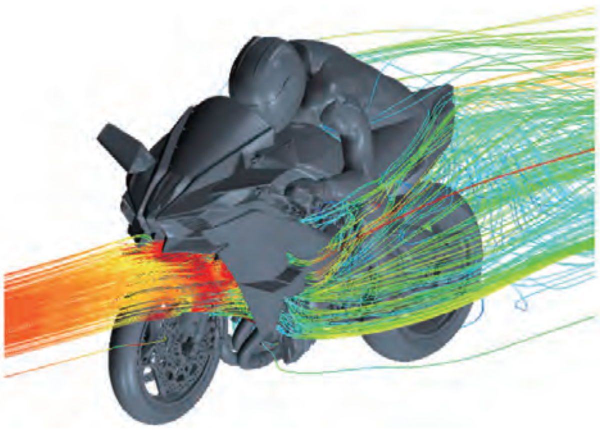


Fig. 8 Analysis results of engine cooling study

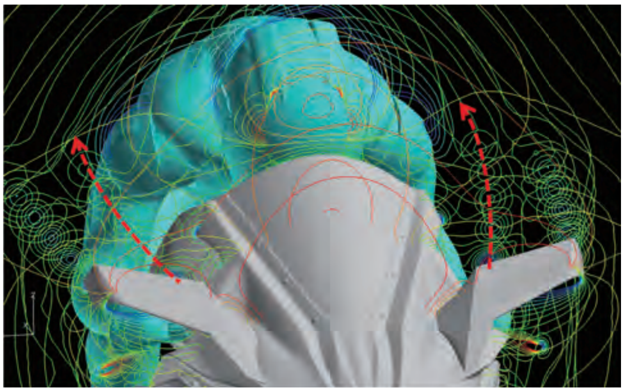


Fig. 9 Visualization of vortex flow using total-vehicle CFD analysis

(ii) Study on aerodynamic devices

In order to maximize the effects of the aerodynamic devices, it is effective to install the aerodynamic devices where the air flow velocity is high. We conducted total-vehicle CFD analysis to determine the most effective positions. In addition, we conducted total-vehicle CFD analysis to study the shape of each aerodynamic device, thereby successfully reducing the lift significantly. Moreover, we designed the strakes shown in **Fig. 7 (b)** so that the vortexes generated by air discharged from the strakes do not collide with the rider as shown in **Fig. 9** because the rider's comfort is adversely affected if these vortexes collide with the rider.

(3) Manufacturing based on craftmanship

The Ninja H2 series was manufactured and finished elaborately based on a design that pursues functional beauty and craftmanship so that not only its ride, but its very presence excites the rider.

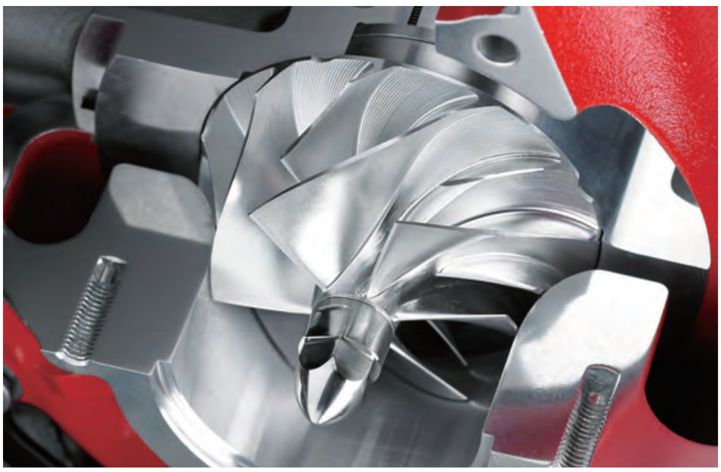
(i) Machining for the supercharger

The supercharger was developed, machined, assembled, and inspected at the Akashi Works in an integrated manner, thereby achieving high compression performance and efficiency.

Especially for the machining of the impeller shown in **Fig. 10**, the impeller blades have an extremely small thickness of approximately 1 mm and has a complicated curve shape that changes continuously in a spiral, which is likely to adversely affect the tool life and surface integrity and cause chattering vibration. For surface integrity, even an error of 10 μm greatly affects the supercharger performance, which could be felt by the rider during running. Therefore, we tested cutting tools of various shapes and conducted inspections well correlated with the riding performance, thereby achieving stable performance.

(ii) Assembly of the supercharger

The impellers rotate at an extremely high speed of 120,000 min^{-1} or higher. To prevent damage or noise due to



Movie

Fig. 10 Supercharger impellers

vibration, advanced balance adjustment is required. We fabricated a dedicated dynamic balancer and combined it with operators' advanced skills to adjust the balance to an accuracy of milligrams.

The supercharger performance also depends on the clearance between the impeller and housing. Therefore, the part shape was measured to an accuracy of micrometers to control the clearance between the impeller blade's end and housing inner wall.

All the finished superchargers are inspected with a special performance tester to check if the required performance is satisfied.

(iii) Frame welding

A typical example of craftmanship is frame welding with the emphasis on a beautiful finish. Conventional frame welding focuses on achieving the required joint strength, but for the Ninja H2 series, the focus was placed on the beauty of the weld beads in addition to the weld strength. The frame welding is evaluated on the following three points: the bead surface and width must be flat and constant; there must be no foreign matter such as weld spatter; and the start and end points of a weld must not be visible from the outside.

The Ninja H2's frame consists of thin pipes assembled in a complicated shape that can been seen on the finished vehicle. In metal active gas (MAG) welding, it is important to control the welding torch that is used to supply welding current and shield gas.

In order to achieve a flat, smooth bead surface, we first conducted basic tests to select the welder, welding conditions, welding wire, and shield gas. We then finely controlled the feeding of the welding wire at the start of welding and the welding current to reduce spatter. In addition, we improved the movement of the torch so that the start and end points of a weld overlap with each other where it is not visible from the outside as shown in **Fig. 11**.

To stably achieve such skillful welding, we developed a multi-axis coordinated-control welding robot cell shown in **Fig. 12**, which consists of a robot and workpiece positioner we produced ourselves. The robot cell controls the positions of the workpiece and torch so that they are always in the optimal positions.

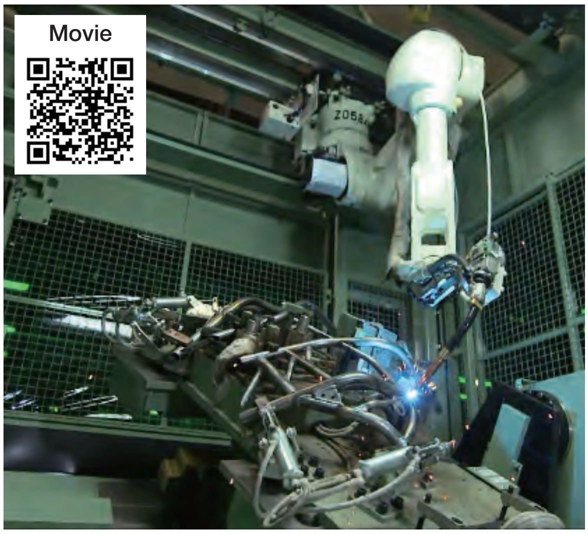


Fig. 12 Multi-axis coordinated-control welding robot cell

(iv) Chassis assembly

To enable mass-production of a motorcycle that gives top priority to achieving ultimate performance and functional beauty, we developed a new dedicated assembly line that is not subject to constraints caused by giving priority to productivity, including ease of assembly and standardization with other models, where assembly is done manually by experienced operators (craftsmen).

For this assembly line, we adopted the semi-automatic system for the first time where, unlike the continuous conveyor system adopted for other assembly lines, a self-propelled carrier having a hoisting function is moved to the next work place by the operator each time he or she has finished a task as shown in **Fig. 13**. With this system, the operator is able to assemble the parts with the vehicle

(a) Conventional welding **(b) Desired welding**

Fig. 11 Appearance of weld beads

Movie

Fig. 13 Self-propelled carrier

stationary, so they can consistently work with the same posture, thereby achieving stable assembly quality.

However, the workload per person for this assembly line is higher than that for other assembly lines, and therefore, we introduced Adrec's work assistance system for the first time so that standardized work is performed properly by each operator. This system displays the work content, the tools needed for the work, and other necessary information as text and images corresponding to the progress on the monitor installed at eye level to assist each operator in performing standardized work properly. In addition, this system has a traceability function to record work history, including the tightening torques and installation of critical parts, so that such information can be confirmed even after sales. This system was developed by modifying the system used for assembling the Trent1000 engine in the Aerospace Systems Company for use with motorcycles.

In addition, we paid particular attention to lighting to achieve the same appearance as under sunlight and have experienced inspectors keep a close watch to prevent defective products (flaws, etc.) from being shipped.

(v) Silver mirror painting

In mass production, we adopted silver mirror painting for the first time in our industry. Silver mirror painting uses a silver mirror reaction to form a real silver film, thereby expressing a "true" metallic feeling unlike conventional metal-like painting. Until now, silver mirror painting has not been used for exterior parts mainly because it was difficult to get another paint to bond to the silver film and the silver film would cause the paint film to deteriorate easily when exposed to sunlight. However, we were finally able to solve these problems and have successfully applied silver mirror painting to mass production. In addition, we reduced the thickness of the silver film so that the black undercoat could be seen through the silver film as shown in **Fig. 14**, thereby expressing "next-generation decorative painting with a luxurious look" with unique colors and shades.

(vi) Highly durable paint

To maintain the beauty of silver mirror painting and satisfy customers, we jointly developed a new paint with a paint manufacturer focusing on self-resilience, which means the ability to recover from scratches. This highly durable paint can recover from scratches with its elastic resilience as shown in **Fig. 15**. We developed this paint with an emphasis on the speed of self-recovery so that the customer could experience the recovery from scratches. At first, none of the paint films with quick recovery could satisfy Kawasaki's quality standards, but we successfully developed Kawasaki's unique self-recovering paint by optimizing the paint composition. We verified the effectiveness of the self-resilience by scraping the fuel tank of the Ninja H2 with wire brush as shown in **Fig. 16**. This highly durable paint has enabled the beauty of silver mirror painting to last longer.

Movie

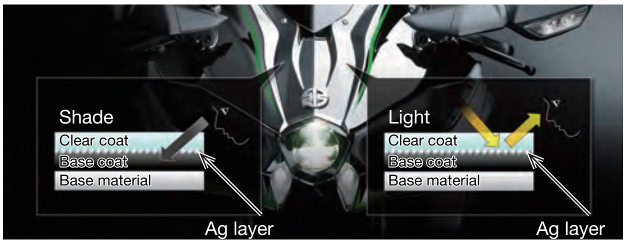


Fig. 14 Silver mirror Paint

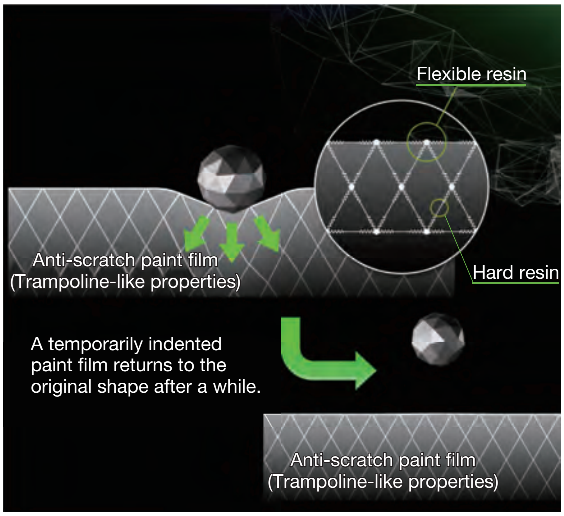


Fig. 15 Recovery mechanism

Fig. 16 Vehicle test results

Conclusion

For the Ninja H2 series, we realized motorcycles incorporating first-class technologies with the synergy of Kawasaki's own technologies, including supercharger technology. At a test-ride event for riders who are motorcycle magazine writers, the Ninja H2 series was highly regarded for its incredibly strong acceleration and ease of riding.

Movie

With further improved fuel economy and daily usability, The Ninja H2 SX has enhanced rider's convenience in a wide range of applications.

We will develop motorcycles that offer riders around the world fulfilled lives and ambitious dreams based on the concepts, "Fun to ride," "Ease of riding," and "Environment."

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Development of Supercharged Motorcycle Engines

We developed supercharged motorcycle engines as power units that meet various customer demands by utilizing our own compressor technology. By developing and fabricating supercharged engines ourselves, we pursued high-level supercharger efficiency and optimal vehicle characteristics, successfully developing a "power-type" supercharged engine, which achieves the ultimate feeling of acceleration with a size of 1, 000 cm³, and a "balanced-type" supercharged engine, which achieves a better-than-ever balance between power and fuel economy.

Introduction

One of the many demands from motorcycle riders[1) is making their lives more productive through extraordinary experiences.

1 Background

Creating a feeling of acceleration that we cannot experience in our daily lives is a part of "Fun to ride" and has always been required of motorcycle engines. However, meeting the rapidly increasing need to satisfy environmental performance requirements conflicts with this, so achieving both of them requires innovative technologies. We adopted compressor technology for superchargers for motorcycle engines that Kawasaki developed on its own with the aim of achieving new heights in technology.

2 Development policy

(1) Characteristics required of supercharged engines for motorcycles

The supercharged engines for motorcycles were required to have the following characteristics:

- Followability to throttle operation: Feeling of being able to get an immediate response from throttle operation (within 0.1 second)
- Linear and quick response to throttle operation: Feeling of throttle operation and response always matching
- Feeling of acceleration: Feeling of being able to feel acceleration as intended

(2) Selection of a supercharger

Turbochargers are commonly used as superchargers for passenger cars. However, because of the way turbochargers work it is difficult to achieve zero turbo lag, and therefore, it is difficult to achieve the previously mentioned characteristics required for motorcycles. Electric superchargers[2) are available but they require a large battery and cannot be mounted in the small space of a motorcycle. For this reason, we selected a mechanically driven supercharger, which can follow the engine speed linearly.

For passenger cars, volumetric superchargers are commonly adopted, which can achieve a high pressure ratio at a low rotation rate. However, volumetric superchages are so large in volume and mass that they cannot be mounted on motorcycles. Therefore, we selected a centrifugal supercharger that is driven by the crankshaft as shown in **Fig. 1**, which is compact and lightweight, has a high flow rate at a high rotation rate, and can quickly follow changes in the engine speed with the small inertial mass of the rotating part.

We decided to develop and manufacture superchargers on our own (machining, assembly, adjustment, and performance measurement) so that we could develop optimal supercharger characteristics according to the application of the vehicle the supercharger was to be adopted for. In addition, we made use of the synergy with Kawasaki's gas turbine division in the development.

(3) Two supercharged engines

To tailor our own supercharged engine technology to various customer preferences, we planned to release

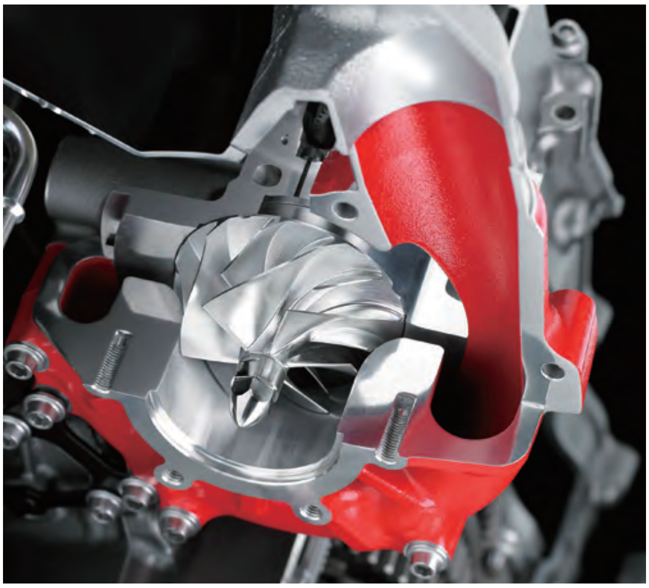


Fig. 1 Centrifugal supercharger (for Ninja H2)

several types of supercharged engines from the beginning of the development.

More specifically, we decided to develop power supercharged engines, as well as balanced supercharged engines, which balance maximum power and fuel economy, one at a time.

For power supercharged engines, we developed the Ninja H2R for riding on closed courses, which is equipped with a power supercharged engine that has a maximum power output of 228 kW (310 PS) and focuses on the power performances, and the Ninja H2 for riding on public roads, which is equipped with a supercharged engine that has maximum power of 147 kW (200 PS) and complies with the regulations of each country (2015 year models). For balanced supercharged engines, we developed the Ninja H2 SX (2018 year model), which is equipped with a balanced supercharged engine that balances maximum power and fuel economy, has maximum power of 147 kW (200 PS), and has 25% better fuel economy than the Ninja H2 in WMTC (World-Wide Motorcycle Test Cycle) mode .

3 Development of power supercharged engines

In the development of power supercharged engines as the first supercharged engine, we faced challenges controlling the intake air temperature, ensuring containment should the compressor impeller break, and establishing a supercharger drive system.

(1) Control of intake air temperature

Common supercharged engines use an intercooler to decrease intake air temperature to enhance charging efficiency and prevent knocking, thereby achieving high efficiency and high power. For motorcycle supercharged engines, however, it is difficult to use an intercooler because of restrictions on mounting space and mass, and therefore, we focused on supercharger compression efficiency. Compression efficiency refers to the ratio of the actual amount of work obtained to the theoretical amount of work that can be obtained, and the difference between the amount of work that can be obtained and the actual amount of work obtained appears as heat, which increases the intake air temperature. This means that increasing the supercharger compression efficiency makes it possible to prevent the intake air temperature from increasing and avoid knocking without using an intercooler. To achieve this goal, the supercharger is required to have the following three characteristics:

- High compression efficiency.
- High-efficiency region in a wide range of speeds.
- Actual service region that is consistent with the high-efficiency region.

To achieve these characteristics, we designed the impeller shape and housing shape of the supercharger with CFD (Computational Fluid Dynamics). We optimized the shape of the impeller so that airflow around each blade does not separate from the blade and stall, and designed the shape of the impeller so as to minimize loss at the flow rates in the low-, medium-, and high-speed ranges to cover the wide range of speeds motorcycles are driven in.

Figure 2 shows compressor maps that represent the compression efficiencies of a common centrifugal supercharger and Kawasaki's supercharger. These compression maps have the mass flow rate of air output from the supercharger on the horizontal axis and the

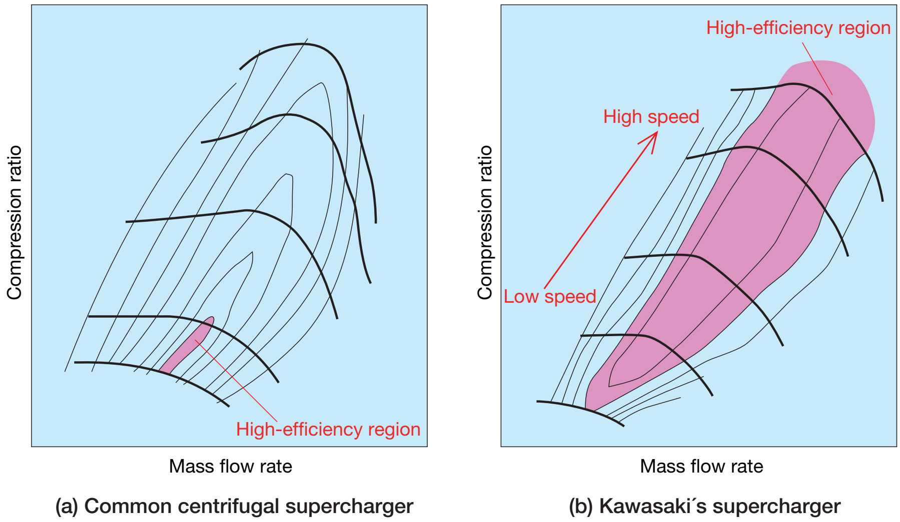


Fig. 2 Compressor map

compression ratio on the vertical axis. The thick lines running from the lower right to the upper left of each figure show the characteristics when the impeller rotates at a constant speed. These compression maps show that the compression ratio on the left side, which indicates the compression ratio at a low flow rate is higher than the compression ratio on the right side on the same lines, which indicates the compression ratio at a high flow rate. The thick lines at the lower left of each figure indicate characteristics when the impeller rotates at a low speed, and the thick lines at the upper right indicate characteristics when the impeller rotates at a high speed.

The thin lines are contour lines indicating the compression ratio, and the compression ratio becomes highest at the center of each line. The common centrifugal supercharger shown in **Fig. 2 (a)** has a high-efficiency region only in a limited area of the compression map. Kawasaki's supercharger shown in **Fig. 2 (b)** has a wide high-efficiency region extending in a ridge-like form and has higher maximum efficiency. This shows that the high-efficiency region lies at any impeller rotational speed, which means that the characteristic required for superchargers has been achieved.

(2) Containment in case the compressor impeller breaks

The supercharger is located very near the riding position, so should the impeller be damaged, broken pieces of the impeller must be contained inside the compressor housing. The compressor housing is required to have adequate strength and be lightweight. We conducted a crash analysis as shown in **Fig. 3** to develop the compressor housing.

For this analysis, the technology used for designing the

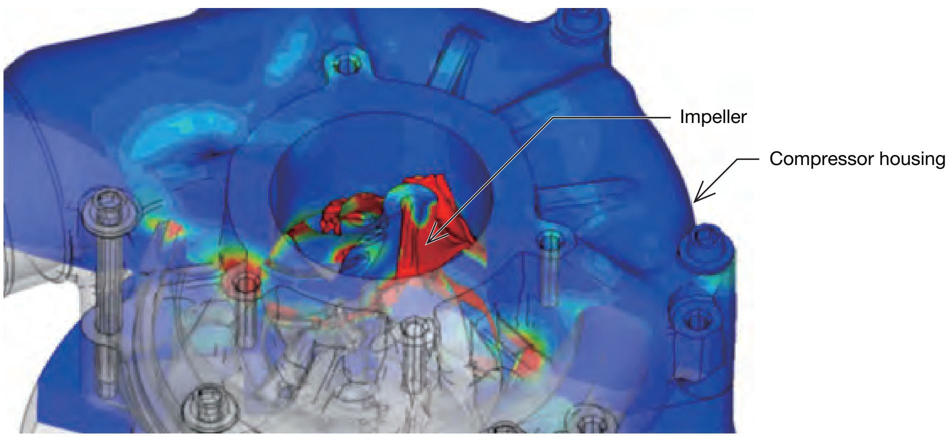


Fig. 3 Crash analysis

fan case of a jet engine was applied, which made it possible to accurately simulate how the impeller will behave after it flies apart and how the housing is damaged due to collision with broken pieces of the impeller. With this crash analysis, we developed a unique housing shape that is lightweight yet able to contain broken pieces of the impeller and at the same time conducted a containment rig test with an actual compressor to verify the performance.

(3) Establishment of a supercharger drive system

Figure 4 shows the drive section of a supercharger. With the gear located at the 6th web on the crankshaft, the shaft coaxial to the supercharger located at the rear of the engine is driven by the chain via the intermediate shaft also connected to the balancer and starter motor. Planetary gears are used as speed-increasing gears between the shaft and supercharger, thereby reducing the volume. With the planetary gears, the speed is increased eight-fold, and with other gears, the speed-increasing ratio totals 9.18, which means that when the crank speed is 14,000 min^{-1}, the impeller speed is approximately 130,000 min^{-1}. Instead of using a special oil, engine oil is used to lubricate the supercharger drive section, contributing to reducing the number of parts, saving space, and reducing the weight.

If the rotating shaft of the supercharger, whose rotational speed can reach 130,000 min^{-1}, resonates, the impeller may be damaged, so an oil film damper mechanism is used to control vibration. As shown in **Fig. 5**, which shows the bearing structure, an oil film layer is formed on the outer wall of the bearing casing to produce

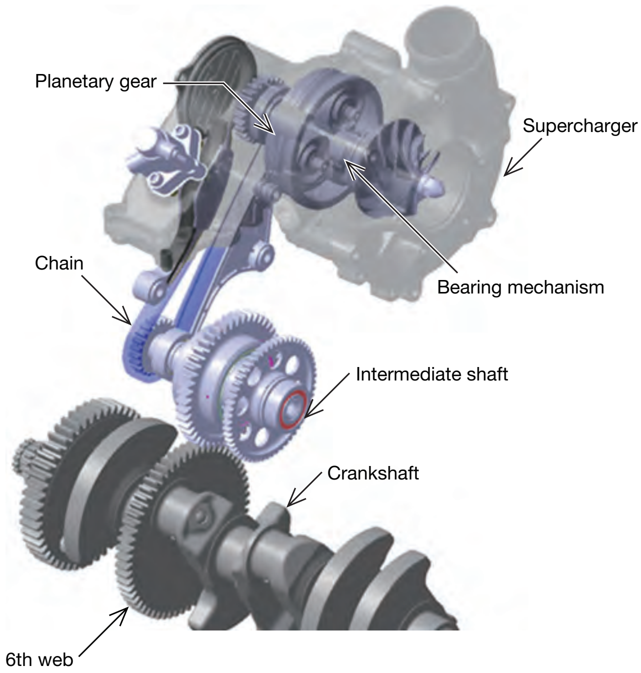


Fig. 4 Supercharger drive mechanism

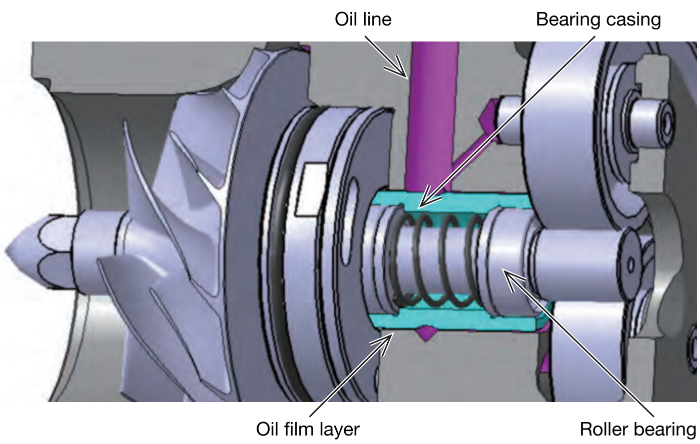


Fig. 5 Bearing structure

a damping effect. This effect varies depending on the oil film thickness, so we selected the optimal film thickness.

4 Development of balanced supercharged engines

We developed balanced supercharged engines based on the power supercharged engines we developed first. Unlike the power supercharged engines, which focus on the high-speed range where the maximum power is generated, balanced supercharged engines were required to have improved fuel economy and torque in the low- and medium-speed ranges for improved usability in daily use. Therefore, we developed balanced supercharged engines with the focus on increasing the compression ratio, optimizing supercharger characteristics, and optimizing the air intake structure.

(1) Increase of the compression ratio

Compression ratio represents the ratio of the minimum and maximum volumes of the combustion chamber when the piston reciprocates up and down. Increasing the compression ratio improves the fuel economy and torque. However, too high a compression ratio causes knocking.

For balanced supercharged engines, we increased the compression ratio from 8.5 (power supercharged engines) to 11.2, and at the same time optimized the supercharger and modified the air intake structure as described below, thereby preventing knocking.

(2) Optimization of the supercharger characteristics

For supercharged engines, the temperature of the air supplied from the supercharger must be lowered to avoid knocking. To achieve this, we optimized the characteristics of the supercharger in the low- and medium-speed ranges, which are more important for balanced supercharged engines. More specifically, we changed the attack angle of the impeller blade as shown in **Fig. 6** so that air flows smoothly when the flow rate is low.

Figure 7 shows the compressor maps of the power supercharger and balanced supercharger.

Unlike the power supercharger shown in **Fig. 7 (a)**, the

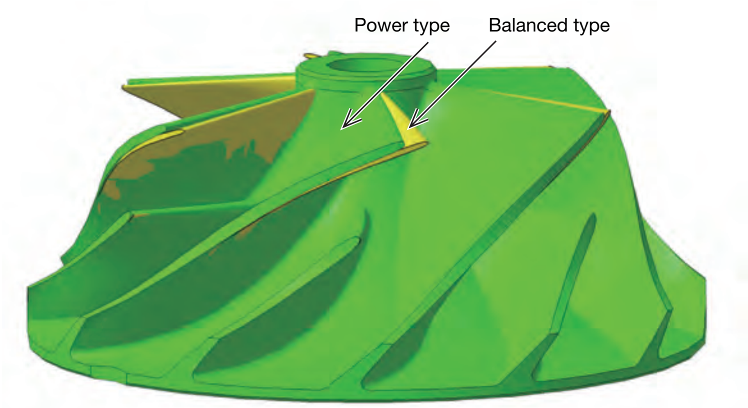
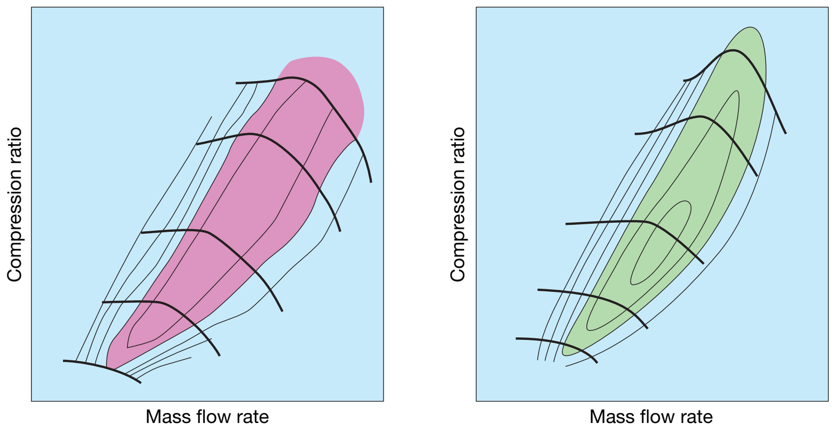


Fig. 6 Impeller blade shape



(a) Power supercharger

(b) Balanced supercharger

Fig. 7 Compressor map

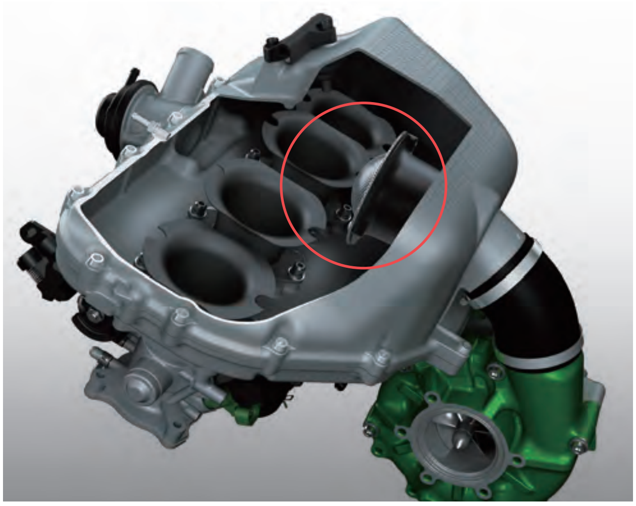


Fig. 8 Diffuser structure inside intake chamber

balanced supercharger shown in **Fig. 7 (b)** has a high-efficiency point on the low-speed low-flow rate side, and has higher maximum compression efficiency, meaning that the desired characteristics have been achieved.

(3) Optimization of the air intake structure

As shown in **Fig. 8**, we added a diffuser in the intake air chamber so that supercharged intake air flows smoothly into the chamber, thereby avoiding knocking with increased compression efficiency in the entire air intake system.

This structure has been applied to subsequent power supercharged engine models, contributing to improving the performance of the entire series.

Conclusion

Applying the compressor technology that Kawasaki developed on its own to motorcycle superchargers, we successfully developed power supercharged engines that offer customers an inspiring feeling of acceleration the likes of which we cannot experience in our daily lives. In addition, the development and deployment of balanced supercharged engines improved fuel economy and torque in the low- and medium-speed ranges for improved usability in daily use and expanded the applications and usage of motorcycles with supercharged engines, so more customers are able to experience Kawasaki's supercharged engines.

We will be developing motorcycles that can offer riders more productive lives and dreams.

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Development of the Latest Retro Sport Model Z900RS

In the motorcycle market, many customers like standard sport models. These customers focus on the history the brand has rather than vehicular performance, such as speed, and prefer relaxing motorcycles. For this reason, we developed a motorcycle that focuses on a neutral steering feel and an engine sound that inspires fun.

Introduction

In advanced countries, many people enjoy motorcycles as a hobby, so it is important to offer attractive models that appeal to customers' sensibilities. Especially in the Japanese market, many people prefer standard sport models.

1 Background

To develop an attractive model like the Kawasaki' standard sport model ZRX1200 DAEG and classic model W800, we conducted a market survey. The survey found that customers who select these categories place more importance on the style and history the brand has than vehicle performance such as speed.

2 Development concept

Based on the results of the market survey, we decided to focus our development on the Z brand, which has a long history beginning with the Z1 released in 1971, and continuing until the latest model, the Z900.

With "Timeless Z: Z, which has modern functions but an appearance that allows us to share timeless values," as the development concept, we decided not to develop a mere nostalgic model, but to incorporate the Z1's traditional style and the latest model's (Z900) performance into a new model. We thought that doing so would allow us to develop a model that could appeal to a wide range of customers from those who know the Z1 to young people. To achieve this, we needed to achieve a good balance between ease of riding and fun.

Therefore, we decided to develop a neutral steering feel that allows the rider to turn at corners as intended so that a wide range of customers can go for a relaxing ride. Moreover, because customers who own standard sport models demand a better sounding engine, we decided to develop comfortable engine sounds and focus our development on the exhaust system.

3 Development of steering feel

To allow a wide range of customers to go for a relaxing ride, a "neutral steering feel" is required, which allows the rider to turn the handlebars without conscious effort when turning. Therefore, we first identified the vehicle specifications that influence the steering feel when the vehicle is turning. Then, we developed a "neutral steering feel" with simulation technology before making prototype vehicles. Finally, using actual vehicles, we verified that a "neutral steering feel" had been achieved.

(1) Quantitative association of steering feel during steady turning with vehicle specifications

Steering feel during turning is closely related to steering torque, which is the force needed for the rider to turn the handlebars. Basic research found that a state in which no steering torque is applied during turning is a "neutral steering feel."[1] In addition, among various parameters of the vehicle, the steering torque during running is greatly affected by the caster angle and trail, shown in **Fig. 1**.

First, we defined steering torque during steady turning as shown in **Fig. 2**.

・Positive torque: Handling torque in the forward direction with respect to the turning direction
・Negative torque: Handling torque in the reverse direction with respect to the turning direction

Next, we quantitatively evaluated how the caster angle and trail affects steering torque. As shown in **Fig. 3**, as the caster angle widens, or as the trail shortens, the positive torque increases. For vehicles having a negative torque, therefore, the caster angle is widened or the trail is shortened to decrease the negative torque, thereby achieving a "neutral steering feel."

(2) Development of steering feel for the Z900RS

In the early stage of development, we developed the steering feel for the Z900RS by using the riding simulator shown in **Fig. 4**. The riding simulator is a real-time simulator that can simulate actual operations, including steering torque, throttle operation, and brake operation, and vehicle roll and pitch motion shown in **Fig. 5** in real time. The riding simulator enables us to experience a steering feel close to that of the actual vehicle even in the conceptual stage before a prototype vehicle has been made, allowing for efficient development.

In this development, we verified that the target steering feel of the Z900RS had been achieved with varying caster angles and trails in various riding situations. We then determined the caster angle and trail so that the most "neutral steering feel" would be achieved and so that the steering feel would remain the same even if the tire characteristics change.

(3) Verification of the steering feel of the Z900RS with the actual vehicle

We made a prototype vehicle having the vehicle specifications confirmed with the simulator and verified

Fig. 1 Caster angle and trail

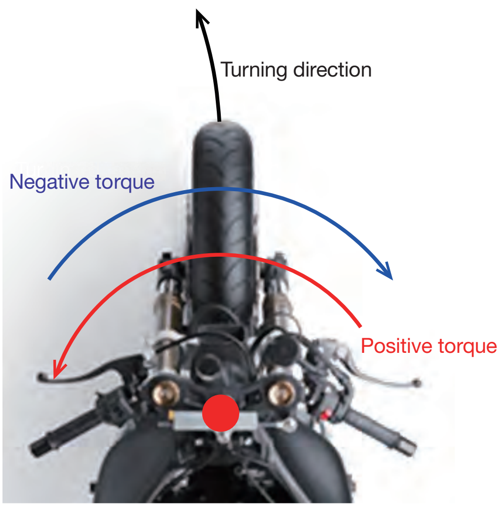

Fig. 2 Positive torque and negative torque

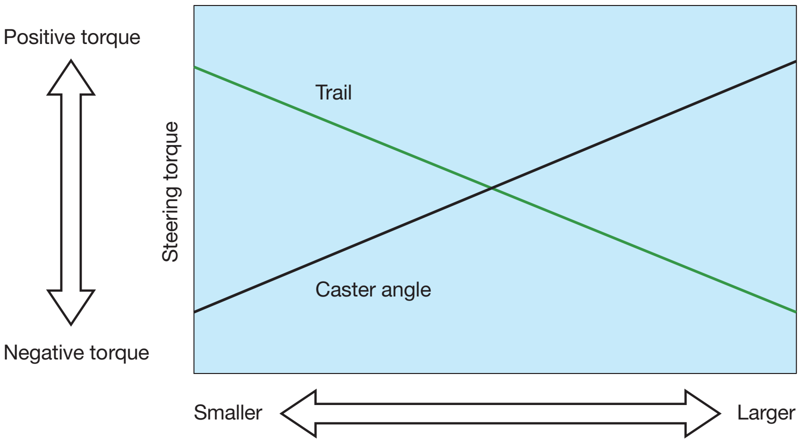

Fig. 3 Effects of caster angle and trail on steering torque

Fig. 4 Riding simulator

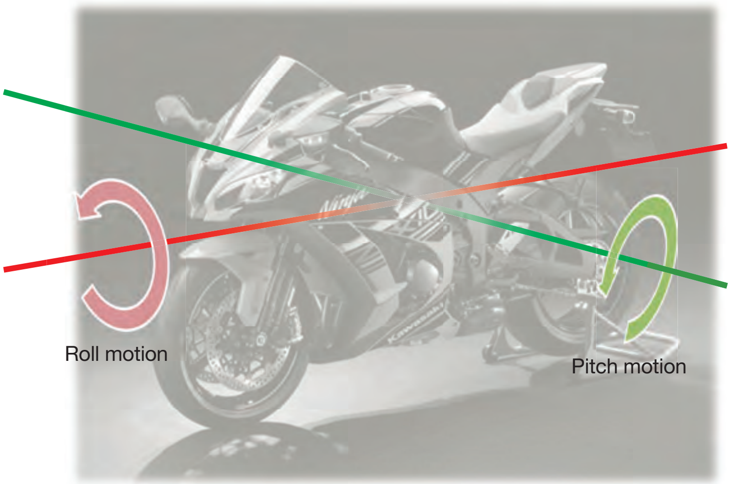

Fig. 5 Roll and pitch motion of motorcycle

the steering feel. Based on the riders' evaluation and measurement data, we confirmed that the target steering feel had been achieved.

Using the simulator enabled efficient development of the steering feel based on the vehicle specifications with a limited amount of time and ride testing.

4 Development of engine sounds

Engine sounds can be classified into the intake sound, exhaust sound, and mechanical sounds of the engine. To add value that could replace speed and performance to the Z900RS, we focused on the exhaust sound during idling and low-speed riding. To meet customer demands, the exhaust sound must be louder at lower engine speeds, where the rider enjoys listening to the exhaust sound, and must be deadened at higher engine speeds, where the exhaust sound is subject to noise regulations. We developed an exhaust system based on the technologies we cultivated for developing the intake sound for the Z1000 and other models[2)].

(1) Target setting with sensory evaluation technology

To scientifically determine what exhaust sound is attractive, or the target exhaust sound, we used an experimental method called the SD (Semantic Differential) method[3)]. The SD method is a sensory evaluation technology to objectively evaluate how humans sense something.

First, we recorded the exhaust sounds from representative models as samples. We had several people listen to these exhaust sounds and evaluate them from a prepared set of adjectives. We conducted a principal component analysis with the aggregation results, and represented the results of the impression evaluation of the exhaust sounds with a map consisting of evaluation and potency factors as shown in **Fig. 6**. Based on the directions of the lines indicating the models and adjectives in the map, we settled on a powerful and heavy sound as the target sound of Z900RS.

Next, we quantified the features of the exhaust sound of each model as physical quantities of sound. By conducting a multiple regression analysis with these values and plotting these values in the image map, the relationships between the adjectives and physical quantities can be identified, thereby enabling the quantification of the target exhaust sound.

(2) Development of the exhaust system

A powerful exhaust sound requires a certain level of sound but volume is limited by noise regulations. In addition, low-pitched tones, which are not contained in the original exhaust sound, are required to achieve a heavy sound. To meet these requirements, we developed a new exhaust system. The following describes the exhaust chamber that has a great influence on the exhaust sound. The exhaust chamber refers to the silencer between the exhaust pipe and muffler as shown in **Fig. 7**. The exhaust gas from the engine first reaches the silencer, making the

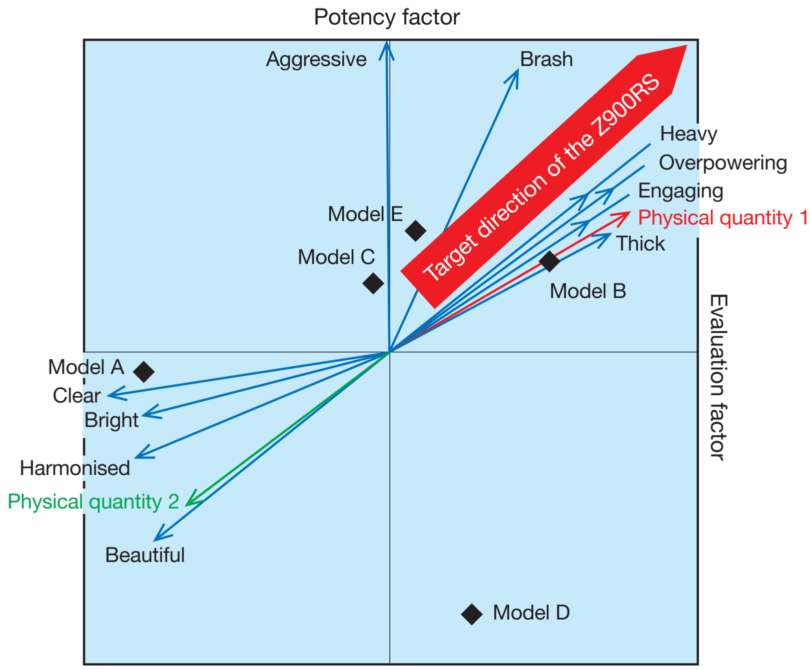

Fig. 6 Image map of engine sound

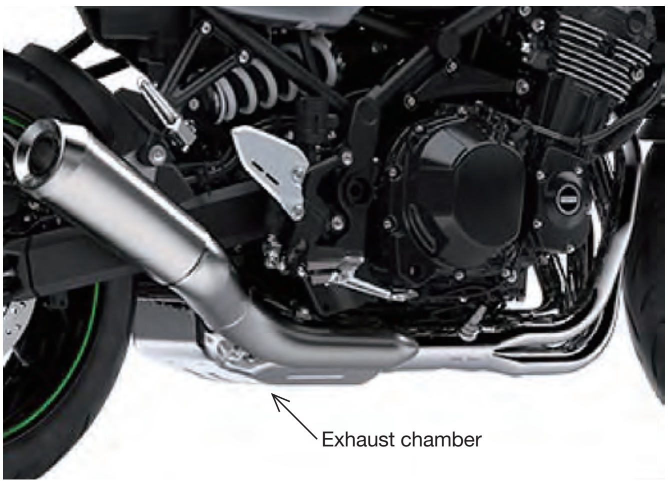

Fig. 7 Location of exhaust chamber

silencer an important part in the development of the exhaust sound.

Achieving the required exhaust sound requires controlling the flow of exhaust gas in the exhaust chamber at different engine speeds. In the exhaust chamber of the Z900RS, a tapered pipe having side holes is placed where the exhaust gas flows into the exhaust chamber from the exhaust pipe as shown in **Fig. 8**, so that the flow of exhaust gas and exhaust pulsation change according to the engine speed as shown in **Fig. 9**. At low engine speeds, a sound close to the original exhaust sound is emitted, which is moderately loud and has a low-pitched tone. At high engine speeds, the expansion chamber in the exhaust chamber is used effectively so that the exhaust chamber works as a silencer.

Using this exhaust chamber with the exhaust system, we successfully developed a "powerful and heavy exhaust sound" that complies with noise regulations.

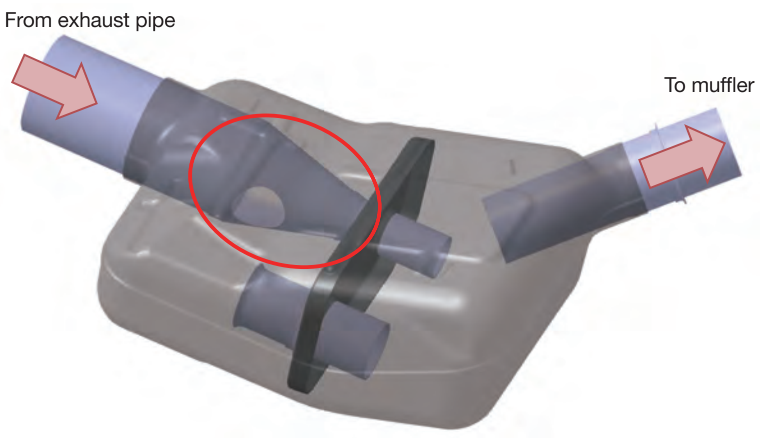

Fig. 8 Internal structure of exhaust chamber

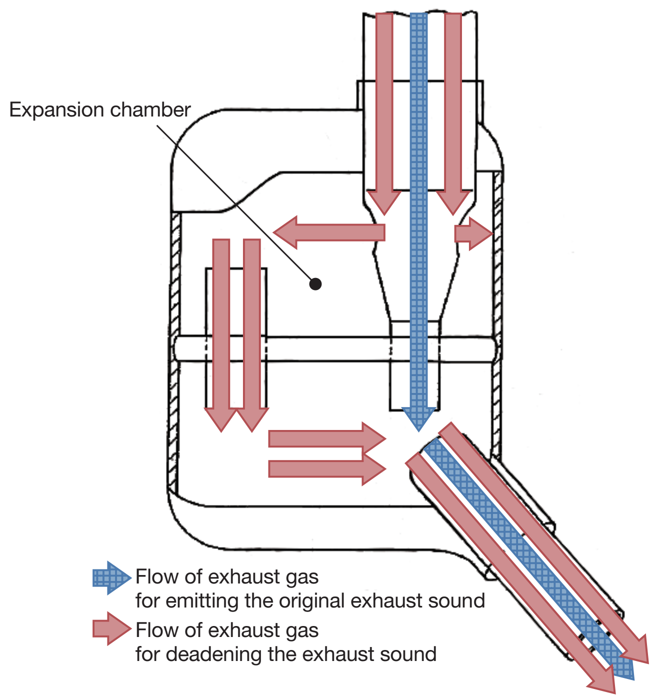

Fig. 9 Exhaust gas flow in exhaust chamber

Conclusion

We began mass-production of the newly developed Z900RS in September 2017, and the Z900RS CAFE, which is equipped with cafe style cowling as a derivative model of the Z900RS, in January 2018, both of which enjoy a high reputation not only in the Japanese market but also in the global market.

In the future, the motorcycle market is expected to become more competitive, and we are required to develop models that can more effectively appeal to customers' sensibilities. Based on the technologies we have so far cultivated and market survey results, we will continue developing our unique technologies and models to offer motorcycles that meet customer demands.

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Development of the Most Powerful Racing Motocrosser KX450

With an uncompromising attitude toward winning races, we have been continuously engaged in development with the aim of creating the fastest motocrosser in the world.

KX450, which has undergone a full model change, provides improved engine performance with finger-follower rocker arms and improved chassis performance with modified chassis stiffness balance.

Introduction

Motocross is a motor sport in which riders compete in speed races on an unpaved loop course of dirt and sand (motocross race track). Motocrossers start at the same time standing side by side and rush into the first corner, which creates a very powerful scene. The course includes huge jump ramps and a series of bumps as well as straight and curved sections, and figuring out how to best run these sections is the key to victory.

Many motocrossers used to have a two-stroke (2st) engine but four-stroke (4st) engine models were released in early 2000. Since then, because of their easy-to-handle torque characteristics, not only experienced riders but also beginner riders have been replacing their 2st models with 4st models, leading to the expansion of the entire motocrosser market.

1 Background

In response to such market trends, Kawasaki changed the engine of the KX, which is Kawasaki's flagship model, from a 2st 250-cm^3 engine to a 4st 450-cm^3 engine in 2005 and has been working to improve the engine power. In addition, we are required to continuously produce competitive products, and so have been continuing technological development.

2 Development concept

We set "Most powerful racing motocrosser" as the development concept. To win the title in a race every year, it is important to improve the machine's fighting power and provide the equipment necessary to constantly earn points.

To improve the fighting power, we decided to improve the engine power, steering stability, and cornering performance, and to constantly earn points, we decided to reduce the operation burden of the clutch lever and improve startability.

3 Improving the engine power

After a manufacturer releases a motocrosser, they continuously work to improve its engine power, so engine power is still increasing each year. Improving the engine power does not merely mean improving the peak power but the engine is required to have torque characteristics that can easily be handled by the rider as well. In racing, all the motocrossers start at the same time standing side by side. In order to be the first motocrosser (holeshot) that reaches the first corner, the engine is required to have excellent acceleration at high engine speeds. In addition, the engine is required to have good response in the low speed range to make a jump immediately after a corner.

In this model change, we adopted the finger-follower rocker arm mechanism shown in **Fig. 1**, instead of the tappet-type direct-hitting valve mechanism, thereby achieving significantly improved engine performance.

The greatest advantage of the finger rocker arm mechanism is that the mass of the moving parts in the valve train can be reduced. This is because the rocker arm has an oscillating motion and has much lighter moving parts than the tappet, which has a reciprocating motion. With the reduced mass, the following performance

Fig. 1 Finger-follower rocker arm

improvements have been achieved:

① Increasing the intake and exhaust valve sizes

We increased the intake valve size from 36 mm to 40 mm in diameter, and the exhaust valve size from 31 mm to 33 mm in diameter, thereby achieving high power with enhanced intake efficiency at high engine speeds.

② Reducing the valve overlap

We adopted a cam profile that provides high maximum lift and acceleration to decrease both the intake and exhaust operating angles and decrease the overlap shown in **Fig. 2** from 76 degrees to 68 degrees, thereby improving the low speed range performance with improved scavenging efficiency in the low speed range.

③ Increasing the maximum engine speed

Thanks to the reduced mass, the maximum speed has been increased by 200 min^{-1} from 11,500 min^{-1} to 11,700 min^{-1}, and the engine speed after an upshift made after the maximum engine speed is reached has also increased further, enabling smooth acceleration. This is a great advantage both at the start of a race and during the race.

For the final engine performance, we port matched the intake and exhaust parts and achieved torque characteristics that have a wide power band with a flat torque curve as shown in **Fig. 3** and can easily be handled by the rider.

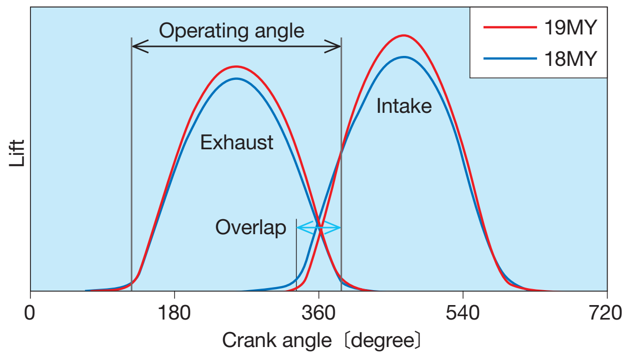

Fig. 2 Cam profile

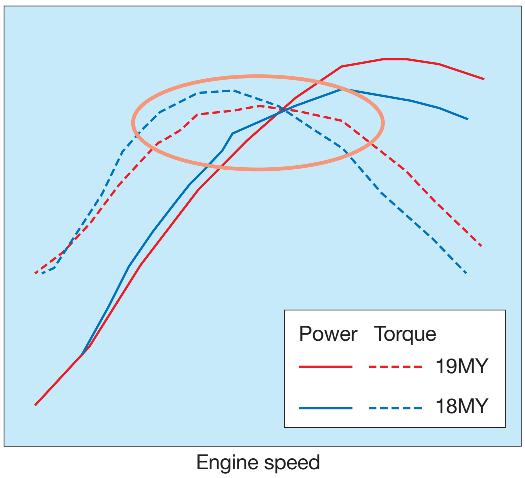

Fig. 3 Engine performance curve

4 Improving steering stability and cornering performance

On rough roads, like motocross race tracks (bumpy, unpaved roads), stable acceleration and deceleration and cornering cannot be achieved merely by increasing the frame stiffness. If it is too stiff, it causes the frame to be subject to direct shocks from bumpy roads and bounce, but if it is not stiff enough, it causes the frame to deform significantly, both of which may cause unstable frame behavior. For stable frame behavior, it is extremely important to allow the frame to bow moderately and absorb the shock with the suspension.

Therefore, we analyzed the strength and stiffness of the frame components, such as the main frame and swing arm and selected appropriate combinations of forged materials, cast materials, and extruded materials for these components, thereby achieving well-balanced stiffness.

(1) Main frame

To improve shock absorption and front and rear traction, we changed the stiffness balance of the main frame, which can be likened to the bone structure of the vehicle. **Figure 4** shows the results of the stiffness analysis.

We repeatedly conducted this stiffness analysis and changed the manufacturing method, shape, and material and clearly distinguished the areas where force is absorbed and where stiffness should be increased as shown in **Fig. 5**, thereby achieving improved shock

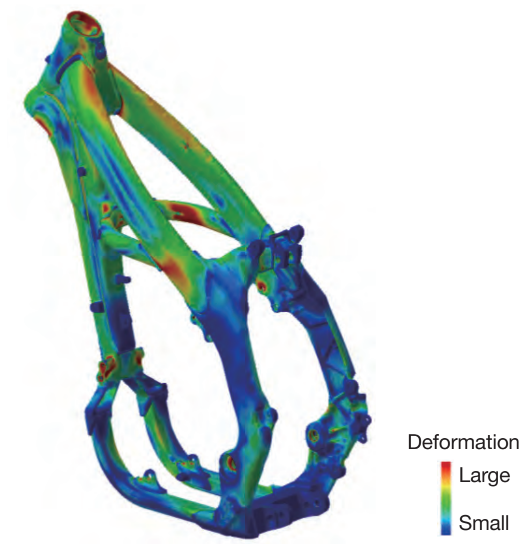

Fig. 4 Stiffness analysis results for main frame

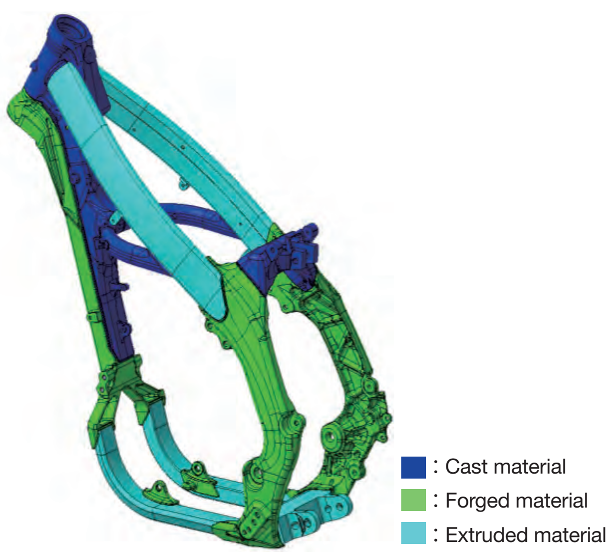

Fig. 5 Manufacturing methods for main frame components

absorbance and front and rear traction.

(2) Swing arm

To improve the rear traction, we changed the stiffness balance of the swing arm that connects the rear wheel and main frame. **Figure 6** shows an example of the stiffness analysis results.

We repeatedly conducted this stiffness analysis and changed the manufacturing method, shape, and material to increase the height of the widest section of the pipe as shown in **Fig. 7**, thereby increasing the longitudinal stiffness. At this time, the torsional stiffness increased, so we decreased the stiffness of the axle bracket, which supports the axle, thereby maintaining the cornering performance with a reduced increase in torsional stiffness. With these improvements, the rear traction has been improved both when the vehicle is traveling straight and turning.

In addition to the main frame and swing arm, we changed the stiffness of other components, such as the rear frame, engine mount, front fork, triple clamp, axle, and axle shaft to develop a frame that has both acceleration, deceleration, and cornering stability and light vehicle handling.

5 Reducing the operational burden of the clutch lever

In motocross, depending on the condition of the track, the clutch is operated frequently, not only when the engine is started and when the gears are changed but also for

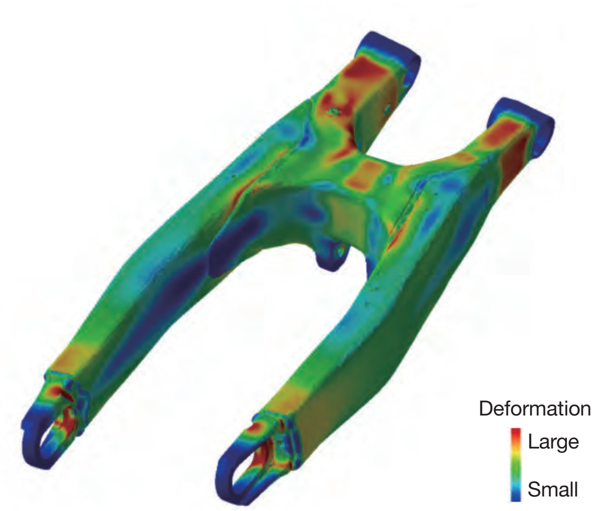

Fig. 6 Stiffness analysis results for swing arm

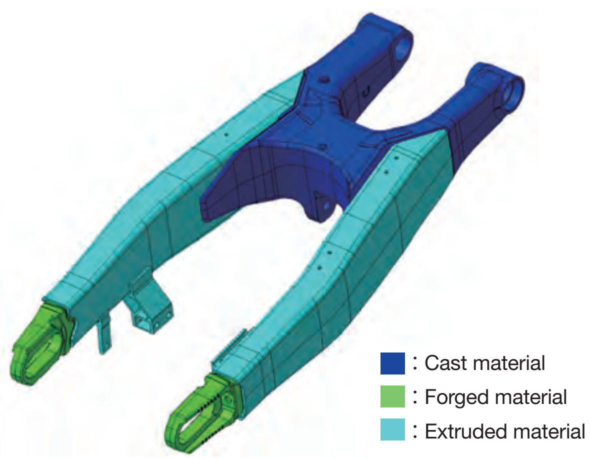

Fig. 7 Manufacturing methods for swing arm components

machine control while running. Especially in racing on sandy tracks and muddy tracks, the clutch is operated more frequently. Frequent clutch operation causes the clutch to get hot and expand in the axial direction, and as a result, the push rod pushing position changes, and the lever play changes accordingly. For a conventional cable clutch, which has been adopted because it is lightweight and can be serviced easily, a play adjustment mechanism is provided around the lever to address this problem. However, adjusting the lever play during a race adds to the burden of the rider.

A hydraulic clutch pushes the push rod via oil and automatically compensates for changes in the push rod pushing position because the amount of oil is automatically adjusted in response to lever operation. This eliminates the need to adjust the lever play while racing, which is the greatest advantage of the hydraulic clutch. However, because of the characteristics of a hydraulic clutch, it has a smaller engagement width than the cable clutch. This makes it difficult to control the clutch engagement at the start of a race, which means stable and quick start is impossible. Therefore, we adopted a judder spring in the clutch to ensure an adequate clutch engagement width.

The hydraulic clutch, which was adopted for the first time on the KX, has provided an adequate engagement width and eliminated the need to adjust the lever play, so it can easily be handled by the rider.

6 Improving startability

In motocross racing, even top-class riders with high-level skills cannot avoid falling. Riders often fall due to contact with another rider immediately after they start at the same time standing side by side. Even while solo, they may fall because the road conditions change every lap. What is most important when a rider falls is returning to the race in the shortest amount of time. Once a rider falls, he or she is required to pick up the machine and restart the engine to return to the race. In such a situation, an electric starter, which only requires pushing the button to start the engine, is much more advantageous than a kick starter, which is lightweight but requires more time to start the engine.

For this model, we adopted a lithium-ion battery for the first time in a Kawasaki motorcycles and improved the main power circuit, thereby achieving safety and excellent startability while minimizing the increase in mass.

(i) Lithium-ion battery

Lithium-ion batteries, which are compact and lightweight, are already in use in many electrical appliances, such as mobile phones. However, not many motorcycles have adopted lithium-ion batteries, but Kawasaki adopted a lithium-ion battery on this model for the first time among its motorcycles. Therefore, careful specification selection was required. We verified the startability and mechanical reliability in the same manner as for conventional motorcycle development, and in addition, tested the following three items specific to lithium-ion batteries:

① Overcharge test

In the event of overcharge, the protection circuit provided with the battery must detect the overvoltage and break the circuit to stop charging.

② Over-discharge/recharge test

The protection circuit provided with the battery must prevent over-discharge and ensure safe recharge.

③ External short circuit

The protection circuit provided with the battery must be partially broken to safely make the battery unusable.

(ii) Main power supply circuit

Unlike most motorcycles, the KX, which is a racing vehicle, does not have a main switch function. For this model, we developed a system to hold the main power supply circuit with the main relay when the user presses the starter button, instead of turning on the main switch. When the engine is stopped, the main power supply circuit is broken after a certain amount of time by the self-shutdown control of the ECU (Electric Control Unit), instead of turning off the main switch. In addition, this self-shutdown control can instantaneously reset the ECU in case of a fall, so even when the engine stops due to a fall, the rider can restart the engine while picking up the machine. With the main switch type, the ECU must be reset manually but with this relay type, the ECU is reset automatically, allowing the rider to return to the race more quickly.

Conclusion

Kawasaki has been continuously developing the KX with the aim of developing an unbeatable motorcycle on motocross race tracks[1]. The KX has won many titles in the main classes, contributing to enhancing Kawasaki's brand image. With the KX, Kawasaki's rider became the second person to win four consecutive championships in the AMA Supercross and the KX boasts an overwhelming number of wins (the numbers of wins and podiums in Supercross between 2006 and 2018 are 84 and 148, respectively). We are confident that the number of wins will increase further with the technologies we adopted this time.

We will be actively developing new technologies without compromise and developing motorcycles that outdo competitors' on our mission to create motocrosser trends with the KX.

Reference

1) Takasu, Matsushita, et al.: "Overwhelming performance motocrosser KX250F," Kawasaki Technical Review, No. 174, p. 39-44 (2014)

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Development of Multipurpose Off-road Vehicles MULE PRO Series

Since 2009, the market for multipurpose off-road vehicles (Side × Side vehicles) has been growing in the U.S.A. Targeting the utility vehicle market among them, Kawasaki has developed and marketed the MULE PRO Series, achieving a leap forward in its multipurpose off-road vehicles business. The MULE PRO Series is our first utility vehicle that can achieve a top speed of over 40 km/h. The engine power was increased with assuring vehicle performance comfortable and a new transformation mechanism was adopted.

Introduction

Because of an aging customer base, the U.S. powersports market is shifting from conventional motorcycles and ATVs (All-Terrain Vehicle) to multipurpose off-road vehicles (Side × Side vehicles). Side × Side vehicles are largely classified into utility vehicles and recreational vehicles, and the utility vehicle market is expected to increase to approximately 380,000 units by 2023. In addition, the demand for higher maximum speeds is increasing recently.

1 Background

Since the sale of the MULE 1000 began in 1988, Kawasaki's utility vehicles have been highly regarded in the market for their durability. In addition, Kawasaki has adopted several engine types and seat arrangements to meet diversifying market needs. In recent years, it is becoming essential to meet the demand for higher maximum speeds (over 40 km/h).

2 Development concept

In developing the MULE PRO series, inheriting the features of the previous MULE models, we set "meeting the recent demand for higher maximum speeds" and "developing a common platform" as concepts, and in addition, set "Durable, Stable, Comfortable, Dependable Work-horse" as development keywords.

(1) Meeting the demand for higher maximum speeds

We aimed to significantly improve engine performance, including an increased maximum speed (over 40 km/h), from the previous MULE models. In addition, we increased the wheelbase, tread, wheel travel, and tire size and changed the front and rear brake types to achieve chassis performance that fits the improved engine performance. **Table 1** compares the major specifications of the previous MULE model and the MULE PRO series.

(2) Developing a common platform (frame)

We decided to develop a profitable common platform that could be used for multiple engine types and seat arrangements. **Table 2** shows specific combinations of engine types and seat arrangements, and **Fig. 1** shows a schematic shape of the frame. We decided to provide a wider space for the engine behind the rear seat as shown in the figure and design the frame so that it can easily be extended and shortened near the longitudinal center.

(3) Realizing the development keywords

(i) Durability

We decided to focus on improving the water and mud protection of the engine and drive train and the strength and durability of the CVT (Continuously Variable Transmission) belt, axles, steering system, and suspension system.

(ii) Stability

We decided to achieve high stability and a secure steering feel at the same time.

Table 1 Comparison of major specifications against the previous MULE model

Item	MULE PRO-FXT (AF820C)	MULE 4010 TRANS4×4 (AF620R)
Maximum power	× 2. 38 (compared with MULE 4010)	Basis for comparison
Maximum torque〔N·m〕	65/3, 500min^{-1}	47/2, 500min^{-1}
Maximum speed	+ 32km/h (compared with MULE 4010)	Basis for comparison
Wheel base〔mm〕	2, 345	2, 165
Tread (F/R)〔mm〕	2, 300	1, 160/1, 180
Wheel travel (F/R)〔mm〕	222/217	100/70
Tire size (F/R)	26 × 9. 00 - R12/26 × 11.00 - R12, radial	23 × 11. 00 - 10, bias
Brake type (F/R)	Disk	Drum

Table 2 Engine type and seat arrangement

Engine type		Seat arrangement	
		Single-row seat model (three seats)	Double-row seat model (3 or 6 seats)
Gasoline	812cm^3	2016MY MULE PRO-FX	2015MY MULE PRO-FXT
	Four-stroke		
	Water-cooled in-line three-cylinder		
	DOHC, four-valve		
Diesel	993cm^3	2016MY MULE PRO-DX	2016MY MULE PRO-DXT
	Four-stroke		
	Water-cooled in-line three-cylinder		
	OHV, two-valve		

※ MY：Model Year

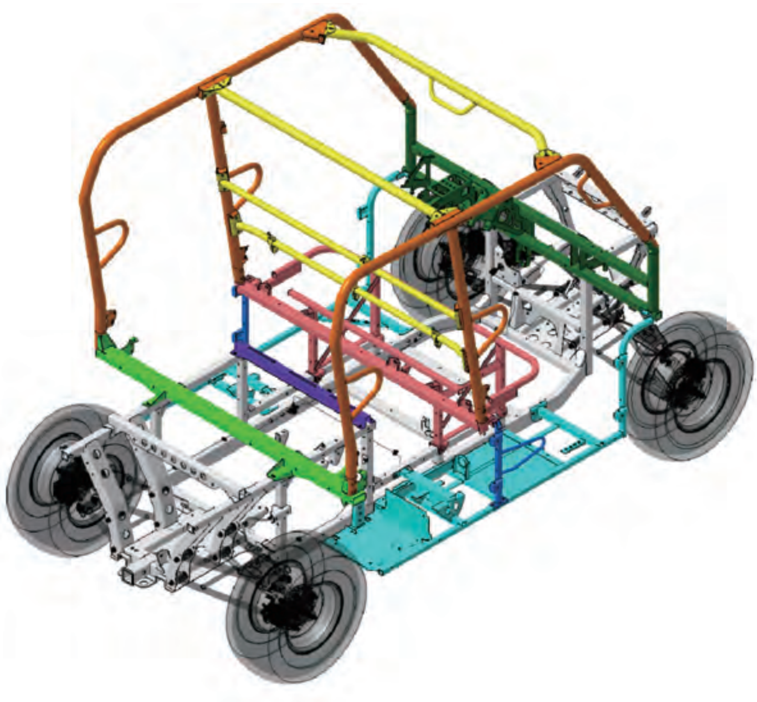


Fig. 1 Schematic shape of frame

(iii) Comfort

We decided to achieve easy-to-handle engine characteristics through optimizing the intake and exhaust systems as well as FI (Fuel Injection) and CVT settings; excellent capabilities with a highly dynamic ground clearance; adequate mud protection with doors; and a versatile, easy-to-handle vehicle with a new transformation mechanism.

3 Technical challenges

To realize the development concepts and development keywords, we set many technical goals for ourselves when we started the design and development.

(1) Increasing the gasoline engine power

For efficient development, we adopted one of CHERY's engines developed for passenger cars and the ECU (Electronic Control Unit) for controlling this engine as a set. We needed to improve the engine and ECU so that they could meet Kawasaki's design standards, and modify the ECU program and its settings so that the ECU could meet the requirements for off-road vehicles.

(2) Improving diesel engine reliability

The diesel engine adopted for the MULE PRO series does not require ignition and uses a mechanical fuel injection system, so it requires many electrical devices that gasoline engines do not have, such as a stop solenoid, which cuts off the fuel supply to stop the engine, and a glow plug, which is used for preheating. These devices needed to be controlled in an integrated manner in terms of cost and reliability.

(3) Improving the strength and reliability of the drive train

In off-road environments, there is much uncertainty in the road surface and vehicle usage, and the drive train may be subjected to an impact load. The rubber belt CVT, which was adopted for the MULE PRO series, has an advantage in that the vehicle can continue to run even if the belt slips to some degree on the sheave, but we needed to pay particular attention to the service life. In addition, the axle was required to have adequate strength because, depending on the road surface, the wheels may decelerate rapidly, causing damage to the axle due to inertia absorption.

(4) Ensuring lateral stability

The MULE PRO series has a seating capacity of six for the first time among Kawasaki's Side × Side vehicles, and we needed to ensure adequate lateral stability when turning not only with one passenger but also with six passengers.

(5) Developing a new transformation mechanism

In 2006, Kawasaki began selling the MULE TRANS 4 × 4 series, a Side × Side vehicle whose main feature is that it can transform between single-row seat mode (two seats) and double-row seat mode (four seats), ahead of competitors. Although the MULE TRANS 4 × 4 series has a shorter wheel base than competing vehicles, this series can be transformed between these seat modes by moving the screen at the front of the cargo bed back and forth. In developing the MULE PRO series, we improved this transformation mechanism significantly for improved ease of handling.

4 Processes of solving the technical challenges

(1) Increasing the gasoline engine power

To adopt CHERY's ECU for the off-road utility vehicle MULE PRO series, we modified the ECU program and at the same time significantly modified control-related settings.

① We achieved the engine power feeling characteristics that permit high vehicle performance during high-speed driving as shown in **Fig. 2**; the FI settings that can meet the exhaust emission regulation standard without sacrificing the feeling of power; and excellent cold startability, which is essential for working use.

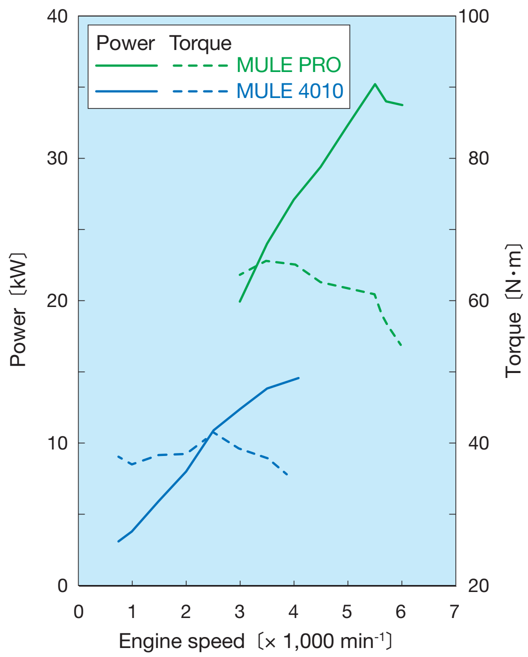


Fig. 2 Engine performance curve

②We added off-road vehicle functions that enable switching between 2WD and 4WD, switching between rear differential lock modes and stopping the engine if the vehicle rolls over.

③ For ease of maintenance in the market, we added the KDS (Kawasaki Diagnostic System) function, which enables failure diagnosis if there is a problem with the FI system.

④ For intake and exhaust system parts, which greatly affect the engine performance, we developed our own unique specifications to match the ECU settings, thereby achieving very easy-to-handle power characteristics.

(2) Improving the reliability of the diesel engine

We developed a new vehicle controller that controls switching between 2WD and 4WD, and rear differential lock modes as we did for the gasoline unit. Moreover, this controller also controls electric devices specific to diesel engines, such as the stop solenoid, glow plug, starter interlock control, and fuel pump, in an integrated manner. This has eliminated the need for many electric devices, such as relays, achieving both low cost and high reliability.

(3) Improving the strength and reliability of the drive train

(i) CVT settings for achieving high belt strength and good ratio change feeling

Figure 3 shows the structure of the CVT. We made the CVT settings so that the required performance, including feeling of acceleration, shifting to low during rapid acceleration, and engine braking, could be satisfied, and in addition, we were able to prevent the squealing that occurs due to the belt slipping. At this time, we optimized the belt clamping force by adjusting the drive-side pulley weight shape, spring load, and driven-side torque cam angle, spring load so that the load on the belt would not increase. We optimized the settings individually for the gasoline and diesel engines according to their engine characteristics.

(ii) Improving air introduction efficiency in the CVT chamber

We optimized a fin on the back of the drive-side fixed sheave and the case shape around the fin in the CVT chamber so that air swirls from around the drive pulley to around the driven pulley, and is discharged from the CVT chamber without getting stagnant. This has provided adequate cooling performance, significantly improving the life of the CVT belt.

(iii) Achieving top-level axle strength in its class

Taking cost and weight into consideration, we achieved top-level axle strength in this class while maintaining the strength balance throughout the entire drive train. **Figure 4** shows a comparison with the previous MULE model.

(iv) Adopting a highly durable CVT belt

We adopted a new CVT belt developed by Mitsuboshi Belting Ltd. that is four times more durable than the CVT belt of the previous MULE model.

(4) Ensuring lateral stability

We adopted a wide tread (see **Table 1**) and at the same time adopted high strength material to reduce the weight of the ROPS (Roll Over Protective Structure), which constitutes part of the upper structure, thereby achieving a lower center of gravity of the vehicle. Moreover, from early on in the design planning stage, we conducted a desk analysis simulating steady state turning to optimize the center of gravity of the vehicle and the alignment of the suspension system, thereby achieving a slight “under

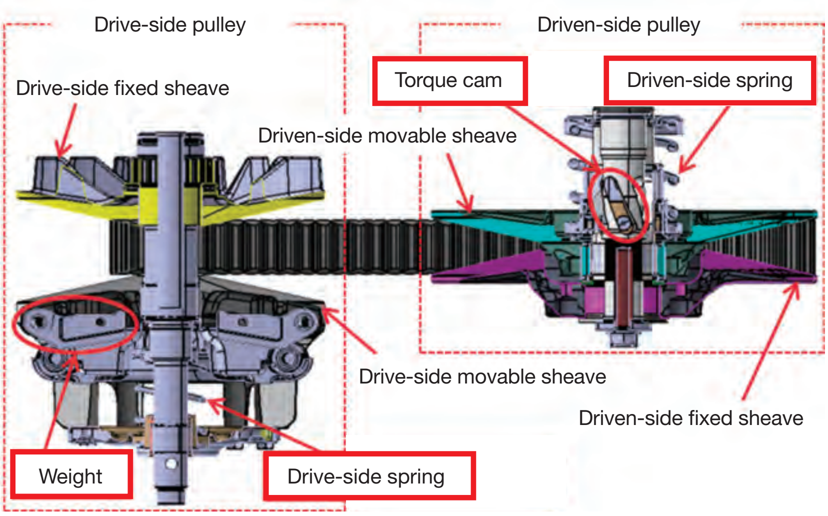


Fig. 3 Structure of CVT (main unit)

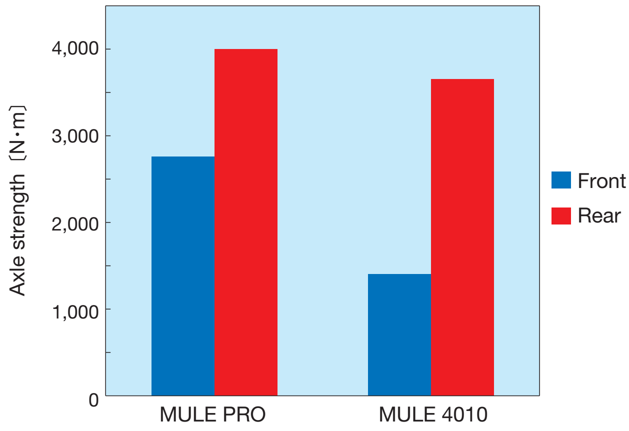


Fig. 4 Comparison of axle strength

steer" characteristic. **Figure 5** shows an example of the measurement results obtained in a vehicle handling test conducted according to the OPEI (Outdoor Power Equipment Institute) standards. From this figure, it can be seen that stable turning has been achieved without increasing the yaw rate rapidly even at a high lateral acceleration range.

(5) Developing a new transformation mechanism

With ensuring its durability in off-road environments, we developed an easy-to-handle, simple transformation mechanism that allows one person to transform the vehicle in one trip around the vehicle in one minute ("1:1:1" policy). More specifically, we changed the screen behind the rear seat from the detachable type to the slide type so that the screen can be moved by one person from one side whereas the screen was moved by two people from both sides before. **Figure 6** shows the right rear views of the screen and cargo bed.

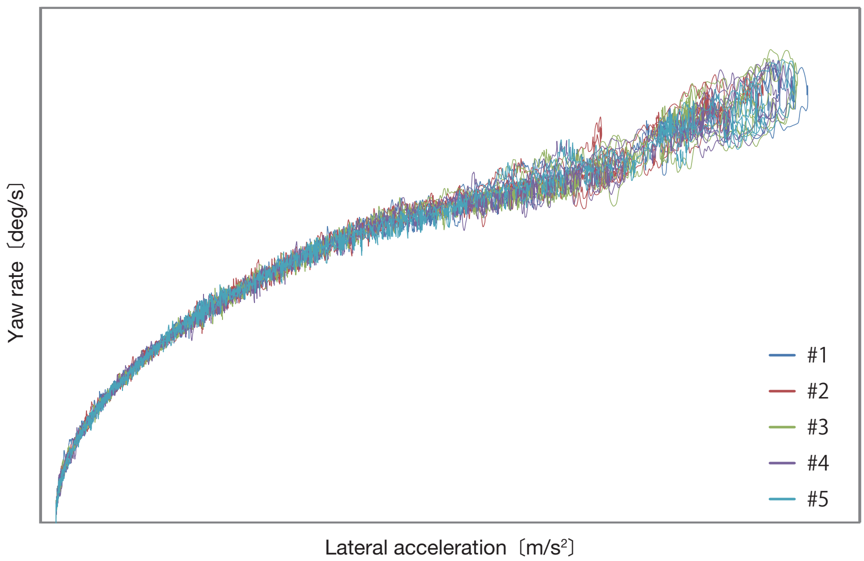
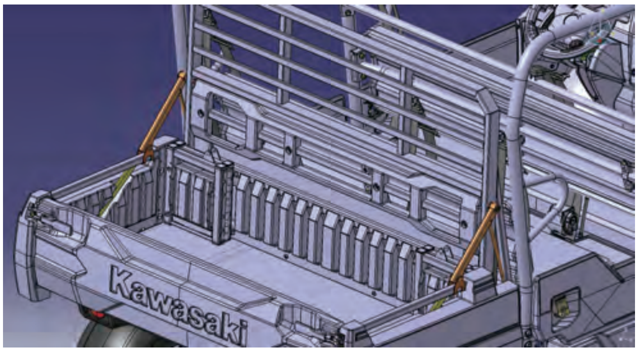
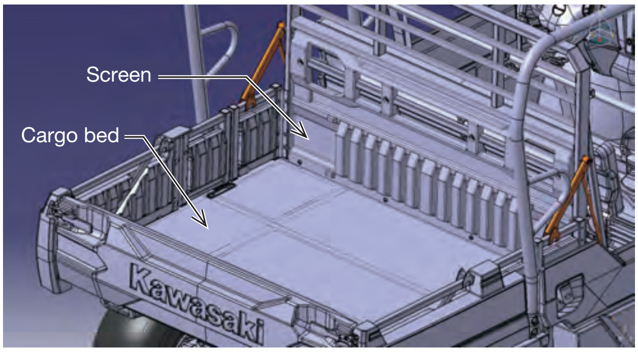


Fig. 5 Example of measurement results of vehicle handling test



(a) Double-row seat mode



(b) Single-row seat mode

Fig. 6 Screen and cargo bed

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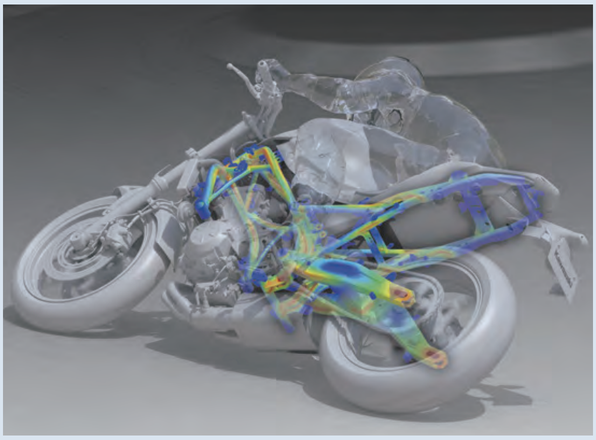
Conclusion

Since we began mass-producing the MULE PRO-FXT as the first MULE PRO series model in 2014, we have developed four vehicle models using a common frame.

In addition, we added the MULE PRO-FXR in 2017, which has a shorter wheel base with a shorter frame than the MULE PRO-FXT, increasing model variations. Currently, the annual sale of these models has reached several tens of billions of yen, allowing Kawasaki's four-wheel vehicle business to grow rapidly. Moreover, in 2018, we began mass-producing the MULE PRO-MX, which has adopted a new engine and frame, as a mid-size model of this series.

We will be making continuous improvements to further enhance customer satisfaction.

Achievement of an Extremely Lightweight Frame



Motorcycle weight reduction has a great impact on the factors that determine vehicular characteristics, such as ease of handling and maneuverability. During the development of the Z650 and Ninja 650, we worked on new techniques to develop lightweight frames, optimized the balance among stiffness, durability and maneuverability, and achieved significant weight reduction.

Introduction

In the development of motorcycle frames, vehicle mass is a key factor that greatly affects the ease of handling and maneuverability.

A smaller vehicle mass offers beginner riders a greater feeling of security in picking up and handling their vehicles. However, excessive weight reduction sacrifices vehicle stiffness and decreases stability during running, making it difficult to achieve vehicle performance that can satisfy intermediate and experienced riders. In addition, the durability of the frame itself, which affects reliability, decreases.

1 Background

The most important challenge in developing lightweight frames is achieving a good balance among stiffness, durability, and maneuverability, which determines a vehicle's characteristics.

In developing the main frame and swing arm, which contribute most to weight reduction among all the frame components, we repeat the cycle of design, static stiffness test, running test, evaluation, and design with an actual machine. Furthermore, in motorcycle development, we spend most of our time tackling this challenge, including replacing parts after modifications and test-riding the vehicle.

2 Policy for developing lightweight frames

We decided to develop a unique frame stiffness evaluation method and apply it to frame development with the aim of reducing the weight and at the same time achieving a good balance among stiffness, durability, and maneuverability for efficient mass-production vehicle development.

3 Conventional development process and challenges

In conventional frame development, the frame was developed by using design based on the static stiffness of the frame and riders' feedback after running tests. However, the static stiffness was calculated by conducting a static load test with the frame secured with a jig, so the load conditions and constraint conditions in the test differed from those during actual running. Because of this, we sometimes had difficulty understanding riders' physical sensations with static displacement only, and did not always achieve significant weight reduction.

4 New lightweight frame development method

(1) New frame stiffness evaluation method

We decided to numerically simulate frame deformation during running based on the motorcycle dynamics as shown in **Fig. 1**, and evaluate frame stiffness based on the displacement.

While a vehicle is running, the tire force and the inertial force of the vehicle are always in balance[1]. Therefore, we numerically and accurately simulated how the inertial force of the vehicle balances with a load applied to the tire contact point.

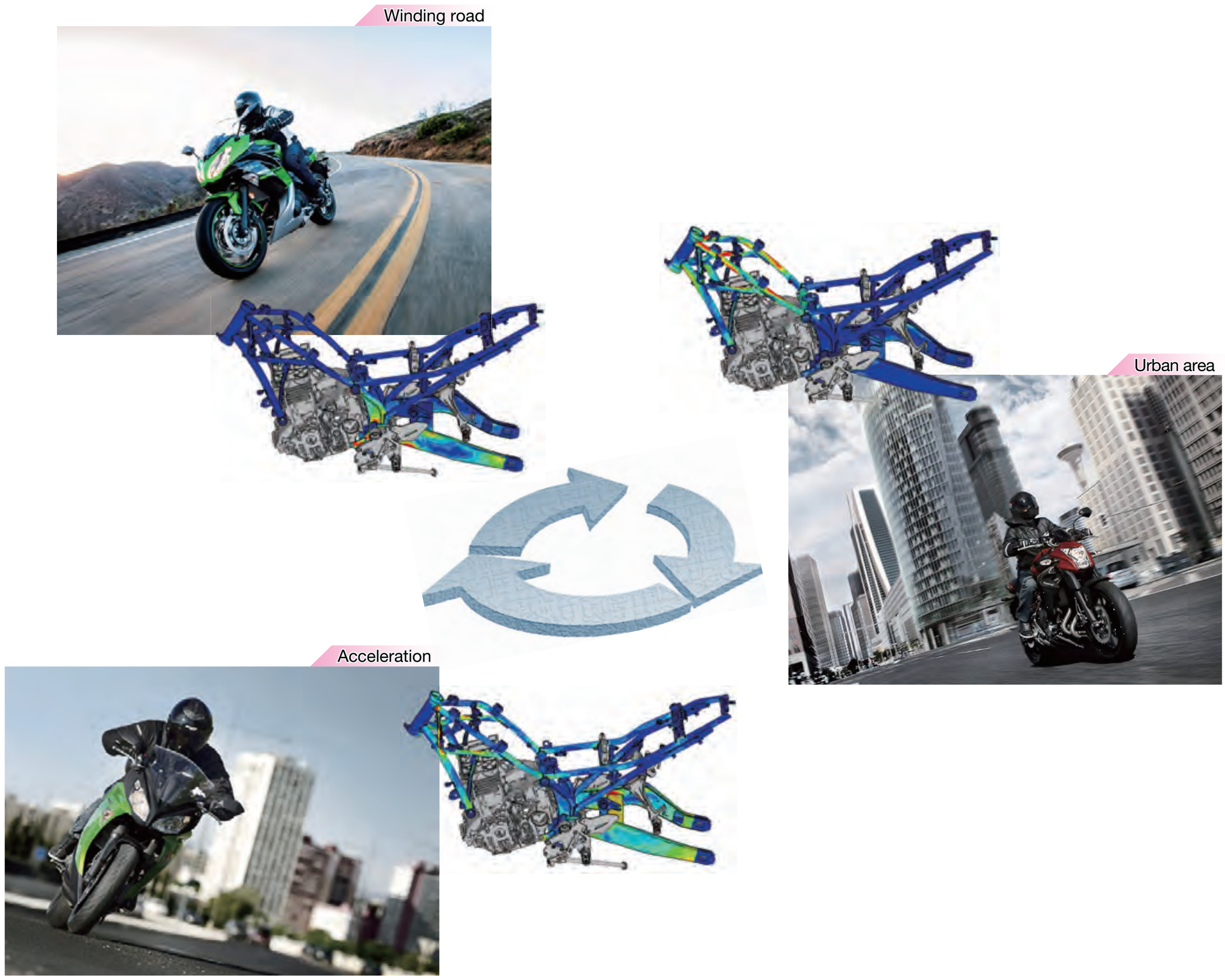


Fig. 1 Quantification of frame deformation during vehicle running

For efficient simulation even in the early stage of development where no detailed layout is available, we adopted a simplified model with the frame, swing arm, and engine only. The engine does not contribute to frame deformation but produces a large part of the inertial force acting on the frame, so modeling the engine was considered to be essential. We replaced the other components with rigid bodies and ignored their impact on frame deformation.

The frame stiffness was calculated based on the relative deformation of the engine, which has the highest stiffness among all the motorcycle components, and the tire.

(2) Running situations subject to stiffness evaluation

We performed stiffness evaluation under the following three running situations where the frame stiffness is greatly affected.

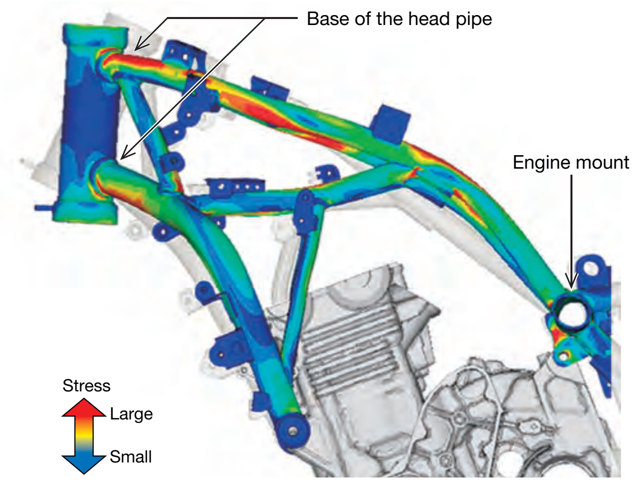
(i) Braking

As shown in **Fig. 2**, a vehicle runs with the braking force of the front tire and the inertial force of the vehicle in balance with each other, and the head pipe is bent by the moment caused by the braking force. A large stress is generated at the base of the head pipe and the front engine mount.

(ii) Steady turning

As shown in **Fig. 3**, a vehicle runs with the lateral forces of the front and rear tires and the centrifugal force of the vehicle in balance with each other, and the head pipe and swing arm are twisted by the lateral forces. A large stress is generated at the base of the head pipe and the joint between the right and left sides of the swing

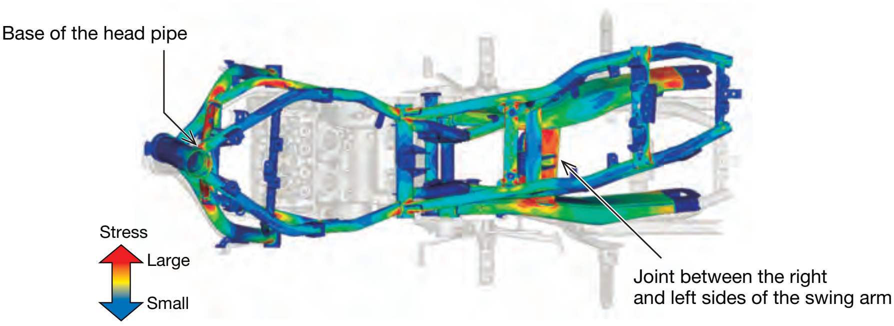
(a) Balance of forces



(b) Analytical result (side view)

Fig. 2 Frame deformation with brake applied

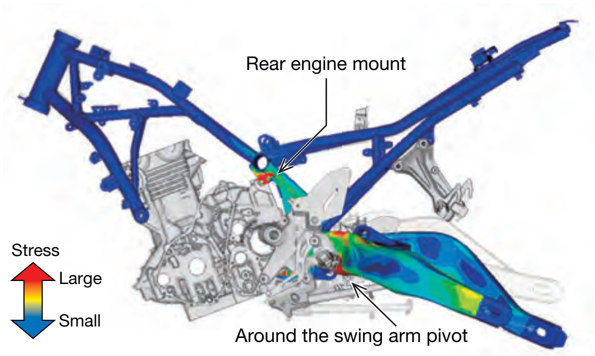
(a) Balance of forces



(b) Analytical result (top view)

Fig. 3 Frame deformation during steady turning

(a) Balance of forces



(b) Analytical result (side view)

Fig. 4 Frame deformation during acceleration

arm.

(iii) Acceleration

As shown in **Fig. 4**, a vehicle runs with the driving force of the rear tire and the inertial force of the vehicle in balance with each other, and the swing arm is bent by the chain force. A large stress is generated around the swing arm pivot and at the rear engine mount.

5 Results of application of this new lightweight frame development method

Figure 5 shows the Z650 and Ninja 650, which are mid-sized models that are sold globally as strategic global models[2)] and offer beginner, intermediate, and experienced

(a) Z650

(b) Ninja 650

Fig. 5 Models developed with new frame weight reduction technique

† These models have 7% better fuel economy than the previous model (ER-6n/6f) in WMTC (Worldwide-harmonized Motorcycle Test Cycle) mode, and have lower CO, THC, and NOx emissions than the ER-6n/6f by 63%, 56%, and 50%, respectively.

riders "a fun to ride" and "ease of riding."

We adopted the new lightweight frame development method for the main frames and swing arms of these models, thereby significantly reducing the number of development manhours and achieving significant weight reduction while maintaining the well-balanced maneuverability of the previous models.

(i) Weight reduction

We derived the appropriate frame shape and optimal pipe diameter and thickness through numerical simulation. As a result, we successfully reduced the weight by over 10 kg in total with the main frame and swing arm shown in **Fig. 6**. **Table 1** shows a comparison of the mass between the Ninja 650 and ER-6n, which uses the frame before the model change.

(ii) Stiffness

Figure 7 shows the index values of frame stiffness. The Z650 and Ninja 650 have an extremely lightweight frame but have the same level of stiffness as the previous models, the ER-6n and Ninja 650.

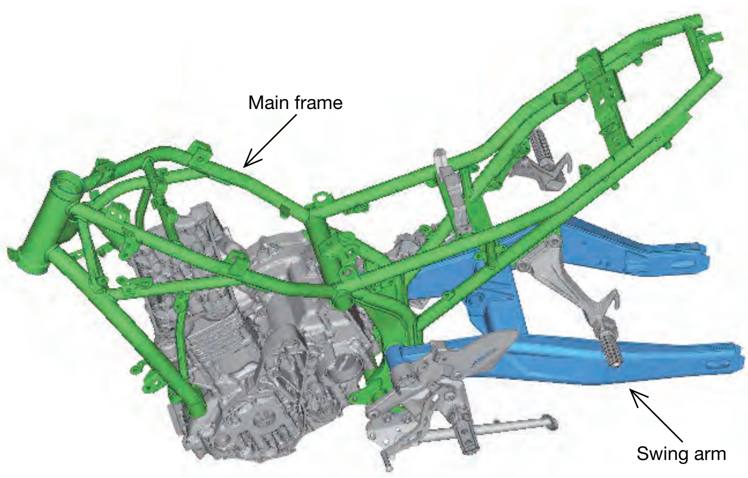


Fig. 6 Components subjected to weight reduction

Table 1 Weight comparison with existing model

Item	Ninja 650	ER-6n
Frame〔kg〕	17. 9	28. 1
Main frame〔kg〕	12. 9	20. 5
Swing arm〔kg〕	5. 0	7. 6

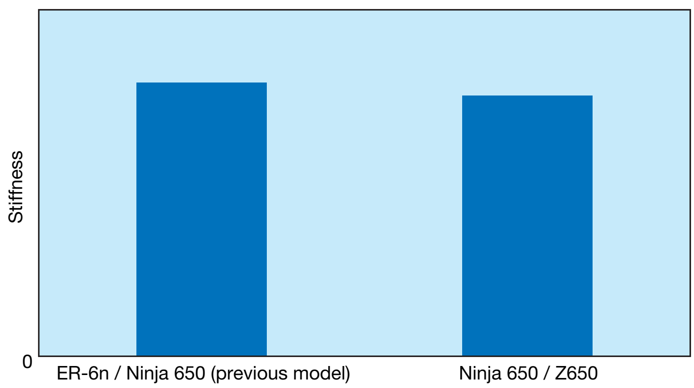


Fig. 7 Stiffness evaluation (during steady turning)

(iii) Evaluation by riders

In evaluations by riders, no comments were made suggesting a decrease in the maneuverability due to weight reduction, and we confirmed that adequate stiffness was achieved in every riding situation.

With this method, we have achieved a significant weight reduction and adequate levels of stiffness, durability, and maneuverability.

Conclusion

Owing to the new lightweight frame development method, the Z650 and Ninja 650 are lighter than the previous models by 19 kg. The method we developed has been applied to the new Ninja 250 and Ninja 400, and will be applied for all models.

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Development of Vehicle Control Technologies for Super Sport Model ZX-10R

With increasingly sophisticated engine and chassis performance, vehicle control technologies that assist the rider in steering are becoming increasingly important.

To achieve for riders a fun and easy ride, we equipped our international model ZX-10R SE with tailored wheelie control and electronic control suspension control to cater for such vehicle behavior.

Introduction

The development of autonomous driving is gaining momentum for passenger cars, and the time is nearing when autonomous driving will be put to practical use in limited environments, such as expressways. Autonomous driving is a conglomeration of control technologies, including environmental recognition, and is intended to eliminate driver's judgments and operations. In motorcycle development, however, autonomous driving is oriented in another direction.

1 Background

Kawasaki's motorcycles are by nature intended for riders to enjoy driving. Seemingly, motorcycles do not require advanced controls. However, now that engine and chassis performance is much more sophisticated than it used to be, various control technologies have been adopted to achieve "ease of riding" and "a fun ride." These control technologies require intervention by riders (humans), so we are working to achieve "Rider-machine cooperative control," which is considered difficult to achieve with autonomous driving.

2 Control technologies for motorcycles

As shown in **Fig. 1**, control technologies for motorcycles have been developed for a long time, mainly for racing. Initially, controls were developed mainly to

Fig. 1 Road racing (World Superbike Championship)

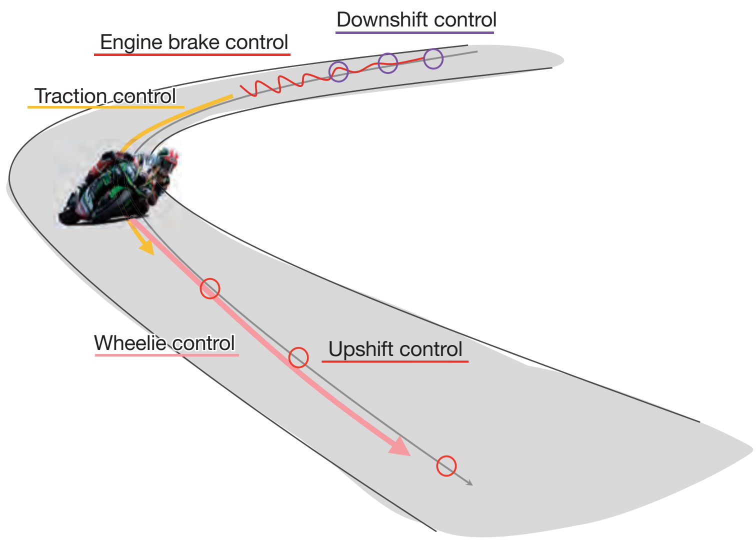

Fig. 2 Controls for racing situations

improve engine performance, and after engine performance was increased to a certain level, traction control was adopted, which prevents the wheels from slipping. After that, engine brake control was developed to mitigate intense engine braking when the vehicle is decelerated. Moreover, as shown in **Fig. 2**, shift control for shifting up or down without having to operate the clutch, wheelie control for keeping the front wheel from lifting during acceleration, and various other controls are used in almost every racing situation.

For racing, technologies are adopted to run faster and win. Now that engine and chassis performance is so sophisticated, technologies that reduce the rider's operational burden through rider-machine cooperation are required. These technologies are not only required for racing but also are a requirement that is consistent with Kawasaki's concepts, "Fun to ride" and "Ease of riding."

Based on control and other technologies cultivated through racing, motorcycle manufacturers are developing supersport models that are designed for circuit riding, which are then used as the base models for racing vehicles and symbolize their brands to show off their technologies.

With the evolution of microcomputers, which serve as control devices, gyro sensors using MEMS (Micro Electro Mechanical Systems) technology have now become cheap enough to be used in commercially available vehicles. In addition, with the progress of technological development, new control devices, such as electronic suspension, can be used in commercially available vehicles.

For the ZX-10R series supersport model, we are applying the control technologies we have cultivated through racing while using commercially available technologies.

3 Concept of the ZX-10R series

The ZX-10R symbolizes Kawasaki's brand and is used as the base model for the World Superbike Championship, which is the biggest race for mass-production motorcycles. The ZX-10R's concept s is "No. 1 circuit performance," and all the knowledge about engines, chassis, and control data obtained from racing have been fed back into the development of mass-production vehicles.

In racing and circuit riding you want controls that produce maximum performance while reducing the operational burden on the rider by having the machine cooperate with them. This applies to riding on public roads and not just extreme situations like in racing.

For racing vehicles, however, the rider that the machine needs to cooperate with and the riding conditions in racing can be limited but for mass-production or commercially available vehicles, there are still hurdles to overcome (e.g., rider's skills, riding conditions, devices (cost)).

As shown in **Fig. 3**, the ZX-10R series has been incorporating the control technologies available at the time of development ever since its first model.

The 2016-year model and subsequent ZX-10R models adopted wheelie control using an IMU (inertial measurement unit), and the 2017-year model and subsequent ZX-10R SE models adopted electronic control suspension. In this way, more and more advanced control technologies are becoming commercially available.

The following describes wheelie control, which is a typical example of control using IMU, and suspension control using electronic control suspension, which is a new

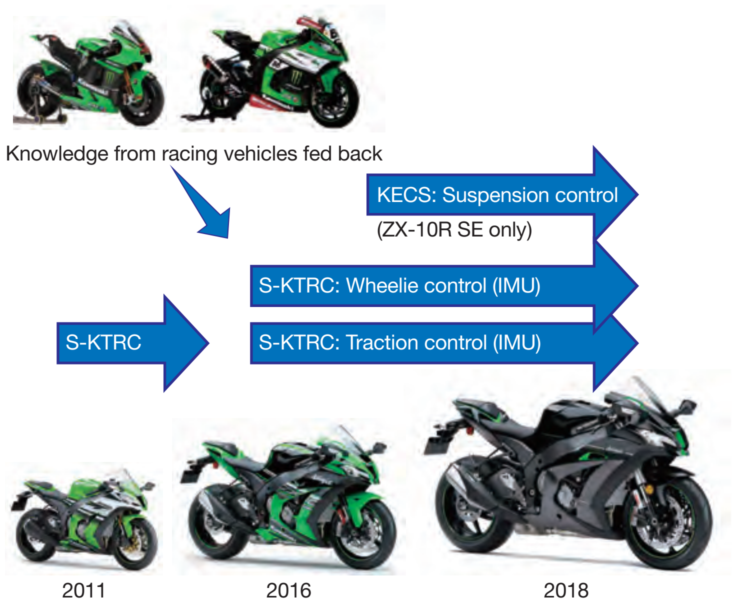

Fig. 3 Introduction of control technologies for ZX-10R

control device.

(1) Wheelie control

When accelerating, if the engine power is too high, it causes the front wheel to lift off the ground, resulting in a wheelie. When doing a wheelie, the vehicle cannot keep running fast but to run fast, ideally, the vehicle should accelerate with the front wheel nearly lifted, but precise throttle operation is required to achieve this.

Wheelie control is a function to monitor the vehicle posture and assists the rider's operation to reduce their operational burden and achieve maximum acceleration.

(2) Suspension control

Common suspensions have a fixed damping amount, and so cannot have different damping amounts for different riding situations, such as accelerating and decelerating, turning, and changing direction.

The electronic control suspension shown in **Fig. 4** has varying damping amounts, enabling optimal damping control according to the vehicle posture and situation.

4 Technological development

To achieve a high level of vehicle control, we are developing and verifying posture and behavior estimation technology, rider-machine cooperation in wheelie control, and electronic control suspension, which is a new device.

(1) Posture and behavior estimation technology

Vehicle behavior involves the rider's intention information in addition to the motorcycle condition

Fig. 4 Electronic control suspension (Kawasaki Electronic Control Suspension)

information, and behavior estimation is essential to achieving control for cooperation with the rider.

In the past, posture could not be estimated directly, so it was estimated indirectly based on the wheel speed and rider's throttle operation. In recent years, gyro sensors shown in **Fig. 5** have become available for mass-production vehicles. However, gyro sensor signals represent angular velocity, and so must be converted to posture or behavior.

Motorcycles have complicated movements, so with cheap gyro sensors, the posture cannot easily be estimated. For example, a turning movement involves a banking movement (lean) and a yawing movement as shown in **Fig. 6**. The banking posture is also a combination of multiple elements, such as the combined center of gravity of the vehicle and rider (balanced angle at a constant radius turn). For this reason, we are developing posture and behavior technology tailored for motorcycle movement characteristics.

In development of the logic, we link the simulation data and actual data of vehicle movements to combine the theoretical and actual environments (measured vibration and variations).

(2) Rider-machine cooperation in wheelie control

Wheelie control is intended to control the engine torque according to the vehicle posture (wheelie), and Kawasaki is developing wheelie control taking "cooperation with the rider" into consideration.

(i) Degree of freedom of rider's operation

During a wheelie as well as during throttle operation, the rider is always paying attention to acceleration and deceleration. Therefore, we developed a control logic that allows the rider's intention to be reflected in the vehicle behavior in the allowable range of the degrees of freedom of the rider's operation as shown in **Fig. 7**, even during control intervention.

(ii) Increased adaptivity

What circumstances a wheelie occurs in depends on


(a) Appearance

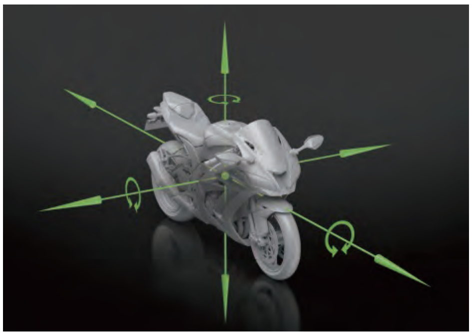
(b) Measured quantities

Fig. 5 Gyro sensor

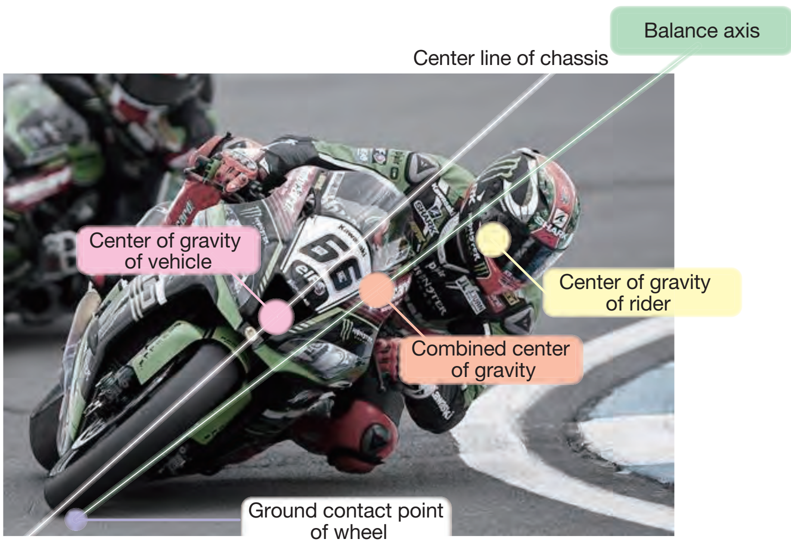

Fig. 6 Motorcycle posture while cornering (leaning)

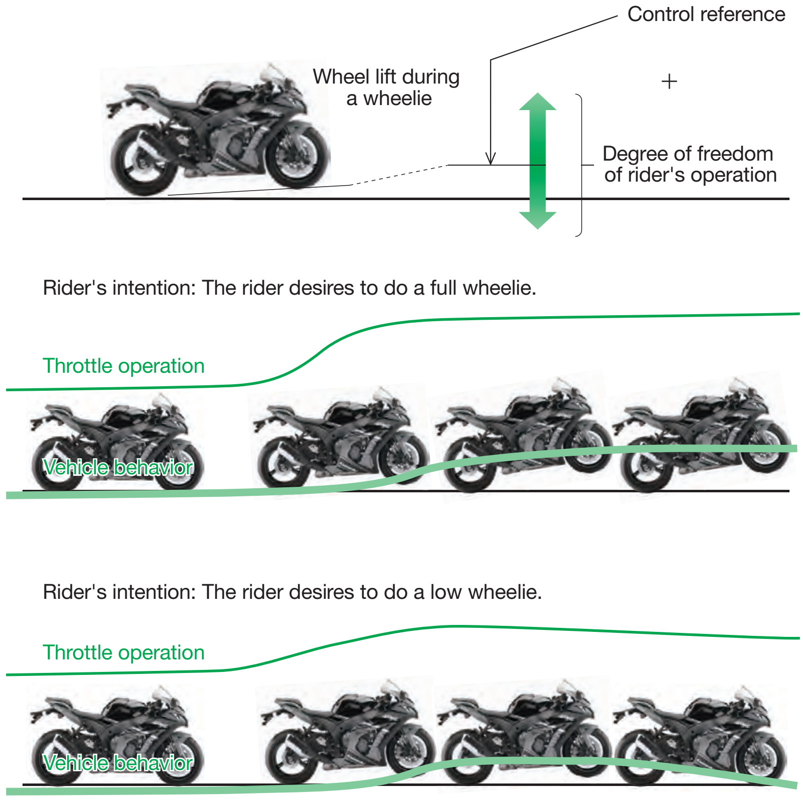

Fig. 7 Rider's degree of freedom during wheelie control

the weights of the vehicle and rider and road conditions. In addition, the required intensity of control intervention depends on the rider's skills and preferences.

For the ZX-10R, the intensity of control intervention can be adjusted in five levels, as shown in **Fig. 8**, making the vehicle adaptive to a wide range of situations. The intensity of the control intervention can easily be adjusted with a handlebar switch.

(3) Development and verification of suspension control

Suspension control is intended to control and optimize the damping amount based on the acceleration and deceleration information from the built-in stroke sensor and gyro sensor.

When developing a new control device, we usually checked and verified the control device by test-riding the vehicle. However, in order to address increased man-hours

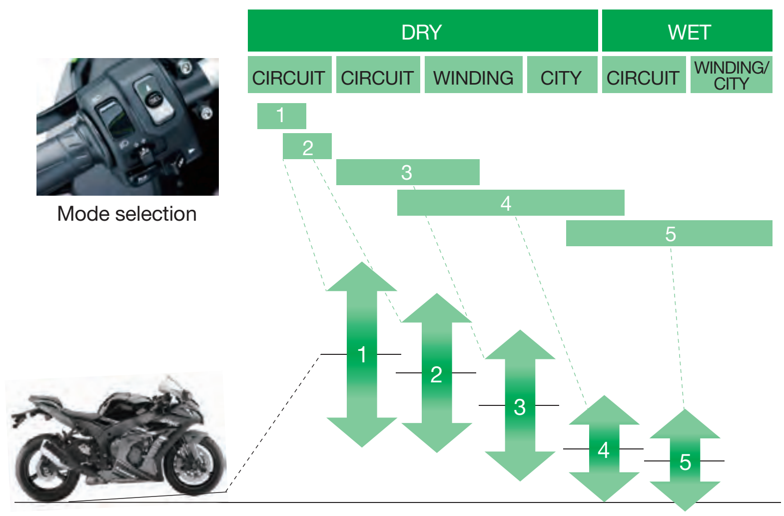

Fig. 8 Mode setting for wheelie control

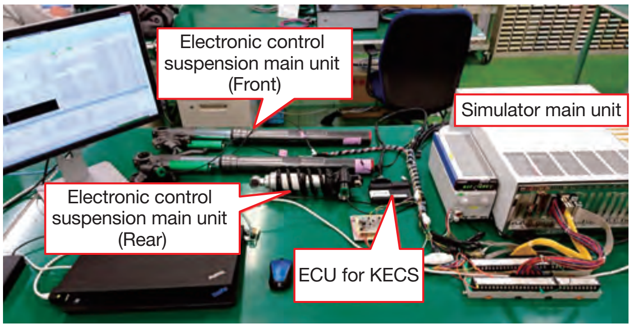

Fig. 9 Verification using HILS

due to increasingly complicated functions and ensure every necessary item is verified, we are using HILS (Hardware-In-the-Loop-Simulation) for verification in the development of suspension control.

In verification using HILS (**Fig. 9**), the actual ECU (Electronic Control Unit), sensors, actuators, and other components are used to conduct a real-time simulation, thereby making it possible to reduce the evaluation time of a test-ride and reproduce conditions that cannot be tested.

Conclusion

Because we fed the technologies that we cultivated through racing back into the ZX-10R, it has satisfactorily achieved a “Fun to Ride” and “Ease of Riding” and will evolve further to a higher level.

Various electronic controls and devices will be added not only to our supersport models, but our other motorcycles as well. Riding is a collaboration between the vehicle (machine) and rider and is based on a relationship of trust between them. This nature will not change even in the coming autonomous driving society. We will continue development to realize controls that can be relied on in a greater way by the rider and that enable rider-machine cooperation.

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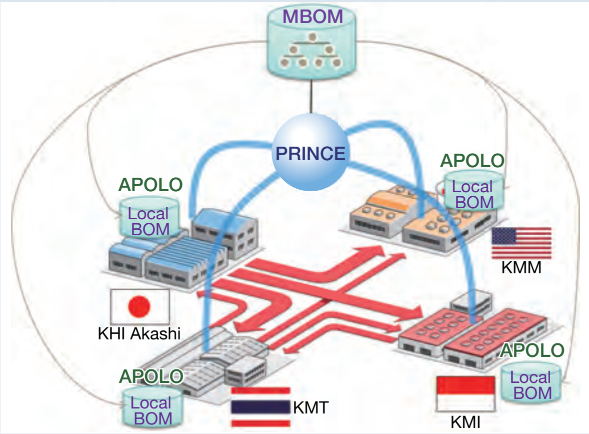
Efforts toward Global Supply Chain Innovation



MBOM : Global manufacturing BOM system, PRINCE : Global production planning system, APOLO : Integrated production management system

While developing our business globally, we are promoting local procurement and in-house production of parts at our overseas production factories, resulting in increased complexity with regard to mutual parts supply among our factories, especially in Asia.

To address this situation, we are developing a business system for enhancing the efficiency of our global supply chain.

Introduction

Today, motorcycles are popular all around the world. In order to respond to the worldwide demand, motorcycle companies have been expanding their business globally.

1 Background

The motorcycle market is likely to grow rapidly in emerging countries, such as India and Vietnam, and especially in India, the market for leisure motorcycles, which Kawasaki excels at, is expected to expand.

We needed to make further efforts toward globalization, in anticipation of making a full-scale entry into these markets.

2 Globalization of production

Kawasaki has been globalizing its production ever since it established its KMM Lincoln Factory in the U.S. in the early 1970's, and after 2000, it has been focusing on producing leisure motorcycles mainly in emerging countries in Asia. Currently, Kawasaki is producing motorcycles at nine factories, four-wheel vehicles and PWC (personal watercraft) at one factory, and general-purpose engines at two factories all over the world as shown in **Fig. 1**.

3 Supply chain in global production

(1) Increased parts supply between factories with an increased local parts procurement rate

In the early stage of production globalization, we normally shipped parts procured in Japan to overseas factories as parts to be assembled locally, and each factory used these parts with parts procured from local suppliers to produce finished vehicles. However, the local procurement rate of low-price parts has increased because local suppliers' capabilities have increased in each country, and in addition, the motorcycle market has become competitive. As a result, more and more low-price parts are procured, not only from Japan or the final assembly factories, but also from many other factories.

(2) Global promotion of "Big Combined Manufacturing"

While the type of models and volume of production are increasing at each factory, their in-house manufacturing capabilities, including assembly, machining, welding, and painting, are improving. Meanwhile, Kawasaki has been globally promoting "Big Combined Manufacturing" as its business strategy through efficient division of labor with a focus on reducing equipment investments and making efficient use of factory capacity throughout the Kawasaki group.

(3) Increasingly complicated global supply chain structure

When we began full-scale production of leisure motorcycles in Asian emerging countries in 2000, both the manufacturing and parts supply structures were simple. However, as a result of expanding parts supply between factories and promoting "Big Combined Manufacturing" in global production as previously described, the manufacturing structure had already become complicated in 2008, with parts being purchased (or supplied), Motorcycle: 9 factories Four-wheel vehicles / PWC: 1 factory / General-purpose engines (GPE): 2 factories

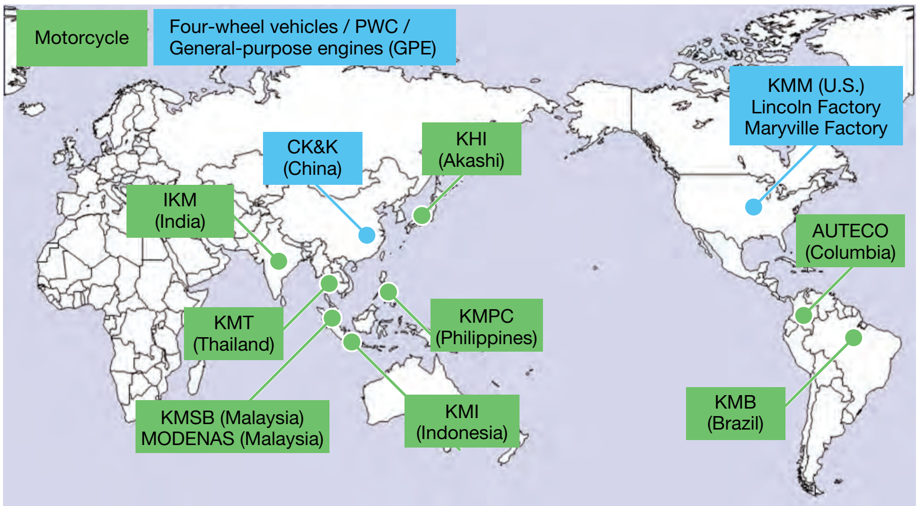


Fig. 1 Overseas production factories for motorcycles

manufactured in-house, and supplied in multiple steps involving multiple factories as shown in **Fig. 2** and **Fig. 3**.

For parts supply among factories throughout the Kawasaki group, it is general that parts supply factory purchases local parts, produces in-house parts, and ships them synchronizing production plan of receiving factory because of the knock-down production system adopted by each overseas factory when it was established. Therefore, each factory must accurately understand the types and numbers of parts and semi-finished parts, which can be classified into the following four categories, before starting relevant operations:

- Parts that a factory must purchase on its own
- Parts and semi-finished parts that a factory must receive from another factory
- Semi-finished parts that a factory must produce in-house
- Parts and semi-finished parts that a factory must ship to another factory

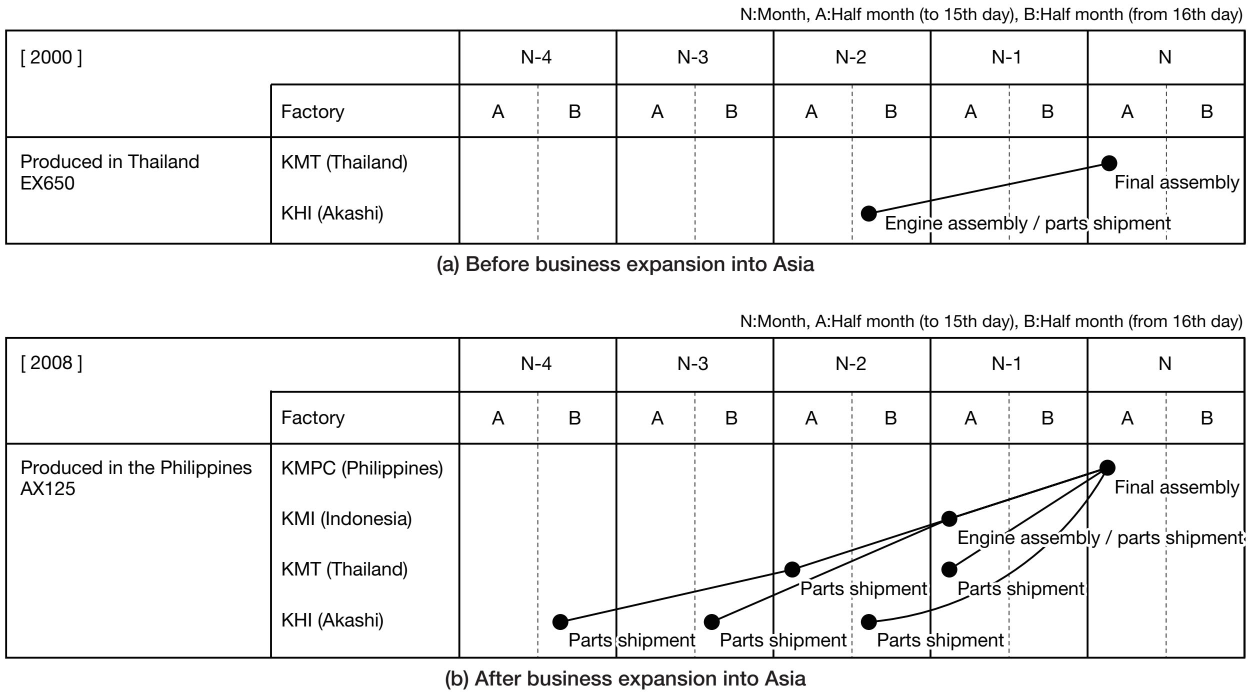


Fig. 2 Changes in manufacturing structure associated with global business expansion into Asia

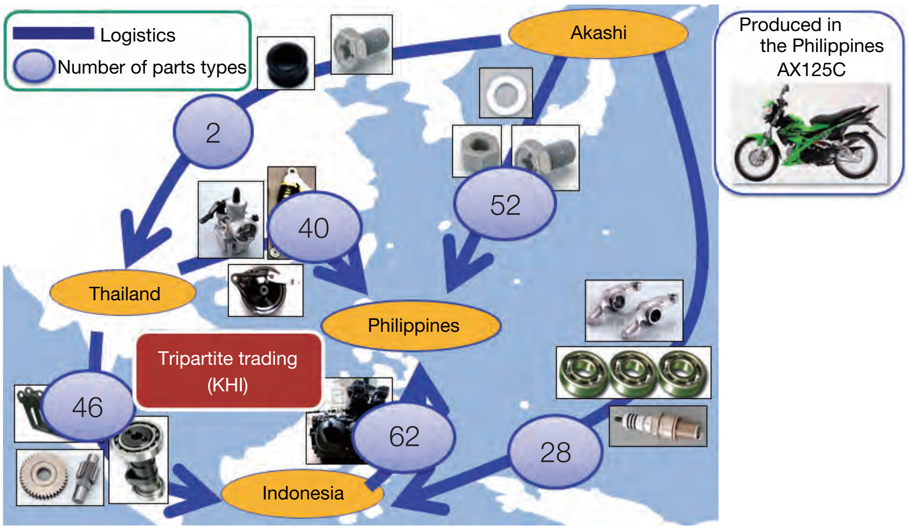


Fig. 3 Parts supply routes among production factories and number of types of parts (AX125C, produced in the Philippines)

However, the types of models and volume of the production are steadily increasing at each factory. The number of parts locally purchased or manufactured in-house by each factory is increasing accordingly. Therefore, it was extremely difficult for each factory to control every part or semi-finished part it is responsible for on its own.

4 Global supply chain innovation

We needed to develop the following three systems in order to ensure that each factory runs efficiently and correctly in the complicated supply chain:

- MBOM (global Manufacturing Bill Of Material), global manufacturing BOM management system that covers the global supply chain
- PRINCE (PRoduction planning system INtegrative for CEntral control), global production planning system used to make a production plan and parts supply plan for each factory based on the MBOM
- APOLO (Akashi PrOduction and LOgistics management system), integrated production management system which supports procurement, production, and shipment operations in a synchronized manner for each factory based on the production plan and parts supply plan

(1) Development of the global manufacturing BOM management system MBOM

We must comprehend clearly which factory must purchase what kind of local parts, which factory must produce what kind of in-house parts, and which factory must ship them to other factory for producing finished vehicle at final assembly factory. Therefore, we developed a system, MBOM, which allows us to easily understand the complicated manufacturing structure of each model. This system can be used effectively on any operations at each factory.

(i) Features

As an information management method for appropriately controlling and showing the manufacturing structure of each model, we decided to apply the same method for managing manufacturing BOM that is applied to each factory's production system with a view to future effective use at each factory.

In addition, we related factory codes, which indicate the factories responsible for parts procurement or in-house manufacture, to each item code in parts structure. The part structure is used to understand how parts and semi-finished parts move among factories and display the global manufacturing structure on a product-by-product basis.

These features have made it possible to not only understand parts supply routes information between factories by confirming the hierarchy of the parts structure but also understand manufacturing structure of each model easily as shown in **Fig. 4**.

(ii) Operation

In order for the MBOM to function globally, we need to understand, consolidate, and manage the roles of each factory and relationships between factories in a comprehensive manner. Therefore, the operation of the MBOM unifies the management at Akashi factory, which is the mother factory.

No	Level	Factory	Item Qty.					
			Local Purchase	Receive	Make	Through	Total	Ship
0001	0----	KMIN	65	371	30	0	466	0
0002	1---	AKA	100	0	3	0	103	98
0003	1---	IKM	5	0	0	0	5	5
0004	1---	KMT	533	86	140	0	759	268
0005	2--	AKA	95	0	22	0	117	86

Fig. 4 Manufacturing structure by MBOM

Operation of the MBOM began in October 2008.

(2) Development of the global production planning management system, PRINCE

To synchronize the supply of purchased parts from other factories and in-house parts with production at the final assembly factory, we developed a system that integrates the production plan for the final assembly factories and parts shipment plans for the parts supply factories.

(i) Features

For controlling parts supply among all factories, we must calculate a parts shipment plan for all factories at the same time based on the master production plan of all the final assembly factories while taking into consideration the procurement, in-house production, and logistics lead times. Therefore, we developed a system that not only integrates management of production planning but also enables management by individual factories.

In regards to controlling the master information system for making multilevel parts shipment plan, we established a master file for managing global shipping. We use a manufacturing structure linked from MBOM for basic master data, and we set standard lead times of parts procurement, in-house production, and logistics to each factory.

In order to create multilevel parts shipment plans for each factory, as shown in **Fig. 5**, we developed a function that creates a leveled daily production plan based on the monthly master production plan of the final assembly factory, creates a daily lot plan based on leveled daily plan, and automatically creates a "slide" multilevel shipment lot plan using the global shipping management master.

In order to apply the system to each factory's local operation, we implemented a function to create a leveled daily production plan for all final assembly lines and engine assembly lines of each factory based on the monthly master plan and parts shipment plan. Currently, this function has been implemented at KHI Akashi Factory only.

(ii) Operation

Creating multilevel parts shipment plan for all factories must be operated in a comprehensive manner. Therefore, Akashi factory is managing all planning operations.

Operation of the PRINCE began in November 2015.

(3) Development of the integrated production control system, APOLO

We needed to restructure Akashi Factory's old production control system. Therefore, we began developing a new production control system in an effort to innovate the supply chain innovation with a view toward implementing it globally.

We established a production control system by making global operation standards of parts ordering/parts inventory management/in-house production control/finished vehicle production/parts shipment based on Akashi Factory's operations. We will implement this system at each factory, thereby strengthening and streamlining the global supply chain.

(i) Features

For the BOM, which constitutes the core part of the production control system, we developed a system that automatically links up the item information and parts structure information from MBOM, just as we did when developing PRINCE.

For parts ordering management, with a view to applying the system globally, we implemented a function that can apply different order processing cycles (Akashi: Four times per month, Overseas factories: Once or twice per month) and can change the ordering cycle as needed.

For parts inventory management, in order to ascertain the difference between physical inventory and system inventory easily, we applied the system for calculating inventory not only by using actual production figures of

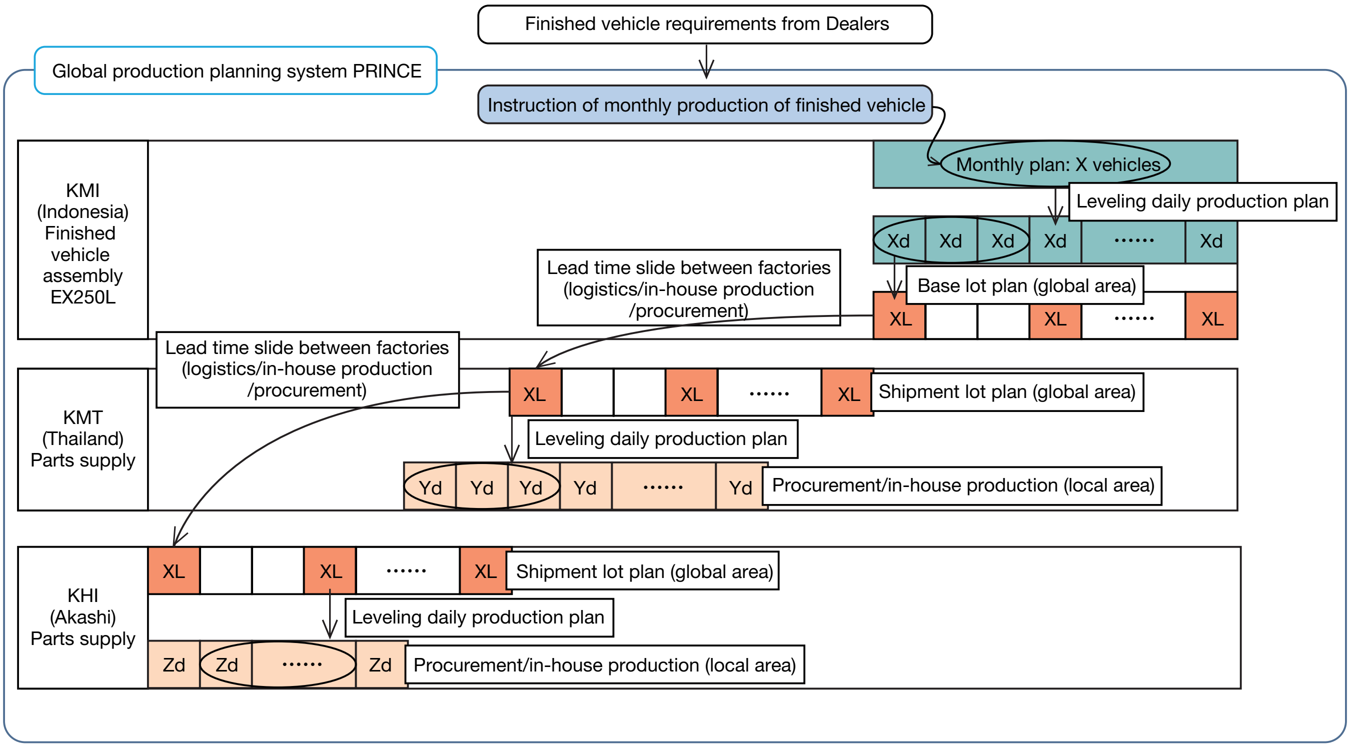


Fig. 5 Multilevel parts shipment plan for each factory

finished vehicles but also the actual production figures of other in-house parts (engine assembly, machining parts, and so on) which are managed by the production plan. In addition, in order to check the excess and shortage of parts at the right time, we implemented a parts shortage check function that matches the parts usage plan calculated based on the production plan, and the system inventory and the parts delivery plan.

(ii) Operation

Operation of the APOLO began in October 2017.

5 Utilization of System

(1) Managing consolidated profit by model

We can summarize proportional cost and shipment cost of each model by linking MBOM managed as the global master by Akashi factory and the local production/ shipment control system managed by each factory. Then we began to manage consolidated profit by a model using cost information and in-house production costs managed by another Akashi Factory system.

(2) New model mass-production preparation

In the work related to start mass-production of a new model, we were able to clearly indicate the factories responsible for of parts procurement, in-house production, and shipment by using MBOM production preparation stage for the new model. This method has been applied for transferring production of models between factories and it is having noticeable effects.

Conclusion

We are promoting the deployment of PRINCE and APOLO at overseas factories in order to further improve and strengthen the global supply chain.

So far, we have developed a production control system at each factory's different environments. However, we will apply the operations and system of the Akashi Factory for each factory as the basic premise and standard going forward.

We will continue to enhancing each factory's operation level including the Akashi Factory and further streamline our operations.

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FX850V-EFI – High-output Riding Mower Engine

In the U.S. commercial mowing market, the demand for engines equipped with an electronic control fuel injection system, which enables high and stable output, from working machine manufacturers is increasing. To meet the market's needs, we developed an EFI model, the FX850V-EFI, using the engine block of the existing carburetor model, which has earned a high reputation in the market. This model has improved maximum service output and a feeling of power in actual work thanks to the electronic governor control.

We have already begun mass-production of this model and put it on the market as riding mowers for several working machine manufacturers.

Introduction

In the U.S. commercial mowing market (for professionals), the demand for engines equipped with EFI (Electronic Fuel Injection), which enables high and stable output, from work machine manufacturers is increasing.

In addition, competing engine manufacturers are enhancing their EFI model lineup for this market, and market demand is expected to increase further.

1 Background of establishing

Kawasaki's FX series riding mower engines have a share of over 50% in the U.S. commercial mowing market, and market research has revealed that this series earned such a high reputation for its quality and durability.

However, when releasing an EFI model in this market, we needed to promptly arrange a more competitive lineup to maintain and increase the market share. Establishing basic technologies for the new EFI system for this model and achieving a high reputation in the market is a key factor to expanding the sales of Kawasaki's EFI engines in the future.

Therefore, giving the highest priority to releasing EFI models as a series as early as possible, we developed the FX850V-EFI based on the engine block of the existing FX850V carburetor model and adopting a new EFI system that had previously been developed for another model.

2 Specifications

Table 1 compares the major specifications of the FX850V-EFI and the FX850V carburetor model. Because these models use the same engine block, they have the same displacement, but the FX850V-EFI has increased maximum service output thanks to its electronic governor control. Electronic governor control uses an ECU (Electronic Control Unit) to process sensor information, such as temperature, intake air pressure, and throttle angle, to automatically control the throttle opening with a motor, mainly according to the engine speed and load.

3 Features

The FX850V-EFI has improved maximum service output, feeling of power in actual work, and cold startability with the EFI and is equipped with additional functions, including a function to facilitate engine inspection.

(1) Improved maximum service output

As shown in **Fig. 1**, the electronic governor control has provided higher maximum service output than conventional governor control.

(2) Improved feeling of power in actual work

The engine speed does not change even if the load

Table 1 Major specifications of FX850V-EFI and FX850V

Item	FX850V-EFI	FX850V
Engine type	Air-cooled vertical V-twin OHV	
Displacement (cm³)	852	852
Bore × Stroke (mm)	84. 5 × 76	84. 5 × 76
Maximum service output (kW)	20. 2/3, 600min^{-1}	18. 2/3, 200min^{-1}
Maximum torque (N·m)	63. 2/2, 400min^{-1}	61. 3/2, 400min^{-1}
Total length × Width × Total height (mm)	516 × 503 × 620	488 × 465 × 626
Dry mass (kg)	59. 7	56. 4

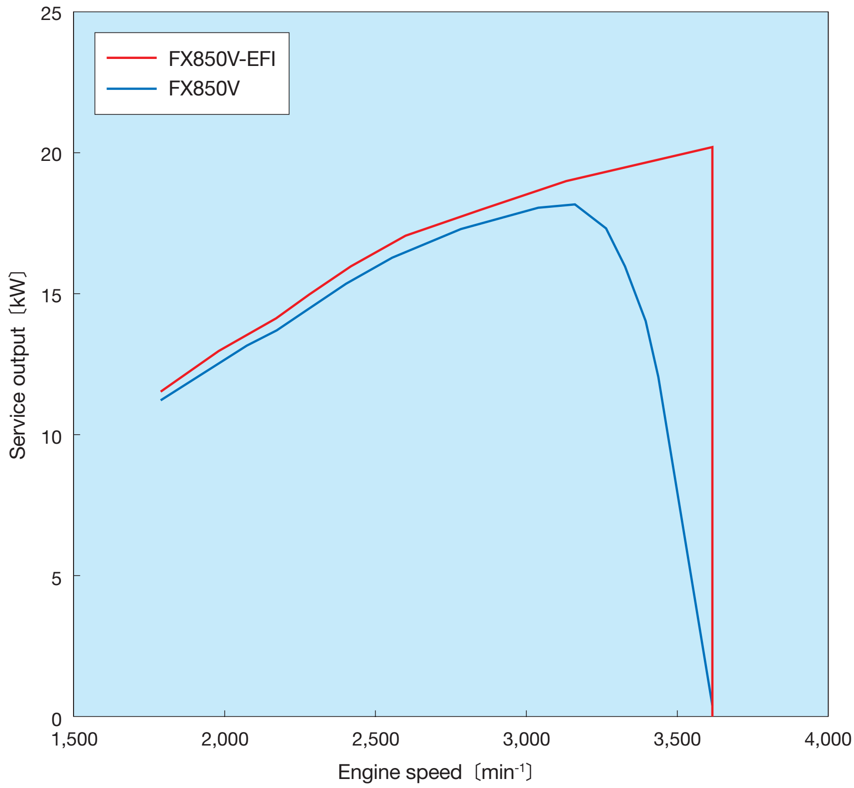

Fig. 1 Performance curves of FX850V-EFI and FX850V

changes as shown in **Fig. 1**, achieving an improved feeling of power in actual work.

The FX850V-EFI can even handle lawns that require such a high load that the FX850V's engine speed (i.e., blade speed) would drop, but without the engine speed falling at all. This means that the FX850V-EFI can mow lawns more evenly for a better appearance.

(3) Cold startability

Information from the temperature sensor installed on the engine is input to the ECU to automatically increase the fuel injection quantity when starting the engine, thereby achieving a smooth engine start without having to use the choke even at low temperatures (as low as -29°C).

(4) Communication with the work machine and the self-diagnosis function

To make communication with the engine easier when electronic control is adopted for work machines in the future, we have adopted an ECU that can communicate via CAN (Controller Area Network) ahead of the competitors.

In addition, this ECU is equipped with a self-diagnosis function with which failure diagnosis can easily be performed even at dealers by connecting it to a computer with a dedicated diagnosis tool.

(5) Engine protection function

The FX850V-EFI is equipped with a protection function to automatically decrease the engine speed when overheating or low oil pressure is detected, thereby preventing serious failures, such as engine seizure.

4 Delivery

In April 2017, we began mass-production of this model for the U.S. market at the KMM/Maryville factory and have already put this model on the market as a ZTR (Zero Turn Radius) mower of several work machine manufacturers as shown in **Fig. 2**. ZTR refers to a riding mower that is

Fig. 2 Riding mower mounted with FX850V-EFI (ZTR)

Fig. 3 FT730V-EFI

steered by using the rotational speed difference between the rear wheels, and causing the right and left wheels to rotate in opposite directions to turn in place.

5 Enhancing the EFI model lineup

In addition to this model, we have been developing other EFI models to increase our share in the commercial market, and are offering a competitive lineup, including FX730V-EFI and FT730V-EFI(**Fig. 3**), which have a slightly smaller displacement of 726 cm^3.

Conclusion

We are confident that our general-purpose engines will maintain their high reputation in the mowing market if we are able to develop high-performance, high-quality engines that meet work machine manufacturers' needs and market needs.

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JET SKI SX-R – A Stand up Type with Unique Maneuverability

In the personal watercraft (PWC) market, the runabout type, which is a stable and easy-to-ride vehicle that is generally ridden in a sitting position, has become the mainstream. However, there is a large demand for the unique maneuverability of the stand-up type, which is why we developed the JET SKI SX-R equipped with an environmentally friendly engine. With overwhelming acceleration performance and high turning performance and stability, the JET SKI SX-R enjoys a high reputation in the market and won Japan's Boat of the Year award in the PWC category in 2017.

Introduction

Personal watercrafts (PWC) are classified into the stand-up type, which has a riding capacity of one person and is generally ridden in a standing position, and the runabout type, which has a riding capacity of two or three people and is generally ridden in a sitting position. The stand-up type is a sporty vehicle and requires some skill to ride. The runabout type is stable and easy to ride, and can tow a wakeboard. The runabout type is a recreational vehicle and has been the most popular in the market.

Emissions regulations are becoming more and more stringent, and two-stroke engines, which have been used for conventional personal watercrafts, are being replaced by environmentally friendly four-stroke engines.

1 Background

The personal watercraft market began with the JS400, which is the stand-up personal watercraft Kawasaki began mass-producing in 1973. Recently, the runabout type has become more popular and since the 2012 model, Kawasaki has been mass-producing only runabout-type personal watercrafts equipped with an environmentally friendly engine.

However, the stand-up type is the origin of Kawasaki's jet skis and there is still a large market demand for stand-up personal watercrafts with unique maneuverability. To meet this demand, we developed the JET SKI SX-R, which is also equipped with an environmentally friendly engine.

2 Specifications

For the engine, we modified the environmentally friendly, high-power, four-stroke, four-cylinder engine with a displacement of 1,498 cm^3 adopted for Kawasaki's STX-15F runabout-type personal watercraft, and adopted this engine for the JET SKI SX-R. The JET SKI SX-R has a large hull for accommodating the high-power engine.

Table 1 shows the major specifications of the SX-R and 800SX-R (previous model). The SX-R's engine has double the maximum power of the previous model, and as shown in **Fig. 1**, has easy-to-handle power characteristics with a wider power band. The SX-R's hull is larger in size than the previous model by 355 mm in total length and 35 mm in width, thereby providing improved stability.

3 Features

To achieve both high performance for experienced riders and an easy ride for beginners, the SX-R has significantly improved acceleration performance, turning

Table 1 Comparison between SX-R and its previous model 800SX-R

Item	SX-R	800SX-R
Engine type	Four-stroke, four-cylinder engine	Two-stroke, two-cylinder engine
Displacement (cm^3)	1, 498	781
Bore × Stroke (mm)	83 × 69. 2	82 × 74
Maximum power (kW)	118/7, 500min^{-1}	58. 9/6, 250min^{-1}
Maximum torque (N·m)	152/7, 250min^{-1}	94. 2/5, 750min^{-1}
Total length (mm)	2, 655	2, 300
Total width (mm)	765	730
Total height (mm)	840	735

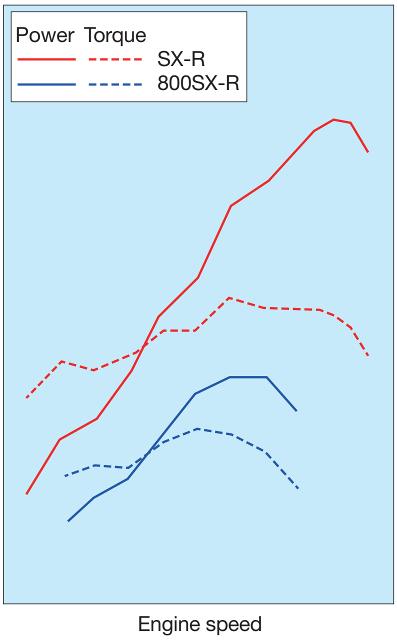

Fig. 1 Comparison of engine output characteristics

performance, and stability.

(1) Acceleration performance

The SX-R has double the maximum engine power of the previous model and has a newly designed, larger hull to accommodate the high engine power, thereby achieving overwhelming acceleration performance. As shown in **Fig. 2**, the SX-R reaches a high speed in a shorter time when accelerated from a stopped state, and in addition, the SX-R has a higher maximum speed than the previous model by approximately 25%.

(2) Turning performance

Based on feedback from people involved in racing, the SR-X was designed to have high turning performance to suit the high-power engine. The SR-X has a different hull bottom width and angles from the bow to the stern, thereby achieving higher turning performance than the previous model, even with its increased size (**Fig. 3**). This enables light turning and tight turning unique to the stand-up type.

(3) Stability

With the increased hull size, the SX-R has improved stability in a stationary state, allowing for easy boarding. The SX-R also has improved riding stability, offers a more flexible riding position as the floor width has been increased to be the same from front to back, and has improved riding performance on various water conditions (**Fig. 4**).

The improved stability in a stationary state and during running has enabled experienced riders to enjoy advanced

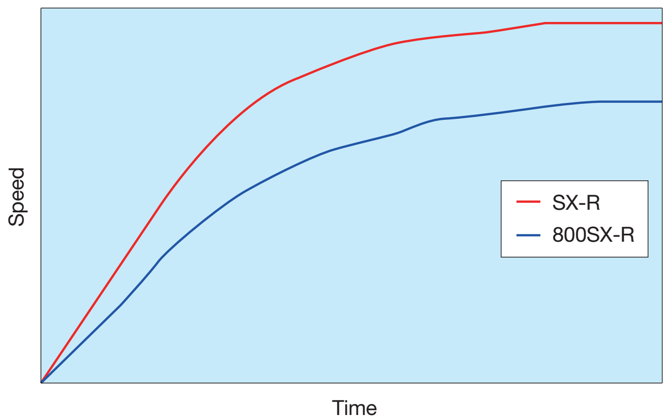

Fig. 2 Acceleration performance

Fig. 3 Hull bottom shape

Fig. 4 Floor shape

riding and beginner riders to handle this personal watercraft easily.

(4) Other

In addition to having high riding performance, the SX-R is equipped with useful functions, such as an anti-theft key and storage space below the handle pole in which ropes and other items can be stored.

Conclusion

The JET SKI SX-R enjoys a high reputation in the market and won Japan's Boat of the Year award in the PWC category in 2017. We will continue developing “fun to ride” products demanded by the market.

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Title of invention: PERSONAL WATERCRAFT
Names of inventers: Hironori Kato, Toshio Araki, Minoru Kanamori, Kenichi Okita

— Reducing the resistance a jet ski receives while planing with stabilizers —

Jet skis and other small planing boats that plane on the water are required to have low resistance on their body to quickly reach a planing state. A boat body consists of a hull, which comes in contact with the water, and a deck, which has passenger space.

As shown in **Fig. 1**, the joint between the hull and deck has a hook shape that faces downward to secure the joint length to achieve adequate joint strength and to position the hull and deck. This joint is seen all around the boat body.

When a small planing boat is planing forward, water flowing along the boat body collides with the erect part extending vertically from the joint at the stern, and the bow is tilted downward as shown in **Fig. 2 (a)** by the force generated by the water stream collision, increasing the resistance the boat receives while planing and decreasing stability when the boat is going over waves.

The PERSONAL WATERCRAFT of this patent has stabilizers on the right and left rear parts of the joint as shown in **Fig. 3** to allow water to flow along the inclined surface at the bottom of each stabilizer as shown in **Fig. 2 (b)**, thereby preventing water streams from colliding with the erect part at the joint of the stern.

This prevents the bow from tilting downward and reduces the resistance on the boat body during planing, thereby enabling small planing boats to plane faster and more stably.

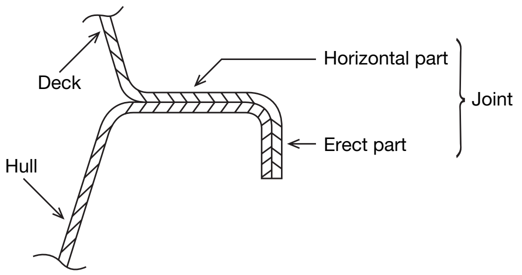
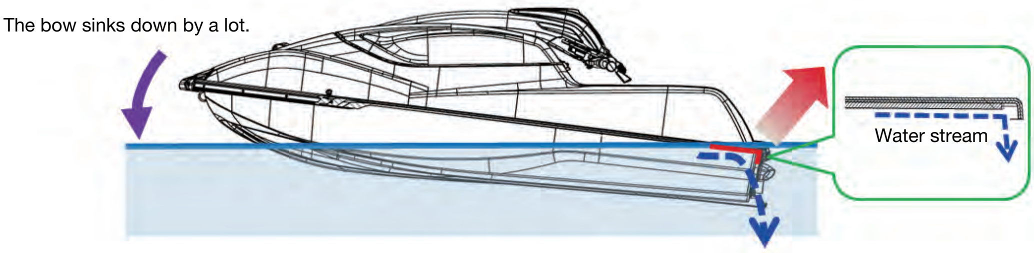
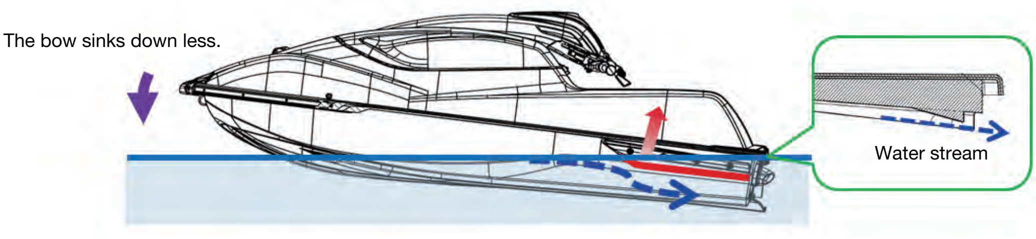


Fig. 1 Joint

Fig. 3 Stabilizer



(a) Conventional boat



(b) This invention

Fig. 2 Structures of this invention and conventional boats

Kawasaki Heavy Industries Group

Main Products and Production Bases by Business Segment

Business Segment	Main Products	Main Production Bases
Ship & Offshore Structure	• 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)*
Rolling Stock	• Train cars, integrated transit systems, freight cars	Hyogo 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, de-icing vehicles • Rail cars, heavy lift cars	NICHIJO CORPORATION. Head Office (Main Plant)(Sapporo, Hokkaido) Akebono Plant (Sapporo, Hokkaido)
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, remodeling	NIPPI Corporation Aerospace Division (Yokohama, Kanagawa Prefecture) and Aircraft Maintenance Division (Yamato, Kanagawa Prefecture)
	• Aircraft engines • Aircraft gear boxes	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe, Hyogo Prefecture)
Energy System & Plant engineering	• Gas turbine engines for ships • Gas turbine generators, gas turbine cogeneration systems	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe, Hyogo Prefecture)
	• Steam turbines, diesel engines, gas engines, large decelerators • Marine propulsion systems (side thrusters, steerable thrusters) • Natural gas compression modules, air blowers and other aerodynamic machinery	Kobe Works (Kobe, 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)
	• Cement, chemical, conveyers, and other industrial plant systems • Industrial boilers for land and marine use • Waste treatment facility • LNG tank and other storage facilities • Shield machines, tunnel boring machines	Harima Works (Harima-cho, Hyogo Prefecture) Shanghai COSCO Kawasaki Heavy Industries Steel Structure Co., Ltd. (China)* Anhui Conch Kawasaki Equipment Manufacturing Co., Ltd. (China)* Anhui Conch Kawasaki Energy Conservation Equipment Manufacturing Co., Ltd. (China)* Shanghai Conch Kawasaki Engineering Co., Ltd.*
	• Crushers, environment-related equipment	EarthTechnica Co., Ltd. Yachiyo Works (Yachiyo, Chiba Prefecture)
Motorcycle & Engine	• Motorcycles, ATVs (all-terrain vehicles), recreational utility vehicles, utility vehicles, Jet Ski watercraft • General-purpose gasoline engines	Akashi 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 Put. Ltd. (India) Kawasaki Motors Enterprise (Thailand) Co., Ltd. (Thailand) PT. Kawasaki Motor Indonesia (Indonesia) Kawasaki Motors (Phils.) Corporation (Philippines) Changzhou Kawasaki and Kwang Yang Engine Co., Ltd. (China)*
Precision Machinery & Robot	• Hydraulic equipment for construction machines, hydraulic equipment and systems for industrial machines • Marine application machines, deck cranes and other marine deck equipment • Industrial robots • Medical and pharmaceutical robot	Akashi Works (Akashi, Hyogo Prefecture) Nishi-Kobe Works (Kobe, Hyogo Prefecture) Kawasaki Precision Machinery (U.K.) Ltd. (U.K.) 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. Flutek, Ltd. (Korea)
	• Hydraulic presses	Kawasaki Hydromechanics Corp. (Akashi, Hyogo Prefecture)

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Kawasaki Green Product Promotion Activity

To achieve our group mission, "Kawasaki, working as one for the good of the planet," we promote Kawasaki Green Products and Kawasaki Super Green Products inside and outside Kawasaki. These products meet the criteria originally established by Kawasaki to assess the conformity of products regarding environmental performance and environmental management in manufacturing processes.

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